ASME B31.3-2020
(Revision of ASME B31.3-2018)

Process Piping

ASME Code for Pressure Piping, B31

AN INTERNATIONAL PIPING CODE®

The American Society of
Mechanical Engineers

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Two Park Avenue • New York, NY • 10016 USA

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The next edition of this Code is scheduled for publication in 2022. This Code will become effective 6 months after the Date of Issuance.

ASME issues written replies to inquiries concerning interpretations of technical aspects of this Code. Interpretations are published on the Committee web page and under http://go.asme.org/InterpsDatabase. Periodically certain actions of the ASME B31 Committee may be published as Cases. Cases are published on the ASME website under the B31 Committee page at http://go.asme.org/B31committee as they are issued.

Errata to codes and standards may be posted on the ASME website under the Committee Pages of the associated codes and standards to provide corrections to incorrectly published items, or to correct typographical or grammatical errors in codes and standards. Such errata shall be used on the date posted.

The B31 Committee Page can be found at http://go.asme.org/B31committee. The associated B31 Committee Page for each code and standard can be accessed from this main page. There is an option available to automatically receive an e-mail notification when errata are posted to a particular code or standard. This option can be found on the appropriate Committee Page after selecting "Errata" in the "Publication Information" section.

The American Society of Mechanical Engineers
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FOREWORD

Responding to evident need and at the request of The American Society of Mechanical Engineers (ASME), the American Standards Association initiated Project B31 in March 1926, with ASME as sole administrative sponsor. The breadth of the field involved required that membership of the Sectional Committee be drawn from some 40 engineering societies, industries, government bureaus, institutes, and trade associations.

Initial publication in 1935 was as the American Tentative Standard Code for Pressure Piping. Revisions from 1942 through 1955 were published as American Standard Code for Pressure Piping, ASA B31.1. It was then decided to publish as separate documents the various industry Sections, beginning with ASA B31.8-1955, Gas Transmission and Distribution Piping Systems. The first Petroleum Refinery Piping Code Section was designated ASA B31.3-1959. ASA B31.3 revisions were published in 1962 and 1966.

In 1967–1969, the American Standards Association became first the United States of America Standards Institute, then the American National Standards Institute (ANSI). The Sectional Committee became American National Standards Committee B31 and the Code was renamed the American National Standard Code for Pressure Piping. The next B31.3 revision was designated ANSI B31.3-1973. Addenda were published through 1975.

A draft Code Section for Chemical Plant Piping, prepared by Section Committee B31.6, was ready for approval in 1974. It was decided, rather than have two closely related Code Sections, to merge the Section Committees and develop a joint Code Section, titled Chemical Plant and Petroleum Refinery Piping. The first edition was published as ANSI B31.3-1976.

In this Code, responsibility for piping design was conceptually integrated with that for the overall processing facility, with safeguarding recognized as an effective safety measure. Three categories of Fluid Service were identified, with a separate Chapter for Category M Fluid Service. Coverage for nonmetallic piping was introduced. New concepts were better defined in five Addenda, the fourth of which added Appendix M, a graphic aid to selection of the proper Fluid Service category.

The Standards Committee was reorganized in 1978 as a Committee operating under ASME procedures with ANSI accreditation. It is now the ASME Code for Pressure Piping, B31 Committee. Section committee structure remains essentially unchanged.

The second edition of Chemical Plant and Petroleum Refinery Piping was compiled from the 1976 Edition and its five Addenda, with nonmetal requirements editorially relocated to a separate Chapter. Its new designation was ANSI/ASME B31.3-1980.

Section Committee B31.10 had a draft Code for Cryogenic Piping ready for approval in 1981. Again, it was decided to merge the two Section Committees and develop a more inclusive Code with the same title. The work of consolidation was partially completed in the ANSI/ASME B31.3-1984 Edition.

Significant changes were made in Addenda to the 1984 Edition: integration of cryogenic requirements was completed; a new stand-alone Chapter on high-pressure piping was added; and coverage of fabrication, inspection, testing, and allowable stresses was reorganized. The new Edition was designated as ASME/ANSI B31.3-1987 Edition.

Addenda to the subsequent five Editions, published at 3-year intervals, were primarily used to keep the Code up to date. New Appendices were added, however, on requirements for bellows expansion joints, estimating service life, submittal of Inquiries, aluminum flanges, and quality control in the 1990, 1993, 1999, and 2002 Editions, all designated as ASME B31.3.

In a program to clarify the application of all Sections of the Code for Pressure Piping, changes were made in the Introduction and Scope statements of the 1996 Edition, and its title was changed to Process Piping.

Under direction of ASME Codes and Standards management, SI (metric) units of measurement were emphasized. With certain exceptions, SI units were listed first in the 1996 Edition and were designated as the standard. Instructions for conversion were given where SI units data were not available. U.S. Customary units also were given. By agreement, either system may have been used.

Beginning with the 2004 Edition, the publication cycle of ASME B31.3 was changed to biennial. Other changes made in the 2004 Edition included the introduction of the weld joint strength reduction factor, W, and the additions of Appendix P, Alternative Rules for Evaluating Stress Range, and Appendix S, Piping System Stress Analysis Examples.

Changes that were made to the 2006 and 2008 Editions of ASME B31.3 included the requirement that valves have blowout-proof stems and the addition of a definition for elevated temperature fluid service, respectively. The most significant change that was made to the 2010 Edition of ASME B31.3 was the addition of Chapter X, High Purity

Piping. In the 2012 Edition, Tables A-1M and A-2M were added to Appendix A that give allowable design values in SI units, and Appendix N, Application of ASME B31.3 Internationally, was also added.

For the 2016 Edition, the allowable design values in SI units as shown in Tables A-1M and A-2M were changed from for information only to values that may be used to meet the requirements of the Code.

In this Edition, SI units are given first, with U.S. Customary units in parentheses. Table K-1 in Appendix K is an exception, containing only U.S. Customary units. The allowable design values in Tables A-1 and A-2 are given in U.S. Customary units, and the SI values are given in Tables A-1M and A-2M. Either the U.S. Customary units or the SI units for these allowable design values may be used. Except for Tables A-1, A-1M, A-2, A-2M, C-1, C-1M, C-6, C-6M, and K-1, values in SI units are to be regarded as the standard, unless otherwise agreed between the contracting parties. Instructions are given in Table K-1 for converting tabular data in U.S. Customary units to appropriate SI units.

Interpretations, Code Cases, and errata to the B31.3 Code on Process Piping are published on the following ASME web page: *https://cstools.asme.org/csconnect/CommitteePages.cfm?Committee=N10020400.*

ASME B31.3-2020 was approved by the American National Standards Institute on September 29, 2020.

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Code for Pressure Piping

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INTRODUCTION

The ASME B31 Code for Pressure Piping consists of a number of individually published Sections, each an American National Standard, under the direction of ASME Committee B31, Code for Pressure Piping.

Rules for each Section reflect the kinds of piping installations considered during its development, as follows:

B31.1	Power Piping: piping typically found in electric power generating stations, in industrial and institutional plants, geothermal heating systems, and central and district heating and cooling systems
B31.3	Process Piping: piping typically found in petroleum refineries; onshore and offshore petroleum and natural gas production facilities; chemical, pharmaceutical, textile, paper, ore processing, semiconductor, and cryogenic plants; food and beverage processing facilities; and related processing plants and terminals
B31.4	Pipeline Transportation Systems for Liquids and Slurries: piping transporting products that are predominately liquid between plants and terminals and within terminals, pumping, regulating, and metering stations
B31.5	Refrigeration Piping and Heat Transfer Components: piping for refrigerants and secondary coolants
B31.8	Gas Transmission and Distribution Piping Systems: piping transporting products that are predominately gas between sources and terminals, including compressor, regulating, and metering stations; gas gathering pipelines
B31.9	Building Services Piping: piping typically found in industrial, institutional, commercial, and public buildings, and in multi-unit residences, which does not require the range of sizes, pressures, and temperatures covered in B31.1
B31.12	Hydrogen Piping and Pipelines: piping in gaseous and liquid hydrogen service and pipelines in gaseous hydrogen service

This is the B31.3 Process Piping Code Section. Hereafter, in this Introduction and in the text of this Code Section B31.3, where the word *Code* is used without specific identification, it means this Code Section.

It is the owner's responsibility to select the Code Section that most nearly applies to a proposed piping installation. Factors to be considered by the owner include limitations of the Code Section; jurisdictional requirements; and the applicability of other codes and standards. All applicable requirements of the selected Code Section shall be met. For some installations, more than one Code Section may apply to different parts of the installation. The owner is also responsible for imposing requirements supplementary to those of the Code if necessary to assure safe piping for the proposed installation.

Certain piping within a facility may be subject to other codes and standards, including but not limited to

— ANSI Z223.1 National Fuel Gas Code: piping for fuel gas from the point of delivery to the connection of each fuel utilization device

— NFPA Fire Protection Standards: fire protection systems using water, carbon dioxide, halon, foam, dry chemicals, and wet chemicals

— NFPA 99 Health Care Facilities: medical and laboratory gas systems

— building and plumbing codes, as applicable, for potable hot and cold water, and for sewer and drain systems

The Code specifies engineering requirements deemed necessary for safe design and construction of pressure piping. While safety is the primary consideration, this factor alone will not necessarily govern the final specifications for any piping installation. The Code is not a design handbook. Many decisions that must be made to produce a sound piping installation are not specified in detail within this Code. The Code does not serve as a substitute for sound engineering judgments by the owner and the designer.

To the greatest possible extent, Code requirements for design are stated in terms of basic design principles and formulas. These are supplemented as necessary with specific requirements to ensure uniform application of principles and to guide selection and application of piping elements. The Code prohibits designs and practices known to be unsafe and contains warnings where caution, but not prohibition, is warranted.

This Code Section includes the following:

(a) references to acceptable material specifications and component standards, including dimensional requirements and pressure–temperature ratings

(b) requirements for design of components and assemblies, including piping supports

(c) requirements and data for evaluation and limitation of stresses, reactions, and movements associated with pressure, temperature changes, and other forces

(d) guidance and limitations on the selection and application of materials, components, and joining methods

(e) requirements for the fabrication, assembly, and erection of piping

(f) requirements for examination, inspection, and testing of piping

Either International System (SI, also known as metric) or U.S. Customary units may be used with this edition. Local customary units may also be used to demonstrate compliance with this Code. One system of units should be used consistently for requirements applying to a specific installation. The equations in this Code may be used with any consistent system of units. It is the responsibility of the organization performing calculations to ensure that a consistent system of units is used.

ASME Committee B31 is organized and operates under procedures of The American Society of Mechanical Engineers that have been accredited by the American National Standards Institute. The Committee is a continuing one, and keeps all Code Sections current with new developments in materials, construction, and industrial practice. New editions are published at intervals of 2 years.

Code users will note that paragraphs in the Code are not necessarily numbered consecutively. Such discontinuities result from following a common outline, insofar as practical, for all Code Sections. In this way, corresponding material is correspondingly numbered in most Code Sections, thus facilitating reference by those who have occasion to use more than one Section.

This edition of Code Section B31.3 is not retroactive. Normally, agreement is made between contracting parties to use a specific edition, considering requirements of the authority having jurisdiction. When specified as the latest edition and when no edition is specified, the specific edition is the one issued at least 6 months prior to the original contract date for the first design activity.

Users of this Code are cautioned against making use of Code revisions without assurance that they are acceptable to the proper authorities in the jurisdiction where the piping is to be installed.

The B31 Committee has established an orderly procedure to consider requests for interpretation and revision of Code requirements. To receive consideration, such request must be in writing and must give full particulars in accordance with Appendix Z.

The approved reply to an inquiry will be sent directly to the inquirer. In addition, the question and reply will be published as part of an Interpretation supplement.

A Case is the prescribed form of reply when study indicates that the Code wording needs clarification, or when the reply modifies existing requirements of the Code or grants permission to use new materials or alternative constructions. The Case will be published as part of a Case supplement.

Code Cases remain available for use until annulled by the ASME B31 Standards Committee.

A request for revision of the Code will be placed on the Committee's agenda. Further information or active participation on the part of the proponent may be requested during consideration of a proposed revision.

Materials ordinarily are listed in the stress tables only when sufficient usage in piping within the scope of the Code has been shown. Requests for listing shall include evidence of satisfactory usage and specific data to permit establishment of allowable stresses, maximum and minimum temperature limits, and other restrictions. Additional criteria can be found in the guidelines for addition of new materials in the ASME Boiler and Pressure Vessel Code, Section II. (To develop usage and gain experience, unlisted materials may be used in accordance with para. 323.1.2.)

ASME B31.3-2020
SUMMARY OF CHANGES

Following approval by the ASME B31 Committee and ASME, and after public review, ASME B31.3-2020 was approved by the American National Standards Institute on September 29, 2020.

ASME B31.3-2020 includes the following changes identified by a margin note, **(20)**.

Page	*Location*	*Change*
xx	Introduction	After subpara. (f), paragraph added
2	300.1.4	Added, and subsequent paragraph redesignated
10	Table 300.4	Appendix D deleted
12	301.3.2	Title revised
12	301.3.3	Title revised
12	301.3.4	Title revised
13	302.2.4	Revised
14	302.2.5	Last sentence deleted
16	Table 302.3.3C	General Note revised
19	302.3.6	Subparagraph (a)(1) revised
24	304.3.1	Subparagraphs (a) and (a)(2) revised
31	304.5.2	Subparagraph (b) revised
32	304.7.2	Subparagraphs (b) and (c) revised
34	306.5.2	Revised
34	307.1.2	Last sentence deleted
36	311.2.2	Subparagraph (d) revised
37	314.2.1	Subparagraph (c) revised
40	319.3.4	Subparagraph (b) revised
40	319.3.6	Revised
41	319.4.4	(1) Subparagraphs (a) and (b) revised
		(2) Subparagraph (c) and eqs. (19) and (20) deleted
43	320.1	Revised
44	320.2	(1) Revised
		(2) Footnote 9 added
49	Table 323.2.2	Items A-3(b) and B-3 revised
56	Table 323.3.1	(1) Items 4, A-5, and B-5 revised
		(2) Note (4) deleted
60	Table 326.1	Revised in its entirety
66	328.5.2	Revised in its entirety
66	328.5.4	Subparagraphs (d), (e)(2), and (f) revised
67	Figure 328.5.2A	Title revised
67	Figure 328.5.2B	Title revised
68	Figure 328.5.2C	(1) Title revised
		(2) Variable for nominal pipe wall thickness revised

Page	*Location*	*Change*
69	328.6	Revised
71	330.1	Last paragraph added
73	331.1.1	Subparagraph (a) revised
73	331.1.3	Subparagraph (b)(5)(-a) revised
74	Table 331.1.1	Note (7) revised
73	331.1.6	Subparagraph (c) revised
75	331.2.6	Revised
78	332.4	Last sentence added
90	344.6.2	Subparagraph (a) revised
103	A321.5.1	Subparagraph (a) revised
103	A321.5.2	Revised in its entirety
106	A328.2.1	Subparagraph (b)(6) revised
107	Table A326.1	Standards ASTM D3309, ASTM D2310, ASTM D2447, ASTM D3309, and ASTM F1974 deleted
109	A328.2.5	Nomenclature in subpara. (c)(1) revised
120	M331	Revised
124	K300	Revised in its entirety
124	K300.1	K300.1.4 added, subsequent paragraphs redesignated, and cross-references updated
125	K302.3.1	Subparagraphs (b) and (d) revised
126	K302.3.2	Subparagraphs (b), (c), and (d) revised
127	K302.3.6	Subparagraph (a) revised
128	K304.1.2	Revised
128	K304.1.3	Revised
128	K304.2.4	Revised
129	K304.7.2	Subparagraph (c) revised
130	K304.7.3	Revised
130	K304.8.1	First paragraph and footnote 6 revised
130	K304.8.2	Former subpara. (a) deleted, and subsequent subparagraphs revised and redesignated
130	K304.8.3	Subparagraph (c) revised
130	K304.8.5	First paragraph revised
131	K307	Revised in its entirety
132	K314.2	Subparagraph (b) revised
133	K317.2	Title revised
134	K322.6.3	(1) Subparagraphs (a) and (b) revised (2) Subparagraph (c) deleted
135	K323.2.2	Revised in its entirety
135	K323.3.1	Revised
135	K323.3.4	Revised in its entirety
139	Table K326.1	(1) Standards under “Bolting” and “Metallic Fittings, Valves, and Flanges” revised (2) Note (1)(c) added
140	K328	Revised
140	K328.1	Revised in its entirety

Page	*Location*	*Change*
140	K328.2.1	Subparagraphs (b) and (f) revised
140	K328.3.1	Revised in its entirety
141	K330.1	Revised
141	K331	Revised in its entirety
143	K332.4.1	Revised
143	K332.4.2	Subparagraph (a) revised
143	K333	Revised in its entirety
144	K341.3.3	Subparagraphs (a) and (b) revised
144	K341.4.1	(1) Subparagraph (b) revised (2) Subparagraph (c) added
148	K345.1	Subparagraphs (a), (b), and (d) revised
148	K345.2.1	Former footnote 10 deleted
149	K346.1	Revised
149	K346.2	(1) Subparagraph (b) added, and subsequent subparagraphs redesignated (2) Subparagraphs (d) and (f) revised
152	U328	Revised
152	U328.2	Revised in its entirety
152	U328.4.2	Added
154	U341.4.1	(1) First paragraph and subparas. (a) and (b) revised (2) Subparagraph (c) added
159	Specification Index for Appendix A	(1) A381, B166, B462, B649, B688, and B690 revised (2) B547 deleted
163	Notes for Tables A-1, A-1M, A-1A, A-1B, A-2, and A-2M	(1) General Note (f) and in-text table in Note (42) revised (2) Note (44) deleted
167	Table A-1	(1) Under Iron — Castings, for Gray A278 40, Note (9) reference deleted (2) Under Carbon Steel — Pipes and Tubes, for A285 Gr. A A134, A285 Gr. B A134, and A285 Gr. C A134, Type/Grade and UNS No. added (3) For A516 Gr. 60, stress values for 700°F and 800°F revised (4) For A516 Gr. 65, stress values for 850°F and 900°F revised (5) Under Carbon Steel — Pipes (Structural Grade), A283 Gr. A and B deleted (6) A1011 Gr. 30, 33, 36, and 40; A36; A283; and A1011 Gr. 45 and 50 revised (7) Under Carbon Steel — Plates, Bars, Shapes, and Sheets (Structural), A283 A and B deleted (8) A1011 30, 33, 36, 40, 45, and 50; A283 C and D; and A36 revised (9) Under Stainless Steel — Pipes and Tubes, A376 16-8-2H deleted (10) A312 TP310S revised (11) A358 310S deleted (12) For A813, A814, A249, and A312 S31254, Notes and stress values revised

Page	Location	Change
		(13) For A358 S31254, stress values revised
		(14) A789 S32900 deleted
		(15) Under Stainless Steel — Plates and Sheets, A240 439 deleted
		(16) A240 310H revised
		(17) A240 S31254 Notes and stress values revised
		(18) Under Stainless Steel — Forgings and Fittings, A182 F10 deleted
		(19) A182 F310, A403 WP310S, and A403 WP310H revised
		(20) For A182 and A403 S31254, Notes and stress values revised
		(21) A403 S31254, A815 S31803, A403 N08367, and A815 S32750 deleted
		(22) A815 S32101, A815 S32205, and A815 S32760 revised
		(23) A182 S41000 and A182 S41026 deleted
		(24) A182 S32750 revised
		(25) Under Stainless Steel — Bar, A479 S31254 Note and stress values revised
		(26) A479 S32205 and A479 S20910 revised
		(27) Under Stainless Steel — Castings, for A351 CH10, A351 CH20, and A351 CF8C, stress values revised
		(28) Under Nickel and Nickel Alloy — Castings, A494 CX2MW reordered and revised
		(29) A494 CW12MW and A494 CW6M revised
		(30) Under Zirconium and Zirconium Alloy — Pipes and Tubes, B523 R60702, B658 R60702, and B658 R60705 revised
		(31) B523 R60705 deleted
		(32) Under Zirconium and Zirconium Alloy — Plates and Sheets, B551 R60702 and B551 R60705 revised
		(33) Under Zirconium and Zirconium Alloy — Forgings and Bar, B493 R60702, B550 R60702, B493 R60705, and B550 R60705 revised
		(34) Aluminum Alloy — Welded Pipes and Tubes category deleted
242	Table A-1M	(1) Listings for Nominal Composition Fe revised in their entirety
		(2) A134 revised
		(3) For A524, A333, A334, A671, A672, A139, API 5L, and A381, stress values revised
		(4) A516, A515, A1011, A283, A36, and A992 revised
		(5) A376 deleted
		(6) For A312, Type/Grade, UNS No., and Notes revised
		(7) A358 deleted
		(8) For A813, A814, A249, and A312, Notes deleted
		(9) A789 and A240 deleted
		(10) For A240 and A403, Type/Grade, UNS No., and Notes revised
		(11) A182, A403, A815, and A479 revised
		(12) For A351, stress values revised
		(13) Wld. tube B626 added
		(14) A494, B523, B658, B551, B493, and B550 revised

Page	*Location*	*Change*
		(15) B547 deleted
349	Table A-1B	B547 deleted
354	Table A-2	(1) A194 4 and A194 4L deleted
		(2) A193 B8 added
364	Table A-2M	(1) A194 4 and A194 4L deleted
		(2) A193 B8 added
385	Specification Index for Appendix B	D2447 and D3309 deleted
386	Table B-1	D3309, D2239, D2447, D3035, and F714 deleted
388	Table B-1M	D3309, D2239, D2447, D3035, and F714 deleted
412	Appendix D	Deleted
413	Appendix E	Revised in its entirety
419	F300.1.5	Former para. F300.1.4 editorially redesignated
419	F301.10.2	Revised
420	F302	Added
421	F323	Subparagraph (b) revised
423	F331.1	Revised
424	FA328	Added
428	H301	Revised
428	H302	Revised
429	H303	Revised
431	H304	Revised
437	Appendix J	Cross-references updated
453	Appendix K	(1) ASTM A928 added to Specification Index
		(2) Page column deleted in Specification Index
455	Notes for Table K-1	(1) General Notes (b) and (d) and Notes (3), (4), and (20) revised
		(2) General Note (h) added
		(3) Notes (6) and (12) deleted
456	Table K-1	Revised in its entirety
474	Figure M300	In Col. 1, cross-references to para. K300.1.5 revised to K300.1.6
477	R301	(1) Subparagraph (b) revised
		(2) Subparagraph (c) deleted
480	Appendix S	Revised in its entirety
495	V304	Revised in its entirety
500	Table W302.1-4	Editorially redesignated
507	Index	Added

Chapter I
Scope and Definitions

300 GENERAL STATEMENTS

(a) Identification. This Process Piping Code is a Section of The American Society of Mechanical Engineers Code for Pressure Piping, ASME B31, an American National Standard. It is published as a separate document for convenience of Code users.

(b) Responsibilities

(1) Owner. The owner of a piping installation shall have overall responsibility for compliance with this Code, and for establishing the requirements for design, construction, examination, inspection, and testing that will govern the entire fluid handling or process installation of which the piping is a part. The owner is also responsible for designating piping in Category D, Category M, High Pressure, and High Purity Fluid Services, and for determining if a specific Quality System is to be employed. [See (d)(4) through (d)(7) and Appendix Q.] Where applicable, the owner shall consider requirements imposed by the authority having jurisdiction regarding the piping installation. The owner may designate a representative to carry out selected responsibilities required by this Code, but the owner retains ultimate responsibility for the actions of the representative.

(2) Designer. The designer is responsible to the owner for assurance that the engineering design of piping complies with the requirements of this Code and with any additional requirements established by the owner.

(3) Manufacturer, Fabricator, and Erector. The manufacturer, fabricator, and erector of piping are responsible for providing materials, components, and workmanship in compliance with the requirements of this Code and of the engineering design.

(4) Owner's Inspector. The owner's Inspector (see para. 340) is responsible to the owner for ensuring that the requirements of this Code for inspection, examination, and testing are met. If a Quality System is specified by the owner to be employed, the owner's Inspector is responsible for verifying that it is implemented.

(c) Intent of the Code

(1) It is the intent of this Code to set forth engineering requirements deemed necessary for safe design and construction of piping installations.

(2) This Code is not intended to apply to the operation, examination, inspection, testing, maintenance, or repair of piping that has been placed in service. See para. F300.1 for examples of standards that may apply in these situations. The provisions of this Code may optionally be applied for those purposes, although other considerations may also be necessary.

(3) The Code generally specifies a simplified approach for many of its requirements. A designer may choose to use a more rigorous analysis to develop design and construction requirements. When the designer decides to take this approach, the designer shall provide to the owner details and calculations demonstrating that design, construction, examination, and testing are consistent with the design criteria of this Code. These details shall be adequate for the owner to verify the validity and shall be approved by the owner. The details shall be documented in the engineering design.

(4) Piping elements shall conform to the specifications and standards listed in this Code or, if not prohibited by this Code, shall be qualified for use as set forth in applicable Chapters of this Code.

(5) The engineering design shall specify any unusual requirements for a particular service. Where service requirements necessitate measures beyond those required by this Code, such measures shall be specified by the engineering design. Where so specified, the Code requires that they be accomplished.

(6) Compatibility of materials with the service and hazards from instability of contained fluids are not within the scope of this Code. See para. F323.

(d) Determining Code Requirements

(1) Code requirements for design and construction include fluid service requirements, which affect selection and application of materials, components, and joints. Fluid service requirements include prohibitions, limitations, and conditions, such as temperature limits or a requirement for safeguarding (see Appendix G). Code requirements for a piping system are the most restrictive of those that apply to any of its elements.

(2) For metallic piping not designated by the owner as Category M, High Pressure, or High Purity Fluid Service (see para. 300.2 and Appendix M), Code requirements are found in Chapters I through VI (the base Code) and fluid service requirements are found in

(-a) Chapter III for materials

(-b) Chapter II, Part 3, for components

(-c) Chapter II, Part 4, for joints

(3) For nonmetallic piping and piping lined with nonmetals, all requirements are found in Chapter VII. Paragraph designations begin with "A."

(4) For piping in a fluid service designated as Category M, all requirements are found in Chapter VIII. Paragraph designations begin with "M."

(5) For piping in a fluid service designated as Category D, piping elements restricted to Category D Fluid Service in Chapters I through VII, as well as elements suitable for other fluid services, may be used.

(6) For piping designated as High Pressure Fluid Service, all requirements are found in Chapter IX. These rules apply only when specified by the owner. Paragraph designations begin with "K."

(7) For piping designated as High Purity Fluid Service, all requirements are found in Chapter X. Paragraph designations begin with "U."

(8) Requirements for Normal Fluid Service in Chapters I through VI are applicable under severe cyclic conditions unless alternative requirements for severe cyclic conditions are stated.

(9) Requirements for Normal Fluid Service in Chapters I through VI are applicable for Elevated Temperature Fluid Service unless alternative requirements for Elevated Temperature Fluid Service are invoked.

(e) *Appendices.* Appendices of this Code contain Code requirements, supplementary guidance, or other information. See para. 300.4 for a description of the status of each Appendix.

(f) *Code Cases.* ASME issues Code Cases that are applicable to this Code. The Code Cases

(1) modify the requirements of this Code

(2) are applicable from the issue date until the Cases are annulled

(3) may be used only when approved by the owner. When so approved, the Code Cases shall be specified in the engineering design and become requirements of this Code.

300.1 Scope

Rules for the Process Piping Code Section B31.3[1] have been developed considering piping typically found in petroleum refineries; onshore and offshore petroleum and natural gas production facilities; chemical, pharmaceutical, textile, paper, ore processing, semiconductor, and cryogenic plants; food and beverage processing facilities; and related processing plants and terminals.

300.1.1 Content and Coverage

(a) This Code prescribes requirements for materials and components, design, fabrication, assembly, erection, examination, inspection, and testing of piping.

(b) This Code applies to piping for all fluids, including

(1) raw, intermediate, and finished chemicals

(2) petroleum products

(3) gas, steam, air, and water

(4) fluidized solids

(5) refrigerants

(6) cryogenic fluids

(c) See Figure 300.1.1 for a diagram illustrating the application of B31.3 piping at equipment. The joint connecting piping to equipment is within the scope of B31.3.

300.1.2 Packaged Equipment Piping. Also included within the scope of this Code is piping that interconnects pieces or stages within a packaged equipment assembly.

300.1.3 Exclusions. This Code excludes the following:

(a) piping systems designed for internal gage pressures at or above zero but less than 105 kPa (15 psi), provided the fluid handled is nonflammable, nontoxic, and not damaging to human tissues as defined in 300.2, and its design temperature is from −29°C (−20°F) through 186°C (366°F)

(b) power boilers in accordance with ASME BPVC,[2] Section I and boiler external piping that is required to conform to ASME B31.1

(c) tubes, tube headers, crossovers, and manifolds of fired heaters that are internal to the heater enclosure

(d) pressure vessels, heat exchangers, pumps, compressors, and other fluid handling or processing equipment, including internal piping and connections for external piping

300.1.4 Units of Measure. This Code states values in both SI and U.S. Customary units. Within the text, the U.S. Customary units are shown in parentheses or in separate tables. The values stated in each system are not exact equivalents; therefore, each system of units should be used independently of the other. (20)

When separate equations are provided for SI and U.S. Customary units, those equations shall be executed using variables in the units associated with the specific equation. The results obtained from execution of these equations may be converted to other units.

When necessary to convert from one system of units to another, conversion should be made by rounding the values to the number of significant digits of implied precision in the starting value but not less than four significant digits for use in calculations.

[1] B31 references here and elsewhere in this Code are to the ASME B31 Code for Pressure Piping and its various Sections, which are identified and briefly described in the Introduction.

[2] ASME BPVC references here and elsewhere in this Code are to the ASME Boiler and Pressure Vessel Code and its various Sections as follows:

Section I, Rules for Construction of Power Boilers

Section II, Materials, Parts C and D

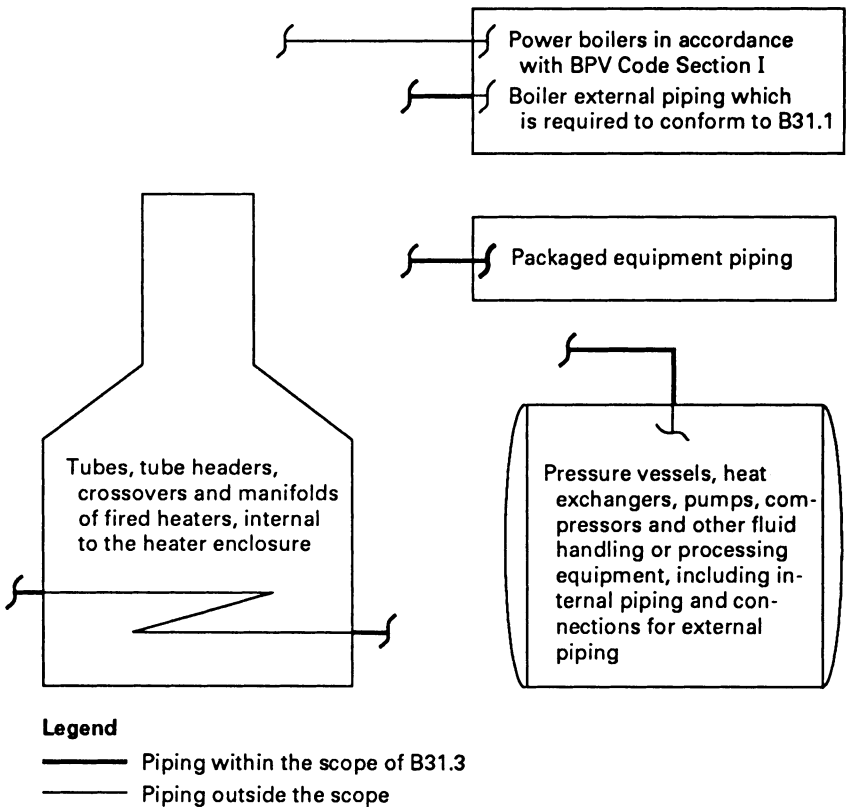
Section III, Rules for Construction of Nuclear Facility Components, Division 1, Subsection NH

Section V, Nondestructive Examination

Section VIII, Rules for Construction of Pressure Vessels, Divisions 1, 2, and 3

Section IX, Welding, Brazing, and Fusing Qualifications

Figure 300.1.1 Diagram Illustrating Application of B31.3 Piping at Equipment



GENERAL NOTE: The means by which piping is attached to equipment is within the scope of the applicable piping code.

300.1.5 Rounding. The rules described in this paragraph apply unless otherwise specified in the Code or the engineering design. For purposes of determining conformance with specified limits in this Code, an observed value or a calculated value shall be rounded "to the nearest unit" in the last right-hand significant digit used in expressing the requirement, in accordance with the rounding method of ASTM E29, Using Significant Digits in Test Data to Determine Conformance with Specifications. ASTM E29 requires that when rounding a number to one having a specified number of significant digits, choose that which is nearest. If two choices are possible, as when the digits dropped are exactly a 5 or a 5 followed only by zeros, choose that ending in an even digit. See Appendix F, para. F300.1.5.

300.2 Definitions

Some of the terms relating to piping are defined below. For welding, brazing, and soldering terms not shown here, definitions in accordance with AWS Standard A3.0[3] apply.

[3] AWS A3.0M/A3.0, Standard Welding Terms and Definitions, Including Terms for Adhesive Bonding, Brazing, Soldering, Thermal Cutting and Thermal Spraying

air-hardened steel: a steel that hardens during cooling in air from a temperature above its transformation range.

anneal heat treatment: see *heat treatment*.

arc cutting: a group of cutting processes wherein the severing or removing of metals is effected by melting with the heat of an arc between an electrode and the base metal. (Includes carbon-arc cutting, metal-arc cutting, gas metal-arc cutting, gas tungsten-arc cutting, plasma-arc cutting, and air carbon-arc cutting.) See also *oxygen-arc cutting*.

arc welding (AW): a group of welding processes that produces coalescence of metals by heating them with an arc or arcs, with or without the application of pressure and with or without the use of filler metal.

assembly: the joining together of two or more piping components by bolting, welding, bonding, screwing, brazing, soldering, cementing, or use of packing devices as specified by the engineering design.

autogenous weld: a weld made by fusion of the base metal without the addition of filler metal [see also *gas tungsten-arc welding (GTAW)*].

automatic welding: welding with equipment that performs the welding operation without adjustment of the controls by an operator. The equipment may or may not perform the loading and unloading of the work.

backing filler metal: see *consumable insert.*

backing ring: material in the form of a ring used to support molten weld metal.

balanced piping system: see para. 319.2.2(a).

base material: the material to be brazed, soldered, welded, or otherwise fused.

basic allowable stress: see *stress terms frequently used.*

bolt design stress: see *stress terms frequently used.*

bonded joint: a permanent joint in nonmetallic piping made by one of the following methods:

(a) *adhesive joint:* a joint made by applying an adhesive to the surfaces to be joined and pressing them together

(b) *butt-and-wrapped joint:* a joint made by butting together the joining surfaces and wrapping the joint with plies of reinforcing fabric saturated with resin

(c) *heat fusion joint:* a joint made by heating the surfaces to be joined and pressing them together to achieve fusion

(d) *hot gas welded joint:* a joint made by simultaneously heating the surfaces to be joined and a filler material with a stream of hot air or hot inert gas, then pressing the surfaces together and applying the filler material to achieve fusion

(e) *solvent cemented joint:* a joint made by using a solvent cement to soften the surfaces to be joined and pressing them together

(f) *electrofusion joint:* a joint made by heating the surfaces to be joined using an electrical resistance wire coil that remains embedded in the joint.

bonder: one who performs a manual or semiautomatic bonding operation.

bonding operator: one who operates machine or automatic bonding equipment.

bonding procedure: the detailed methods and practices involved in the production of a bonded joint.

bonding procedure specification (BPS): the document that lists the parameters to be used in the construction of bonded joints in accordance with the requirements of this Code.

borescopic examination: a visual examination aided by a mechanical or electromechanical device to examine the inside diameter of inaccessible welds.

branch connection fitting: an integrally reinforced fitting welded to a run pipe and connected to a branch pipe by a buttwelding, socket welding, threaded, or flanged joint; includes a branch outlet fitting conforming to MSS SP-97.

brazing: a metal joining process wherein coalescence is produced by use of a nonferrous filler metal having a melting point above 427°C (800°F), but lower than that of the base metals being joined. The filler metal is distributed between the closely fitted surfaces of the joint by capillary attraction.

butt joint: a joint between two members aligned approximately in the same plane.

Category D: see *fluid service*.

Category M: see *fluid service*.

caulked joint: a joint in which suitable material (or materials) is either poured or compressed by the use of tools into the annular space between a bell (or hub) and spigot (or plain end), thus comprising the joint seal.

chemical plant: an industrial plant for the manufacture or processing of chemicals, or of raw materials or intermediates for such chemicals. A chemical plant may include supporting and service facilities, such as storage, utility, and waste treatment units.

cold spring: see para. 319.2.4.

compression type tube fittings: tube fittings consisting of a flareless, mechanical grip connection, including a body, nut, and single or dual ferrules. See also para. U306.6.

connections for external piping: those integral parts of individual pieces of equipment that are designed for attachment of external piping.

consumable insert: preplaced filler metal that is completely fused into the root of the joint and becomes part of the weld.

damaging to human tissues: for the purposes of this Code, this phrase describes a fluid service in which exposure to the fluid, caused by leakage under expected operating conditions, can harm skin, eyes, or exposed mucous membranes so that irreversible damage may result unless prompt restorative measures are taken. (Restorative measures may include flushing with water, administration of antidotes, or medication.)

design minimum temperature: see para. 301.3.1.

design pressure: see para. 301.2.

design temperature: see para. 301.3.

designer: the person or organization in responsible charge of the engineering design.

displacement stress range: see para. 319.2.3.

elements: see *piping elements*.

engineering design: the detailed design governing a piping system, developed from process and mechanical requirements, conforming to Code requirements, and including all necessary specifications, drawings, and supporting documents.

equipment connection: see *connections for external piping*.

erection: the complete installation of a piping system in the locations and on the supports designated by the engineering design including any field assembly, fabrication, examination, inspection, and testing of the system as required by this Code.

examination, examiner: see paras. 341.1 and 341.2.

examination, types of: see para. 344.1.3 for the following:
(a) 100% examination
(b) random examination
(c) spot examination
(d) random spot examination

extruded outlet header: see para. 304.3.4.

fabrication: the preparation of piping for assembly, including cutting, threading, grooving, forming, bending, and joining of components into subassemblies. Fabrication may be performed in the shop or in the field.

face of weld: the exposed surface of a weld on the side from which the welding was done.

face seal fitting: a High Purity Fluid Service fitting that incorporates two machined faces and a metallic gasket within an external/internal nut configuration to attain a high leak integrity seal. See also para. U315.3(b).

filler material: the material to be added in making metallic or nonmetallic joints.

fillet weld: a weld of approximately triangular cross section joining two surfaces approximately at right angles to each other in a lap joint, tee joint, or corner joint. (See also *size of weld* and *throat of a fillet weld.*)

flammable: for the purposes of this Code, describes a fluid that under ambient or expected operating conditions is a vapor or produces vapors that can be ignited and continue to burn in air. The term thus may apply, depending on service conditions, to fluids defined for other purposes as flammable or combustible.

fluid service: a general term concerning the application of a piping system, considering the combination of fluid properties, operating conditions, and other factors that establish the basis for design of the piping system. See Appendix M.

(a) Category D Fluid Service: a fluid service in which all of the following apply:

(1) the fluid handled is nonflammable, nontoxic, and not damaging to human tissues as defined in para. 300.2

(2) the design gage pressure does not exceed 1 035 kPa (150 psi)

(3) the design temperature is not greater than 186°C (366°F)

(4) the fluid temperature caused by anything other than atmospheric conditions is not less than −29°C (−20°F)

(b) Category M Fluid Service: a fluid service in which both of the following apply:

(1) the fluid is so highly toxic that a single exposure to a very small quantity of the fluid, caused by leakage, can produce serious irreversible harm to persons on breathing or bodily contact, even when prompt restorative measures are taken

(2) after consideration of piping design, experience, service conditions, and location, the owner determines that the requirements for Normal Fluid Service do not sufficiently provide the leak tightness required to protect personnel from exposure

(c) Elevated Temperature Fluid Service: a fluid service in which the piping metal temperature is sustained equal to or greater than T_{cr} as defined in Table 302.3.5, General Note (b).

(d) High Pressure Fluid Service: a fluid service for which the owner specifies the use of Chapter IX for piping design and construction; see also para. K300.

(e) High Purity Fluid Service: a fluid service that requires alternative methods of fabrication, inspection, examination, and testing not covered elsewhere in the Code, with the intent to produce a controlled level of cleanness. The term thus applies to piping systems defined for other purposes as high purity, ultra high purity, hygienic, or aseptic.

(f) Normal Fluid Service: a fluid service pertaining to most piping covered by this Code, i.e., not subject to the rules for Category D, Category M, Elevated Temperature, High Pressure, or High Purity Fluid Service.

full fillet weld: a fillet weld whose size is equal to the thickness of the thinner member joined.

fusion: the melting together of filler material and base material, or of base material only, that results in coalescence.

gas metal-arc welding (GMAW): an arc-welding process that produces coalescence of metals by heating them with an arc between a continuous filler metal (consumable) electrode and the work. Shielding is obtained entirely from an externally supplied gas, or gas mixture. Some variations of this process are called MIG or CO_2 welding (nonpreferred terms).

gas tungsten-arc welding (GTAW): an arc-welding process that produces coalescence of metals by heating them with an arc between a single tungsten (nonconsumable) electrode and the work. Shielding is obtained from a gas or gas mixture. Pressure may or may not be used and filler metal may or may not be used. (This process has sometimes been called TIG welding.)

gas welding: a group of welding processes wherein coalescence is produced by heating with a gas flame or flames, with or without the application of pressure, and with or without the use of filler material.

groove weld: a weld made in the groove between two members to be joined.

heat-affected zone: that portion of the base material which has not been melted, but whose mechanical properties or microstructure have been altered by the heat of welding, brazing, soldering, forming, or cutting.

heat treatment: the following terms describe various types and processes of heat treatment:

(a) annealing: heating to and holding at a suitable temperature above the transformation temperature range, followed by slow cooling to well below the transformation temperature range.

(b) normalizing: heating a ferrous metal to a temperature above the transformation temperature range, followed by cooling in room-temperature still air to well below the transformation temperature range.

(c) quenching: when used as a part of a heat-treating operation, a rapid cooling process that results in microstructural stabilization or changes in material properties that would not have occurred without rapid cooling.

(d) recommended or required heat treatment: the application of heat to a metal section subsequent to a cutting, forming, or welding operation, as provided in para. 331.

(e) solution heat treatment: heating an alloy to a suitable temperature, holding at that temperature long enough to allow one or more constituents to enter into solid solution, and then cooling rapidly enough to hold the constituents in solution.

(f) stress-relief: uniform heating of a structure or portion thereof to a sufficient temperature below the transformation temperature range to relieve the major portion of the residual stresses, followed by uniform cooling slowly enough to minimize development of new residual stresses.

(g) tempering: reheating a hardened metal to a temperature below the transformation range to improve toughness.

(h) transformation range: the temperature range over which a phase change occurs.

(i) transformation temperature: the temperature at which a phase change begins or ends. In metals, phase changes can be solid-state changes.

High Pressure Fluid Service: see *fluid service*.

High Purity Fluid Service: see *fluid service.*

hygienic clamp joint: a tube outside-diameter union consisting of two neutered ferrules having flat faces with a concentric groove and mating gasket that is secured with a clamp, providing a nonprotruding, recessless product contact surface. See also para. U315.3(b).

indication, linear: in nondestructive examination, an indication having a length greater than 3 times its width.

indication, rounded: in nondestructive examination, an indication with a length equal to or less than 3 times its width. These indications may be circular, elliptical, conical, or irregular in shape and may have tails.

inline portions of instruments: pressure-containing portions of instruments that are in direct contact with the fluid when installed in a piping system. Permanently sealed fluid-filled tubing systems furnished with instruments as temperature- or pressure-responsive devices, e.g., pressure gages, pressure transmitters, and transducers, are excluded.

in-process examination: see para. 344.7.

inspection, Inspector: see para. 340.

integrally reinforced branch connection fitting: see *branch connection fitting.*

joint design: the joint geometry together with the required dimensions of the welded joint.

listed: for the purposes of this Code, describes a material or component that conforms to a specification in Appendix A, Appendix B, or Appendix K or to a standard in Table 326.1, A326.1, or K326.1.

manual welding: a welding operation performed and controlled completely by hand.

may: a term that indicates a provision is neither required nor prohibited.

mechanical joint: a joint for the purpose of mechanical strength or leak resistance, or both, in which the mechanical strength is developed by threaded, grooved, rolled, flared, or flanged pipe ends; or by bolts, pins, toggles, or rings; and the leak resistance is developed by threads and compounds, gaskets, rolled ends, caulking, or machined and mated surfaces.

miter or miter bend: for the purposes of this Code, two or more straight sections of pipe matched and joined in a plane bisecting the angle of junction so as to produce a change in direction greater than 3 deg.

nominal: a numerical identification of dimension, capacity, rating, or other characteristic used as a designation, not as an exact measurement.

Normal Fluid Service: see *fluid service*.

normalizing: see *heat treatment*.

notch-sensitive: describes a metal subject to reduction in strength in the presence of stress concentration. The degree of notch sensitivity is usually expressed as the strength determined in a notched specimen divided by the strength determined in an unnotched specimen, and can be obtained from either static or dynamic tests.

NPS : nominal pipe size (followed, when appropriate, by the specific size designation number without an inch symbol).

orbital welding: automatic or machine welding in which the electrode rotates (orbits) around the circumference of a stationary pipe or tube.

owner: the person, partnership, organization, or business ultimately responsible for design, construction, operation, and maintenance of a facility.

oxygen-arc cutting (OAC): an oxygen-cutting process that uses an arc between the workpiece and a consumable electrode, through which oxygen is directed to the workpiece. For oxidation-resistant metals, a chemical flux or metal powder is used to facilitate the reaction.

oxygen cutting (OC): a group of thermal cutting processes that severs or removes metal by means of the chemical reaction between oxygen and the base metal at elevated temperature. The necessary temperature is maintained by the heat from an arc, an oxyfuel gas flame, or other source.

oxygen gouging: thermal gouging that uses an oxygen cutting process variation to form a bevel or groove.

packaged equipment: an assembly of individual pieces or stages of equipment, complete with interconnecting piping and connections for external piping. The assembly may be mounted on a skid or other structure prior to delivery.

petroleum refinery: an industrial plant for processing or handling of petroleum and products derived directly from petroleum. Such a plant may be an individual gasoline recovery plant, a treating plant, a gas processing plant (including liquefaction), or an integrated refinery having various process units and attendant facilities.

pipe: a pressure-tight cylinder used to convey a fluid or to transmit a fluid pressure, ordinarily designated "pipe" in applicable material specifications. Materials designated "tube" or "tubing" in the specifications are treated as pipe when intended for pressure service. Types of pipe, according to the method of manufacture, are defined as follows:

(a) electric resistance-welded pipe: pipe produced in individual lengths or in continuous lengths from coiled skelp and subsequently cut into individual lengths, having a longitudinal butt joint wherein coalescence is produced by the heat obtained from resistance of the pipe to the flow of electric current in a circuit of which the pipe is a part, and by the application of pressure.

(b) furnace butt welded pipe, continuous welded: pipe produced in continuous lengths from coiled skelp and subsequently cut into individual lengths, having its longitudinal butt joint forge welded by the mechanical pressure developed in passing the hot-formed and edge-heated skelp through a set of round pass welding rolls.

(c) electric-fusion welded pipe: pipe having a longitudinal butt joint wherein coalescence is produced in the preformed tube by manual or automatic electric-arc welding. The weld may be single (welded from one side) or double (welded from inside and outside) and may be made with or without the addition of filler metal.

(d) double submerged-arc welded pipe: pipe having a longitudinal butt joint produced by at least two passes, one of which is on the inside of the pipe. Coalescence is produced by heating with an electric arc or arcs between the bare metal electrode or electrodes and the work. The welding is shielded by a blanket of granular fusible material on the work. Pressure is not used and filler metal for the inside and outside welds is obtained from the electrode or electrodes.

(e) seamless pipe: pipe produced by piercing a billet followed by rolling or drawing, or both.

(f) spiral (helical seam) welded pipe: pipe having a helical seam with a butt, lap, or lock-seam joint that is welded using an electrical resistance, electric fusion, or double-submerged arc welding process.

pipe-supporting elements: pipe-supporting elements consist of fixtures and structural attachments as follows:

(a) fixtures: fixtures include elements that transfer the load from the pipe or structural attachment to the supporting structure or equipment. They include hanging type fixtures, such as hanger rods, spring hangers, sway braces, counterweights, turnbuckles, struts, chains, guides, and anchors; and bearing type fixtures, such as saddles, bases, rollers, brackets, and sliding supports.

(b) structural attachments: structural attachments include elements that are welded, bolted, or clamped to the pipe, such as clips, lugs, rings, clamps, clevises, straps, and skirts.

piping: assemblies of piping components used to convey, distribute, mix, separate, discharge, meter, control, or snub fluid flows. Piping also includes pipe-supporting elements, but does not include support structures, such as building frames, bents, foundations, or any equipment excluded from this Code (see para. 300.1.3).

piping components: mechanical elements suitable for joining or assembly into pressure-tight fluid-containing piping systems. Components include pipe, tubing, fittings, flanges, gaskets, bolting, valves, and devices such as expansion joints, flexible joints, pressure hoses, traps, strainers, inline portions of instruments, and separators.

piping elements: any material or work required to plan and install a piping system. Elements of piping include design specifications, materials, components, supports, fabrication, examination, inspection, and testing.

piping installation: designed piping systems to which a selected Code edition and addenda apply.

piping subassembly: a portion of a piping system that consists of one or more piping components.

piping system: interconnected piping subject to the same set or sets of design conditions.

plasma arc cutting (PAC): an arc cutting process that uses a constricted arc and removes molten metal with a high velocity jet of ionized gas issuing from the constricting orifice.

postweld heat treatment: see *heat treatment*.

preheating: the application of heat to the base material immediately before or during a forming, welding, or cutting process. See para. 330.

procedure qualification record (PQR): a document listing all pertinent data, including the essential variables employed and the test results, used in qualifying the procedure specification.

process unit: an area whose boundaries are designated by the engineering design within which reactions, separations, and other processes are carried out. Examples of installations that are *not* classified as process units are loading areas or terminals, bulk plants, compounding plants, and tank farms and storage yards.

quench annealing: see *solution heat treatment* under *heat treatment.*

quenching: see *heat treatment*.

readily accessible (for visual examination) : those surfaces that can be examined from a distance of not more than 600 mm (24 in.) and at an angle of not less than 30 deg to the surface to be examined.

reinforcement: see paras. 304.3 and A304.3. See also *weld reinforcement.*

representative: a person, partnership, organization, or business designated by the owner to carry out selected responsibilities on the owner's behalf.

room temperature: temperature between 10°C and 38°C (50°F and 100°F).

root opening: the separation between the members to be joined, at the root of the joint.

safeguarding: provision of protective measures of the types outlined in Appendix G, where deemed necessary. See Appendix G for detailed discussion.

seal bond: a bond intended primarily to provide joint tightness against leakage in nonmetallic piping.

seal weld: a weld intended primarily to provide joint tightness against leakage in metallic piping.

semiautomatic arc welding: arc welding with equipment that controls only the filler metal feed. The advance of the welding is manually controlled.

severe cyclic conditions: conditions applying to specific piping components or joints for which the owner or the designer determines that construction to better resist fatigue loading is warranted. See Appendix F, para. F301.10.3 for guidance on designating piping as being under severe cyclic conditions.

shall : a term that indicates a provision is a Code requirement.

shielded metal-arc welding (SMAW): an arc welding process that produces coalescence of metals by heating them with an arc between a covered metal electrode and the work. Shielding is obtained from decomposition of the electrode covering. Pressure is not used and filler metal is obtained from the electrode.

should : a term that indicates a provision is recommended as good practice but is not a Code requirement.

size of weld:

(a) *fillet weld:* the leg lengths (the leg length for equal-leg welds) of the sides, adjoining the members welded, of the largest triangle that can be inscribed within the weld cross section. For welds between perpendicular members, the definitions in Figure 328.5.2A apply.

NOTE: When the angle between members exceeds 105 deg, size is of less significance than effective throat (see also *throat of a fillet weld*).

(b) *groove weld:* the joint penetration (depth of bevel plus the root penetration when specified). The size of a groove weld and its effective throat are the same.

slag inclusion: nonmetallic solid material entrapped in weld metal or between weld metal and base metal.

soldering: a metal joining process wherein coalescence is produced by heating to suitable temperatures and by using a nonferrous alloy fusible at temperatures below 427°C (800°F) and having a melting point below that of the base metals being joined. The filler metal is distributed between closely fitted surfaces of the joint by capillary attraction. In general, solders are lead-tin alloys and may contain antimony, bismuth, and other elements.

solution heat treatment: see *heat treatment.*

stress ratio: see para. 323.2.2(b).

stress relief: see *heat treatment*.

stress terms frequently used:

(a) *basic allowable stress:* this term, symbol *S*, represents the stress value for any material determined by the appropriate stress basis in para. 302.3.2

(b) *bolt design stress:* this term represents the design stress used to determine the required cross-sectional area of bolts in a bolted joint

(c) *hydrostatic design basis:* selected properties of plastic piping materials to be used in accordance with ASTM D2837 or D2992 to determine the HDS [see (d) below] for the material

(d) *hydrostatic design stress (HDS):* the maximum continuous stress due to internal pressure to be used in the design of plastic piping, determined from the hydrostatic design basis by use of a service (design) factor

submerged arc welding (SAW): an arc welding process that produces coalescence of metals by heating them with an arc or arcs between a bare metal electrode or electrodes and the work. The arc is shielded by a blanket of granular, fusible material on the work. Pressure is not used and filler metal is obtained from the electrode and sometimes from a supplemental source (welding rod, flux, or metal granules).

tack weld: a weld made to hold parts of a weldment in proper alignment until the final welds are made.

tempering: see *heat treatment*.

thermoplastic: a plastic that is capable of being repeatedly softened by increase of temperature and hardened by decrease of temperature.

thermosetting resin: a resin capable of being changed into a substantially infusible or insoluble product when cured at room temperature, or by application of heat, or by chemical means.

throat of a fillet weld:

(a) *theoretical throat:* the perpendicular distance from the hypotenuse of the largest right triangle that can be inscribed in the weld cross section to the root of the joint

(b) *actual throat:* the shortest distance from the root of a fillet weld to its face

(c) *effective throat:* the minimum distance, minus any reinforcement (convexity), between the weld root and the face of a fillet weld

toe of weld: the junction between the face of a weld and the base material.

tube: see *pipe*.

tungsten electrode: a nonfiller-metal electrode used in arc welding or cutting, made principally of tungsten.

unbalanced piping system: see para. 319.2.2(b).

undercut: a groove melted into the base material adjacent to the toe or root of a weld and left unfilled by weld material.

visual examination: see para. 344.2.1.

weld: a localized coalescence of material wherein coalescence is produced either by heating to suitable temperatures, with or without the application of pressure, or by application of pressure alone, and with or without the use of filler material.

weld coupon: a sample weld used to determine weld acceptance. Types of weld coupons are defined as follows:

(a) primary weld coupon: made prior to the start of production welding to establish a benchmark of weld acceptance

(b) production weld coupon: made when any of the conditions in para. U341.4.5 exist and used to compare against a corresponding primary weld coupon to demonstrate continued acceptability of welds during production welding

weld coupon examination: see para. U344.8.1.

weld reinforcement: weld material in excess of the specified weld size.

welder: one who performs a manual or semi-automatic welding operation. (This term is sometimes erroneously used to denote a welding machine.)

welding operator: one who operates machine or automatic welding equipment.

welding procedure: the detailed methods and practices involved in the production of a weldment.

welding procedure specification (WPS): the document that lists the parameters to be used in construction of weldments in accordance with requirements of this Code.

weldment: an assembly whose component parts are joined by welding.

300.3 Nomenclature

Dimensional and mathematical symbols used in this Code are listed in Appendix J, with definitions and location references to each. Uppercase and lowercase English letters are listed alphabetically, followed by Greek letters.

300.4 Status of Appendices

Table 300.4 indicates for each Appendix of this Code whether it contains Code requirements, guidance, or supplemental information. See the first page of each Appendix for details.

(20) **Table 300.4 Status of Appendices in B31.3**

Appendix	Title	Status
A	Allowable Stresses and Quality Factors for Metallic Piping and Bolting Materials	Requirements
B	Stress Tables and Allowable Pressure Tables for Nonmetals	Requirements
C	Physical Properties of Piping Materials	Requirements (1)
E	Reference Standards	Requirements
F	Guidance and Precautionary Considerations	Guidance (2)
G	Safeguarding	Guidance (2)
H	Sample Calculations for Branch Reinforcement	Guidance
J	Nomenclature	Information
K	Allowable Stresses for High Pressure Piping	Requirements (3)
L	Aluminum Alloy Pipe Flanges	Specification (4)
M	Guide to Classifying Fluid Services	Guidance (2)
N	Application of ASME B31.3 Internationally	Guidance (2)
Q	Quality System Program	Guidance (2)
R	Use of Alternative Ultrasonic Acceptance Criteria	Requirements (5)
S	Piping System Stress Analysis Examples	Guidance (2)
V	Allowable Variations in Elevated Temperature Service	Guidance (2)
W	High-Cycle Fatigue Assessment of Piping Systems	Requirements
X	Metallic Bellows Expansion Joints	Requirements
Z	Preparation of Technical Inquiries	Requirements (5)

NOTES:
(1) Contains default requirements, to be used unless more directly applicable data are available.
(2) Contains no requirements but Code user is responsible for considering applicable items.
(3) Contains requirements applicable only when use of Chapter IX is specified.
(4) Contains pressure–temperature ratings, materials, dimensions, and markings of forged aluminum alloy flanges.
(5) Contains administrative requirements.

Chapter II
Design

PART 1
CONDITIONS AND CRITERIA

301 DESIGN CONDITIONS

Paragraph 301 states the qualifications of the Designer, defines the temperatures, pressures, and forces applicable to the design of piping, and states the consideration that shall be given to various effects and their consequent loadings. See also Appendix F, para. F301.

301.1 Qualifications of the Designer

The Designer is the person(s) in charge of the engineering design of a piping system and shall be experienced in the use of this Code. The qualifications and experience required of the Designer will depend on the complexity and criticality of the system and the nature of the individual's experience. The owner's approval is required if the individual does not meet at least one of the following criteria:

(a) Completion of a degree, accredited by an independent agency [such as ABET (U.S. and international), NBA (India), CTI (France), and CNAP (Chile)], in engineering, science, or technology, requiring the equivalent of at least 4 yr of full-time study that provides exposure to fundamental subject matter relevant to the design of piping systems, plus a minimum of 5 yr of experience in the design of related pressure piping.

(b) Professional Engineering registration, recognized by the local jurisdiction, and experience in the design of related pressure piping.

(c) Completion of an accredited engineering technician or associates degree, requiring the equivalent of at least 2 yr of study, plus a minimum of 10 yr of experience in the design of related pressure piping.

(d) Fifteen yr of experience in the design of related pressure piping.

Experience in the design of related pressure piping is satisfied by piping design experience that includes design calculations for pressure, sustained and occasional loads, and piping flexibility.

301.2 Design Pressure

301.2.1 General

(a) The design pressure of each component in a piping system shall be not less than the pressure at the most severe condition of coincident internal or external pressure and temperature (minimum or maximum) expected during service, except as provided in para. 302.2.4.

(b) The most severe condition is that which results in the greatest required component thickness and the highest component rating.

(c) When more than one set of pressure–temperature conditions exist for a piping system, the conditions governing the rating of components conforming to listed standards may differ from the conditions governing the rating of components designed in accordance with para. 304.

(d) When a pipe is separated into individualized pressure-containing chambers (including jacketed piping, blanks, etc.), the partition wall shall be designed on the basis of the most severe coincident temperature (minimum or maximum) and differential pressure between the adjoining chambers expected during service, except as provided in para. 302.2.4.

301.2.2 Required Pressure Containment or Relief

(a) Provision shall be made to safely contain or relieve (see para. 322.6.3) any expected pressure to which the piping may be subjected. Piping not protected by a pressure-relieving device, or that can be isolated from a pressure-relieving device, shall be designed for at least the highest expected pressure.

(b) Sources of pressure to be considered include ambient influences, pressure oscillations and surges, improper operation, decomposition of unstable fluids, static head, and failure of control devices.

(c) The allowances of para. 302.2.4(f) are permitted, provided that the other requirements of para. 302.2.4 are also met.

301.3 Design Temperature

The design temperature of each component in a piping system is the temperature at which, under the coincident pressure, the greatest thickness or highest component rating is required in accordance with para. 301.2. (To satisfy the requirements of para. 301.2, different components in the same piping system may have different design temperatures.)

In establishing design temperatures, consider at least the fluid temperatures, ambient temperatures, solar radiation, heating or cooling medium temperatures, and the applicable provisions of paras. 301.3.2, 301.3.3, and 301.3.4.

301.3.1 Design Minimum Temperature. The design minimum temperature is the lowest component temperature expected in service. This temperature may establish special design requirements and material qualification requirements. See also paras. 301.4.4 and 323.2.2.

(20) **301.3.2 Uninsulated Piping Components**

(a) For fluid temperatures below 65°C (150°F), the component temperature shall be taken as the fluid temperature unless solar radiation or other effects result in a higher temperature.

(b) For fluid temperatures 65°C (150°F) and above, unless a lower average wall temperature is determined by test or heat transfer calculation, the temperature for uninsulated components shall be no less than the following values:

(1) valves, pipe, lapped ends, welding fittings, and other components having wall thickness comparable to that of the pipe — 95% of the fluid temperature

(2) flanges (except lap joint) including those on fittings and valves — 90% of the fluid temperature

(3) lap joint flanges — 85% of the fluid temperature

(4) bolting — 80% of the fluid temperature

(20) **301.3.3 Externally Insulated Piping Components.** The component design temperature shall be the fluid temperature unless calculations, tests, or service experience based on measurements support the use of another temperature. Where piping is heated or cooled by tracing or jacketing, this effect shall be considered in establishing component design temperatures.

(20) **301.3.4 Internally Insulated Piping Components.** The component design temperature shall be based on heat transfer calculations or tests.

301.4 Ambient Effects

See Appendix F, para. F301.4.

301.4.1 Cooling — Effects on Pressure. The cooling of a gas or vapor in a piping system may reduce the pressure sufficiently to create an internal vacuum. In such a case, the piping shall be capable of withstanding the external pressure at the lower temperature, or provision shall be made to break the vacuum.

301.4.2 Fluid Expansion Effects. Provision shall be made in the design either to withstand or to relieve increased pressure caused by the heating of static fluid in a piping component. See also para. 322.6.3(b)(2).

301.4.3 Atmospheric Icing. Where the design minimum temperature of a piping system is below 0°C (32°F), the possibility of moisture condensation and buildup of ice shall be considered and provisions made in the design to avoid resultant malfunctions. This applies to surfaces of moving parts of shutoff valves, control valves, pressure-relief devices including discharge piping, and other components.

301.4.4 Low Ambient Temperature. Consideration shall be given to low ambient temperature conditions for displacement stress analysis.

301.5 Dynamic Effects

301.5.1 Impact. Impact forces caused by external or internal conditions (including changes in flow rate, hydraulic shock, liquid or solid slugging, flashing, and geysering) shall be taken into account in the design of piping. See Appendix F, para. F301.5.1.

301.5.2 Wind. The effect of wind loading shall be taken into account in the design of exposed piping. The analysis considerations and loads may be as described in ASCE 7. Authoritative local meteorological data may also be used to define or refine the design wind loads.

301.5.3 Earthquake. The effect of earthquake loading shall be taken into account in the design of piping. The analysis considerations and loads may be as described in ASCE 7. Authoritative local seismological data may also be used to define or refine the design earthquake loads.

301.5.4 Vibration. Piping shall be designed, arranged, and supported to eliminate excessive and harmful effects of vibration that may arise from such sources as impact, pressure pulsation, turbulent flow vortices, resonance in compressors, external vortex shedding (e.g., wind), and acoustically induced vibration.

301.5.5 Discharge Reactions. Piping shall be designed, arranged, and supported so as to withstand reaction forces due to let-down or discharge of fluids.

301.6 Weight Effects

The following weight effects, combined with loads and forces from other causes, shall be taken into account in the design of piping.

301.6.1 Live Loads. These loads include the weight of the medium transported or the medium used for test. Snow and ice loads due to both environmental and operating conditions shall be considered.

301.6.2 Dead Loads. These loads consist of the weight of piping components, insulation, and other superimposed permanent loads supported by the piping.

301.7 Thermal Expansion and Contraction Effects

The following thermal effects, combined with loads and forces from other causes, shall be taken into account in the design of piping. See also Appendix F, para. F301.7.

301.7.1 Thermal Loads Due to Restraints. These loads consist of thrusts and moments that arise when free thermal expansion and contraction of the piping are prevented by restraints or anchors.

301.7.2 Loads Due to Temperature Gradients. These loads arise from stresses in pipe walls resulting from large rapid temperature changes or from unequal temperature distribution as may result from a high heat flux through a comparatively thick pipe or stratified two-phase flow causing bowing of the line.

301.7.3 Loads Due to Differences in Expansion Characteristics. These loads result from differences in thermal expansion where materials with different thermal expansion coefficients are combined, as in bimetallic, lined, jacketed, or metallic–nonmetallic piping.

301.8 Effects of Support, Anchor, and Terminal Movements

The effects of movements of piping supports, anchors, and connected equipment shall be taken into account in the design of piping. These movements may result from the flexibility and/or thermal expansion of equipment, supports, or anchors; and from settlement, tidal movements, or wind sway.

301.9 Reduced Ductility Effects

The harmful effects of reduced ductility shall be taken into account in the design of piping. The effects may, for example, result from welding, heat treatment, forming, bending, or low operating temperatures, including the chilling effect of sudden loss of pressure on highly volatile fluids. Low ambient temperatures expected during operation shall be considered.

301.10 Cyclic Effects

Fatigue due to pressure cycling, thermal cycling, and other cyclic loadings shall be considered in the design of piping. See Appendix F, para. F301.10.

301.11 Air Condensation Effects

At operating temperatures below −191°C (−312°F) in ambient air, condensation and oxygen enrichment occur. These shall be considered in selecting materials, including insulation, and adequate shielding and/or disposal shall be provided.

302 DESIGN CRITERIA

302.1 General

Paragraph 302 states pressure–temperature ratings, stress criteria, design allowances, and minimum design values together with permissible variations of these factors as applied to the design of piping.

302.2 Pressure–Temperature Design Criteria

302.2.1 Listed Components Having Established Ratings. Except as limited elsewhere in the Code, pressure–temperature ratings contained in standards for piping components listed in Table 326.1 are acceptable for design pressures and temperatures in accordance with this Code. When the owner approves, provisions of this Code may be used to extend the pressure–temperature ratings of a component beyond the ratings contained in the listed standard.

302.2.2 Listed Components Not Having Specific Ratings

(a) Some of the standards for fittings in Table 326.1 (e.g., ASME B16.9 and B16.11) state that pressure–temperature ratings are based on straight seamless pipe. Such fittings shall be rated as calculated for straight seamless pipe with the same allowable stresses as the fitting and the nominal thickness corresponding to the wall thickness or class designation of the fitting, less all applicable allowances (e.g., thread depth and corrosion allowance), and considering the manufacturing undertolerances of the fittings and the pipe.

(b) For components with straight or spiral (helical seam) longitudinal welded joints, the pressure rating as determined for seamless pipe shall be multiplied by the weld joint strength reduction factor, *W*, as defined in para. 302.3.5(e).

(c) Other listed components not addressed in para. 302.2.1 or 302.2.2(a) shall have their pressure–temperature ratings established in accordance with the rules in para. 304.

302.2.3 Unlisted Components. Piping components not listed in Table 326.1 may be used subject to all of the following requirements:

(a) The material shall comply with para. 323.

(b) The designer shall be satisfied that the design is suitable for the intended service.

(c) Pressure–temperature ratings shall be established in accordance with the rules in para. 304.

302.2.4 Allowances for Pressure and Temperature Variations. Occasional variations of pressure, temperature, or both may occur in a piping system. Such variations shall be considered in selecting design pressure (para. 301.2) and design temperature (para. 301.3). The most severe coincident pressure and temperature (20) shall determine the design conditions unless all of the following criteria are met (see Appendix F, para. F302.2.4):

(a) The piping system shall have no pressure-containing components of gray iron or other nonductile metal.

(b) Circumferential pressure stresses (based on minimum pipe wall thickness, less allowances) shall not exceed the yield strength at temperature (see para. 302.3 of this Code and S_y data in ASME BPVC, Section II, Part D, Table Y-1).

(c) Combined stresses shall not exceed the limits established in para. 302.3.6.

(d) The total number of pressure–temperature variations above the design conditions shall not exceed 1 000 during the life of the piping system.

(e) In no case shall the increased pressure exceed the test pressure used under para. 345 for the piping system.

(f) Occasional variations above design conditions shall remain within one of the following limits for pressure design.

(1) Subject to the owner's approval, it is permissible to exceed the pressure rating or the allowable stress for pressure design at the temperature of the increased condition by not more than

(-a) 33% for no more than 10 h at any one time and no more than 100 h/y, or

(-b) 20% for no more than 50 h at any one time and no more than 500 h/y

The effects of such variations shall be determined by the designer to be safe over the service life of the piping system by methods acceptable to the owner. (See Appendix V.)

(2) When the variation is self-limiting (e.g., due to a pressure-relieving event), and lasts no more than 50 h at any one time and not more than 500 h/y, it is permissible to exceed the pressure rating or the allowable stress for pressure design at the temperature of the increased condition by not more than 20%.

(g) The combined effects of the sustained and cyclic variations on the serviceability of all components in the system shall have been evaluated.

(h) Temperature variations below the minimum temperature shown in Appendix A are not permitted unless the requirements of para. 323.2.2 are met for the lowest temperature during the variation.

(i) The application of pressures exceeding pressure–temperature ratings of valves may under certain conditions cause loss of seat tightness or difficulty of operation. The differential pressure on the valve closure element should not exceed the maximum differential pressure rating established by the valve manufacturer. Such applications are the owner's responsibility.

(20) **302.2.5 Ratings at Junction of Different Services.** When two services that operate at different pressure–temperature conditions are connected, the valve segregating the two services shall be rated for the more severe service condition. Where multiple valves are used (e.g., in a double block and bleed arrangement), all of the valves shall be rated for the more severe service condition. If the valve(s) will operate at a different temperature due to remoteness from a header or piece of equipment, the valve(s) (and any mating flanges) may be selected on the basis of the different temperature.

302.3 Allowable Stresses and Other Stress Limits

302.3.1 General. The allowable stresses defined in (a), (b), and (c) shall be used in design calculations unless modified by other provisions of this Code.

(a) Tension. Basic allowable stresses, *S*, in tension for metals listed in Tables A-1 and A-1M, and design stresses, *S*, for bolting materials listed in Tables A-2 and A-2M were determined in accordance with para. 302.3.2.

In equations elsewhere in the Code where the product *SE* appears, the value *S* is multiplied by one of the following quality factors:[1]

(1) casting quality factor E_c as defined in para. 302.3.3 and tabulated for various material specifications in Table A-1A, and for various levels of supplementary examination in Table 302.3.3C, or

(2) longitudinal weld joint factor E_j as defined in 302.3.4 and tabulated for various material specifications and classes in Table A-1B, and for various types of joints and supplementary examinations in Table 302.3.4

The stress values in Tables A-1, A-1M, A-2, and A-2M are grouped by materials and product forms, and are for stated temperatures up to the limit provided in para. 323.2.1(a). Straight-line interpolation between temperatures is permissible. The temperature intended is the design temperature (see para. 301.3).

(b) Shear and Bearing. Allowable stresses in shear shall be 0.80 times the basic allowable stress in tension tabulated in Appendix A. Allowable stress in bearing shall be 1.60 times that value.

(c) Compression. Allowable stresses in compression shall be no greater than the basic allowable stresses in tension as tabulated in Appendix A. Consideration shall be given to structural stability.

[1] If a component is made of castings joined by longitudinal welds, both a casting and a weld joint quality factor shall be applied. The equivalent quality factor *E* is the product of E_c, Table A-1A, and E_j, Table A-1B.

302.3.2 Bases for Design Stresses.[2] The bases for establishing design stress values for bolting materials and basic allowable stress values for other metallic materials in this Code are specified in (a) through (d). In the application of these criteria, the yield strength at temperature is considered to be $S_Y R_Y$ and the tensile strength at temperature is considered to be $1.1 S_T R_T$, where

R_T = ratio of the average temperature-dependent trend curve value of tensile strength to the room temperature tensile strength

R_Y = ratio of the average temperature-dependent trend curve value of yield strength to the room temperature yield strength

S_T = specified minimum tensile strength at room temperature

S_Y = specified minimum yield strength at room temperature

(a) Bolting Materials. Design stress values at temperature for bolting materials shall not exceed the lowest of the following:

(1) at temperatures below the creep range, for bolting materials whose strength has not been enhanced by heat treatment or strain hardening, the lowest of one-fourth of S_T, one-fourth of tensile strength at temperature, two-thirds of S_Y, and two-thirds of yield strength at temperature

(2) at temperatures below the creep range, for bolting materials whose strength has been enhanced by heat treatment or strain hardening, the lowest of one-fifth of S_T, one-fourth of the tensile strength at temperature, one-fourth of S_Y, and two-thirds of the yield strength at temperature (unless these values are lower than corresponding values for annealed material, in which case the annealed values shall be used)

(3) 100% of the average stress for a creep rate of 0.01% per 1 000 h

(4) 67% of the average stress for rupture at the end of 100 000 h

(5) 80% of minimum stress for rupture at the end of 100 000 h

(b) Gray Iron. Basic allowable stress values at temperature for gray iron shall not exceed the lower of the following:

(1) one-tenth of S_T

(2) one-tenth of the tensile strength at temperature

(c) Malleable Iron. Basic allowable stress values at temperature for malleable iron shall not exceed the lower of the following:

(1) one-fifth of S_T

(2) one-fifth of the tensile strength at temperature

(d) Other Materials. Basic allowable stress values at temperature for materials other than bolting materials, gray iron, and malleable iron shall not exceed the lowest of the following:

(1) the lower of one-third of S_T and one-third of tensile strength at temperature.

(2) except as provided in (3) below, the lower of two-thirds of S_Y and two-thirds of yield strength at temperature.

(3) for austenitic stainless steels and nickel alloys having similar stress–strain behavior, the lower of two-thirds of S_Y and 90% of yield strength at temperature [see (e)].

(4) 100% of the average stress for a creep rate of 0.01% per 1 000 h.

(5) for temperatures up to and including 815°C (1,500°F), 67% of the average stress for rupture at the end of 100 000 h.

(6) for temperatures higher than 815°C (1,500°F), $(100 \times F_{avg})$% times the average stress for rupture at the end of 100 000 h. F_{avg} is determined from the slope, n, of the log time-to-rupture versus log stress plot at 100 000 h such that $\log F_{avg} = 1/n$. F_{avg} shall not exceed 0.67.

(7) 80% of the minimum stress for rupture at the end of 100 000 h.

For structural grade materials, the basic allowable stress shall be 0.92 times the lowest value determined in (1) through (7).

(e) Application Limits. Application of stress values determined in accordance with (d)(3) is not recommended for flanged joints and other components in which slight deformation can cause leakage or malfunction.

(1) These values are shown in italics or boldface in Table A-1, as explained in Note (4a) to Appendix A Tables. Instead, either 75% of the stress value in Table A-1 or two-thirds of the yield strength at temperature listed in ASME BPVC, Section II, Part D, Table Y-1 should be used.

(2) Stress values determined in accordance with (d)(3) are not identified in Table A-1M. See Note (4b) to Appendix A. When using Table A-1M, two-thirds of the yield strength at temperature listed in ASME BPVC, Section II, Part D, Table Y-1 should be used.

302.3.3 Casting Quality Factor, E_c

(a) General. The casting quality factors, E_c, defined herein shall be used for cast components not having pressure–temperature ratings established by standards in Table 326.1.

[2] These bases are the same as those for ASME BPVC, Section III, Class 1 materials, given in ASME BPVC, Section II, Part D. Stress values in B31.3, Appendix A, at temperatures below the creep range generally are the same as those listed in ASME BPVC, Section II, Part D, Tables 2A and 2B, and in Table 3 for bolting, corresponding to those bases. They have been adjusted as necessary to exclude casting quality factors and longitudinal weld joint quality factors. Stress values at temperatures in the creep range generally are the same as those in ASME BPVC, Section II, Part D, Tables 1A and 1B, corresponding to the bases for ASME BPVC, Section VIII, Division 1.

(20) **Table 302.3.3C Increased Casting Quality Factors, E_c**

Supplementary Examination in Accordance With Note(s)	Factor, E_c
(1)	0.85
(2)(a) or (2)(b)	0.85
(3)(a) or (3)(b)	0.95
(1) and (2)(a) or (2)(b)	0.90
(1) and (3)(a) or (3)(b)	1.00
(2)(a) or (2)(b) and (3)(a) or (3)(b)	1.00

GENERAL NOTE: Titles of standards referenced in this Table's Notes are as follows:

ASME B46.1	Surface Texture (Surface Roughness, Waviness and Lay)
ASTM E94	Guide for Radiographic Examination Using Industrial Radiographic Film
ASTM E114	Practice for Ultrasonic Pulse-Echo Straight-Beam Contact Testing
ASTM E165	Practice for Liquid Penetrant Testing for General Industry
ASTM E709	Guide for Magnetic Particle Testing
MSS SP-53	Quality Standard for Steel Castings and Forgings for Valves, Flanges, Fittings, and Other Piping Components — Magnetic Particle Examination Method
MSS SP-93	Quality Standard for Steel Castings and Forgings for Valves, Flanges, Fittings, and Other Piping Components — Liquid Penetrant Examination Method

NOTES:

(1) Machine all surfaces to a finish of 6.3 μm R_a (250 μin. R_a in accordance with ASME B46.1), thus increasing the effectiveness of surface examination.

(2)

(a) Examine all surfaces of each casting (ferromagnetic material only) by the magnetic particle method in accordance with ASTM E709. Judge acceptability in accordance with MSS SP-53, Table 1.

(b) Examine all surfaces of each casting by the liquid penetrant method, in accordance with ASTM E165. Judge acceptability in accordance with SP-93, Table 1.

(3)

(a) Fully examine each casting ultrasonically in accordance with ASTM E114, accepting a casting only if there is no evidence of depth of defects in excess of 5% of wall thickness.

(b) Fully radiograph each casting in accordance with ASTM E94. Judge in accordance with the stated acceptance levels in Table 302.3.3D.

(b) Basic Quality Factors. Castings of gray and malleable iron, conforming to listed specifications, are assigned a basic casting quality factor, E_c, of 1.00 (due to their conservative allowable stress basis). For most other metals, static castings that conform to the material specification and have been visually examined as required by MSS SP-55, Quality Standard for Steel Castings for Valves, Flanges and Fittings and Other Piping Components — Visual Method, are assigned a basic casting quality factor, E_c, of 0.80. Centrifugal castings that meet specification requirements only for chemical analysis, tensile, hydrostatic, and flattening tests, and visual examination are assigned a basic casting quality factor of 0.80. Basic casting quality factors are tabulated for listed specifications in Table A-1A.

(c) Increased Quality Factors. Casting quality factors may be increased when supplementary examinations are performed on each casting. Table 302.3.3C states the increased casting quality factors, E_c, that may be used for various combinations of supplementary examination. Table 302.3.3D states the acceptance criteria for the examination methods specified in the Notes to Table 302.3.3C. Quality factors higher than those shown in Table 302.3.3C do not result from combining tests (2)(a) and (2)(b), or (3)(a) and (3)(b). In no case shall the quality factor exceed 1.00.

Several of the specifications in Appendix A require machining of all surfaces and/or one or more of these supplementary examinations. In such cases, the appropriate increased quality factor is shown in Table A-1A.

302.3.4 Weld Joint Quality Factor, E_j

(a) Basic Quality Factors. The weld joint quality factors, E_j, tabulated in Table A-1B are basic factors for straight or spiral (helical seam) welded joints for pressure-containing components as shown in Table 302.3.4.

(b) Increased Quality Factors. Table 302.3.4 also indicates higher joint quality factors that may be substituted for those in Table A-1B for certain kinds of welds if additional examination is performed beyond that required by the product specification.

302.3.5 Limits of Calculated Stresses Due to Sustained Loads and Displacement Strains

(a) Internal Pressure Stresses. Stresses due to internal pressure shall be considered safe when the wall thickness of the piping component, including any reinforcement, meets the requirements of para. 304.

(b) External Pressure Stresses. Stresses due to external pressure shall be considered safe when the wall thickness of the piping component, and its means of stiffening, meet the requirements of para. 304.

(c) Stresses Due to Sustained Loads, S_L. The stresses due to sustained loads, S_L, in any component in a piping system (see para. 320), shall not exceed S_h, where S_h is the basic allowable stress provided in Table A-1 or Table A-1M at

Table 302.3.3D Acceptance Levels for Castings

Material Examined Thickness, T	Applicable Standard	Acceptance Level (or Class)	Acceptable Discontinuities
Steel $T \le$ 25 mm (1 in.)	ASTM E446	1	Types A, B, C
Steel $T >$ 25 mm, $\le$ 51 mm (2 in.)	ASTM E446	2	Types A, B, C
Steel $T >$ 51 mm, $\le$ 114 mm (4½ in.)	ASTM E186	2	Categories A, B, C
Steel $T >$ 114 mm, $\le$ 305 mm (12 in.)	ASTM E280	2	Categories A, B, C
Aluminum and magnesium	ASTM E155	...	Shown in reference radiographs
Copper, Ni–Cu	ASTM E272	2	Codes A, Ba, Bb
Bronze	ASTM E310	2	Codes A and B

GENERAL NOTE: Titles of ASTM standards referenced in this Table are as follows:

E155 Reference Radiographs for Inspection of Aluminum and Magnesium Castings
E186 Reference Radiographs for Heavy-Walled (2 to 4-½-in. (50.8 to 114 mm)) Steel Castings
E272 Reference Radiographs for High-Strength Copper-Base and Nickel-Copper Alloy Castings
E280 Reference Radiographs for Heavy-Walled (4-½ to 12 in. (114 to 305 mm)) Steel Castings
E310 Reference Radiographs for Tin Bronze Castings
E446 Reference Radiographs for Steel Castings Up to 2 in. (50.8 mm) in Thickness

the metal temperature for the operating condition being considered.

(d) Allowable Displacement Stress Range, S_A. The computed displacement stress range, S_E, in a piping system (see para. 319.4.4) shall not exceed the allowable displacement stress range, S_A (see paras. 319.2.3 and 319.3.4), calculated by eq. (1a)

$$S_A = f(1.25S_c + 0.25S_h) \tag{1a}$$

When S_h is greater than S_L, the difference between them may be added to the term $0.25S_h$ in eq. (1a). In that case, the allowable stress range is calculated by eq. (1b)

$$S_A = f[1.25(S_c + S_h) - S_L] \tag{1b}$$

For eqs. (1a) and (1b)

f = stress range factor,[3] calculated by eq. (1c)[4]

$$f \text{ (see Figure 302.3.5)} = 6.0(N)^{-0.2} \le f_m \tag{1c}$$

f_m = maximum value of stress range factor; 1.2 for ferrous materials with specified minimum tensile strengths ≤517 MPa (75 ksi) and at metal temperatures ≤371°C (700°F); otherwise f_m = 1.0

N = equivalent number of full displacement cycles during the expected service life of the piping system[5]

S_c = basic allowable stress[6] at minimum metal temperature expected during the displacement cycle under analysis
= 138 MPa (20 ksi) maximum

S_h = basic allowable stress[6] at maximum metal temperature expected during the displacement cycle under analysis
= 138 MPa (20 ksi) maximum

S_L = stress due to sustained loads; in systems where supports may be active in some conditions and inactive in others, the maximum value of sustained stress, considering all support conditions, shall be used

When the computed stress range varies, whether from thermal expansion or other conditions, S_E is defined as the greatest computed displacement stress range. The value of N in such cases can be calculated by eq. (1d)

$$N = N_E + \sum \left(r_i^5 N_i\right) \text{ for } i = 1, 2, \ldots, n \tag{1d}$$

where

N_E = number of cycles of maximum computed displacement stress range, S_E

N_i = number of cycles associated with displacement stress range, S_i

r_i = S_i / S_E

S_i = any computed displacement stress range smaller than S_E

When the total number of significant stress cycles due to all causes exceeds 100 000, and with the owner's approval, the designer may elect to apply the alternative fatigue

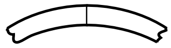
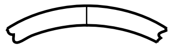
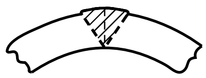
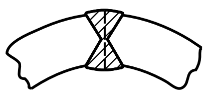
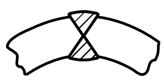
[3] Applies to essentially noncorroded piping. Corrosion can sharply decrease cyclic life; therefore, corrosion resistant materials should be considered where a large number of major stress cycles is anticipated.

[4] The minimum value for f is 0.15, which results in an allowable displacement stress range, S_A, for an indefinitely large number of cycles.

[5] The designer is cautioned that the fatigue life of materials operated at elevated temperature may be reduced.

[6] For castings, the basic allowable stress shall be multiplied by the applicable casting quality factor, E_c. For longitudinal welds, the basic allowable stress need not be multiplied by the weld quality factor, E_j.

Table 302.3.4 Longitudinal Weld Joint Quality Factor, E_j

No.	Type of Joint		Type of Seam	Examination	Factor, E_j
1	Furnace butt weld, continuous weld		Straight	As required by listed specification	0.60 [Note (1)]
2	Electric resistance weld		Straight or spiral (helical seam)	As required by listed specification	0.85 [Note (1)]
3	Electric fusion weld				
	(a) Single butt weld		Straight or spiral (helical seam)	As required by listed specification or this Code	0.80
	(with or without filler metal)			Additionally spot radiographed in accordance with para. 341.5.1	0.90
				Additionally 100% radiographed in accordance with para. 344.5.1 and Table 341.3.2	1.00
	(b) Double butt weld		Straight or spiral (helical seam) (except as provided in 4 below)	As required by listed specification or this Code	0.85
	(with or without filler metal)			Additionally spot radiographed in accordance with para. 341.5.1	0.90
				Additionally 100% radiographed in accordance with para. 344.5.1 and Table 341.3.2	1.00
4	Specific specification				
	API 5L, electric fusion weld, double butt seam		Straight (with one or two seams) or spiral (helical seam)	As required by specification	0.95
				Additionally 100% radiographed in accordance with para. 344.5.1 and Table 341.3.2	1.00

NOTE: (1) It is not permitted to increase the joint quality factor by additional examination for joint 1 or 2.

assessment rules in Appendix W to satisfy the displacement stress range requirements of this paragraph and of para. 319. A significant stress cycle is defined in para. W300. When the alternative rules of Appendix W are applied, the calculations shall be documented in the engineering design.

(e) Weld Joint Strength Reduction Factor, W. At elevated temperatures, the long-term strength of weld joints may be lower than the long-term strength of the base material.

The weld joint strength reduction factor, *W*, is the ratio of the nominal stress to cause failure of a weld joint to that of the corresponding base material for an elevated temperature condition of the same duration. It only applies at weld locations in longitudinal or spiral (helical seam) welded piping components. The designer is responsible for the application of weld joint strength reduction factors to other welds (e.g., circumferential).

When determining the required wall thickness for internal pressure in accordance with para. 304, for each coincident operating pressure–temperature condition under consideration, the product of the *basic* allowable stress and the applicable weld quality factor, *SE*, shall be multiplied by *W*.

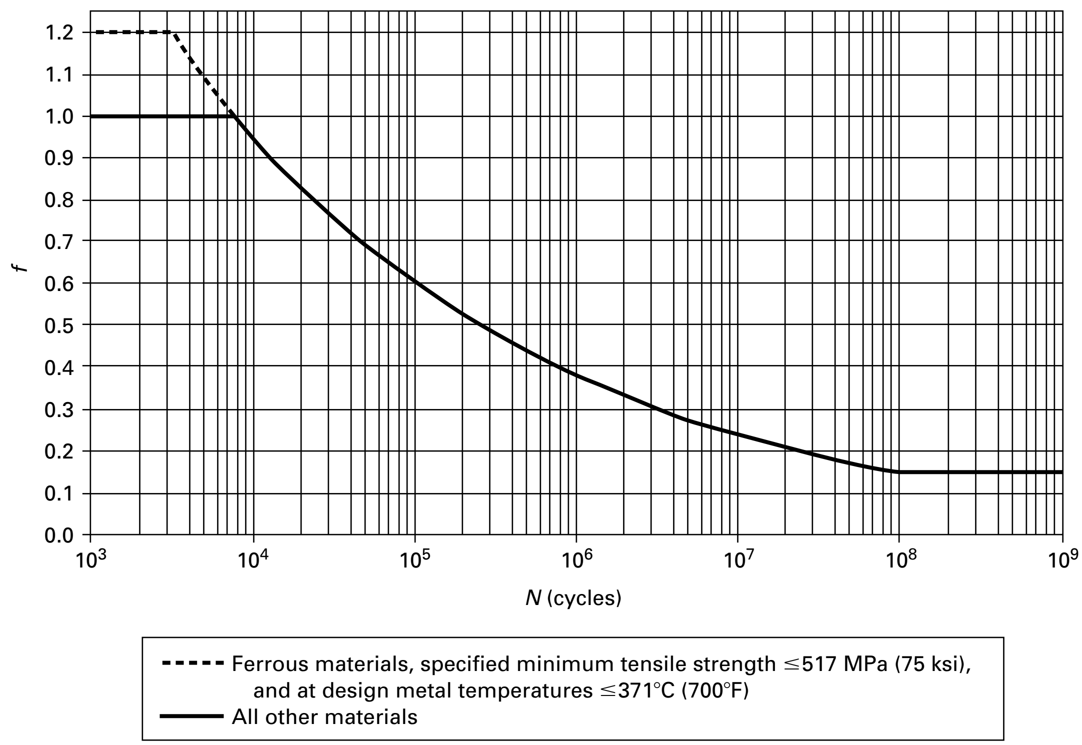
W is equal to 1.0 when evaluating occasional loads, e.g., wind and earthquake, or when evaluating permissible variations in accordance with para. 302.2.4. Application of *W* is not required when determining the pressure rating for the occasional load or *permissible* variation condition. It is also not required when calculating the allowable stress range for displacement stresses, S_A, in (d).

For other than occasional loads or permissible variations, *W* shall be in accordance with Table 302.3.5 except as provided in (f).

(f) Alternative Weld Strength Reduction Factors. A weld strength reduction factor other than that listed in Table 302.3.5 may be used in accordance with one of the following criteria:

(1) Creep test data may be used to determine the weld joint strength reduction factor, *W*. However, the use of creep test data to increase the factor *W* above that shown in Table 302.3.5 is not permitted for the CrMo and Creep Strength Enhanced Ferritic (CSEF) steels materials, as defined in Table 302.3.5. Creep testing of weld joints to determine weld joint strength reduction factors, when permitted, should be full thickness cross-weld specimens with test durations of at least 1 000 h. Full thickness tests shall be used unless

Figure 302.3.5 Stress Range Factor, *f*



the designer otherwise considers effects such as stress redistribution across the weld.

(2) With the owner's approval, extensive successful experience may be used to justify the factor *W* above that shown in Table 302.3.5. Successful experience must include same or like material, weld metal composition, and welding process under equivalent, or more severe, sustained operating conditions.

(20) **302.3.6 Limits of Calculated Stresses Due to Occasional Loads**

(a) Operation. Stresses due to occasional loads may be calculated using the equations for stress due to sustained loads in para. 320.2.

(1) Subject to the limits of para. 302.2.4, the sum of the stresses due to sustained loads, such as pressure and weight, S_L, and of the stresses produced by occasional loads, such as wind and earthquake, shall not exceed 1.33 times the basic allowable stress provided in Table A-1 or Table A-1M at the metal temperature for the occasional condition being considered. Wind and earthquake forces need not be considered as acting concurrently.

(2) For Elevated Temperature Fluid Service (see definition in para. 300.2) of materials having ductile behavior, as an alternative to the use of 1.33 times the basic allowable stress provided in Table A-1 or Table A-1M, the allowable stress for occasional loads of short duration, e.g., surge, extreme wind, or earthquake, may be taken as the lowest of the following:

(-a) the weld strength reduction factor times 90% of the yield strength at the metal temperature for the occasional condition being considered

(-b) four times the basic allowable stress provided in Appendix A

(-c) for occasional loads that exceed 10 h over the life of the piping system, the stress resulting in a 20% creep usage factor in accordance with Appendix V

For (-a), the yield strength shall be as listed in ASME BPVC, Section II, Part D, Table Y-1 or determined in accordance with para. 302.3.2. The strength reduction factor represents the reduction in yield strength with long-term exposure of the material to elevated temperatures and, in the absence of more-applicable data, shall be taken as 1.0 for austenitic stainless steel and 0.8 for other materials.

For (-b), the basic allowable stress for castings shall also be multiplied by the casting quality factor, E_c. Where the allowable stress value exceeds two-thirds of yield strength at temperature, the allowable stress value must be reduced as specified in para. 302.3.2(e).

(b) Test. Stresses due to test conditions are not subject to the limitations in para. 302.3. It is not necessary to consider other occasional loads, e.g., wind and earthquake, as occurring concurrently with test loads.

302.4 Allowances

In determining the minimum required thickness of a piping component, allowances shall be included for corrosion, erosion, and thread depth or groove depth. See definition for c in para. 304.1.1(b).

302.5 Mechanical Strength

(a) Designs shall be checked for adequacy of mechanical strength under applicable loadings. When necessary, the wall thickness shall be increased to prevent overstress, damage, collapse, or buckling due to superimposed loads from supports, ice formation, backfill, transportation, handling, or other loads enumerated in para. 301.

(b) Where increasing the thickness would excessively increase local stresses or the risk of brittle fracture, or is otherwise impracticable, the impact of applied loads may be mitigated through additional supports, braces, or other means without requiring an increased wall thickness. Particular consideration should be given to the mechanical strength of small pipe connections to piping or equipment.

PART 2
PRESSURE DESIGN OF PIPING COMPONENTS

303 GENERAL

Components manufactured in accordance with standards listed in Table 326.1 shall be considered suitable for use at pressure–temperature ratings in accordance with para. 302.2.1 or 302.2.2, as applicable. The rules in para. 304 are intended for pressure design of components not covered in Table 326.1, but may be used for a special or more-rigorous design of such components, or to satisfy requirements of para. 302.2.2. Designs shall be checked for adequacy of mechanical strength as described in para. 302.5.

304 PRESSURE DESIGN OF COMPONENTS

304.1 Straight Pipe

304.1.1 General

(a) The required thickness of straight sections of pipe shall be determined in accordance with eq. (2)

$$t_m = t + c \tag{2}$$

The minimum thickness, T, for the pipe selected, considering manufacturer's minus tolerance, shall be not less than t_m.

(b) The following nomenclature is used in the equations for pressure design of straight pipe:

c = sum of the mechanical allowances (thread or groove depth) plus corrosion and erosion allowances. For threaded components, the nominal thread depth (dimension h of ASME B1.20.1, or equivalent) shall apply. For machined surfaces or grooves where the tolerance is not specified, the tolerance shall be assumed to be 0.5 mm (0.02 in.) in addition to the specified depth of the cut.

D = outside diameter of pipe as listed in tables of standards or specifications or as measured

d = inside diameter of pipe. For pressure design calculation, the inside diameter of the pipe is the maximum value allowable under the purchase specification.

E = quality factor from Table A-1A or Table A-1B

P = internal design gage pressure

S = stress value for material from Table A-1 or Table A-1M

T = pipe wall thickness (measured or minimum in accordance with the purchase specification)

t = pressure design thickness, as calculated in accordance with para. 304.1.2 for internal pressure or as determined in accordance with para. 304.1.3 for external pressure

t_m = minimum required thickness, including mechanical, corrosion, and erosion allowances

W = weld joint strength reduction factor in accordance with para. 302.3.5(e)

Y = coefficient from Table 304.1.1, valid for $t < D/6$ and for materials shown. The value of Y may be interpolated for intermediate temperatures. For $t \geq D/6$,

$$Y = \frac{d + 2c}{D + d + 2c}$$

304.1.2 Straight Pipe Under Internal Pressure

(a) For $t < D/6$, the internal pressure design thickness for straight pipe shall be not less than that calculated in accordance with either eq. (3a) or eq. (3b)

$$t = \frac{PD}{2(SEW + PY)} \tag{3a}$$

$$t = \frac{P(d + 2c)}{2[SEW - P(1 - Y)]} \tag{3b}$$

(b) For $t \geq D/6$ or for $P/SE > 0.385$, calculation of pressure design thickness for straight pipe requires special consideration of factors such as theory of failure, effects of fatigue, and thermal stress.

304.1.3 Straight Pipe Under External Pressure. To determine wall thickness and stiffening requirements for straight pipe under external pressure, the procedure outlined in ASME BPVC, Section VIII, Division 1, UG-28 through UG-30 shall be followed, using as the design length, L, the running centerline length between any

Table 302.3.5 Weld Joint Strength Reduction Factor, *W*

Steel Group	Component Temperature, T_i, °C (°F)														
	≤427 (≤800)	454 (850)	482 (900)	510 (950)	538 (1,000)	566 (1,050)	593 (1,100)	621 (1,150)	649 (1,200)	677 (1,250)	704 (1,300)	732 (1,350)	760 (1,400)	788 (1,450)	816 (1,500)
Carbon Steel	1	1	1	1	1	1	1	...	...	...	...	...	...	...	...
CrMo [Notes (1)–(3)]	1	0.95	0.91	0.86	0.82	0.77	0.73	0.68	0.64	...	...	...	...	...	...
CSEF (N + T) [Notes (3)–(5)]	...	...	...	1	0.95	0.91	0.86	0.82	0.77	...	...	...	...	...	...
CSEF [Notes (3) and (4)] (Subcritical PWHT)	...	...	1	0.5	0.5	0.5	0.5	0.5	0.5	...	...	...	...	...	...
Autogenous welds in austenitic stainless grade 3xx, and N088xx and N066xx nickel alloys [Note (6)]	...	...	...	1	1	1	1	1	1	1	1	1	1	1	1
Austenitic stainless grade 3xx and N088xx nickel alloys [Notes (7) and (8)]	...	...	...	1	0.95	0.91	0.86	0.82	0.77	0.73	0.68	0.64	0.59	0.55	0.5
Other materials [Note (9)]	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...

GENERAL NOTES:

(a) Weld joint strength reduction factors at temperatures above the upper temperature limit listed in Appendix A for the base metal or outside of the applicable range in Table 302.3.5 are the responsibility of the designer. At temperatures below those where weld joint strength reduction factors are tabulated, a value of 1.0 shall be used for the factor *W* where required; however, the additional rules of this Table and Notes do not apply.

(b) T_{cr} = temperature 25°C (50°F) below the temperature identifying the start of time-dependent properties listed under "NOTES - TIME-DEPENDENT PROPERTIES" (Txx) in the Notes to ASME BPVC, Section II, Part D, Tables 1A and 1B for the base metals joined by welding. For materials not listed in Section II, Part D, T_{cr} shall be the temperature where the creep rate or stress rupture criteria in paras. 302.3.2(d)(4), (5), (6), and (7) governs the basic allowable stress value of the metals joined by welding. When the base metals differ, the lower value of T_{cr} shall be used for the weld joint.

(c) T_i = temperature, °C (°F), of the component for the coincident operating pressure–temperature condition, *i*, under consideration.

(d) CAUTIONARY NOTE: There are many factors that may affect the life of a welded joint at elevated temperature and all of those factors cannot be addressed in a table of weld strength reduction factors. For example, fabrication issues such as the deviation from a true circular form in pipe (e.g., "peaking" at longitudinal weld seams) or offset at the weld joint can cause an increase in stress that may result in reduced service life and control of these deviations is recommended.

(e) The weld joint strength reduction factor, *W*, may be determined using linear interpolation for intermediate temperature values.

NOTES:

(1) The Cr–Mo Steels include: ½Cr–½Mo, 1Cr–½Mo, 1¼Cr–½Mo–Si, 2¼Cr–1Mo, 3Cr–1Mo, 5Cr–½Mo, 9Cr–1Mo. Longitudinal and spiral (helical seam) welds shall be normalized, normalized and tempered, or subjected to proper subcritical postweld heat treatment (PWHT) for the alloy. Required examination is in accordance with para. 341.4.4 or 305.2.4.

(2) Longitudinal and spiral (helical seam) seam fusion welded construction is not permitted for C–½Mo steel above 454°C (850°F).

(3) The required carbon content of the weld filler metal shall be ≥0.05 C wt. %. See para. 341.4.4(b) for examination requirements. The basicity index of SAW flux shall be ≥1.0.

(4) The CSEF (Creep Strength Enhanced Ferritic) steels include grades 91, 92, 911, 122, and 23.

(5) N + T = Normalizing + Tempering PWHT.

(6) Autogenous welds without filler metal in austenitic stainless steel (grade 3xx) and austenitic nickel alloys UNS Nos. N066xx and N088xx. A solution anneal after welding is required for use of the factors in the Table. See para. 341.4.3(b) for examination requirements.

(7) Alternatively, the 100,000 hr Stress Rupture Factors listed in ASME BPVC, Section III, Division 1, Subsection NH, Tables I-14.10 A-xx, B-xx, and C-xx may be used as the weld joint strength reduction factor for the materials and welding consumables specified.

Table 302.3.5 Weld Joint Strength Reduction Factor, *W* (Cont'd)

NOTES: (Cont'd)

(8) Certain heats of the austenitic stainless steels, particularly for those grades whose creep strength is enhanced by the precipitation of temper-resistant carbides and carbonitrides, can suffer from an embrittlement condition in the weld heat-affected zone that can lead to premature failure of welded components operating at elevated temperatures. A solution annealing heat treatment of the weld area mitigates this susceptibility.

(9) For materials other than carbon steel, CrMo, CSEF, and the austenitic alloys listed in Table 302.3.5, W shall be as follows: For $T_i \le T_{cr}$, $W = 1.0$. For SI units, for $T_{cr} < T_i \le 816°C$, $W = 1 - 0.00164(T_i - T_{cr})$. For U.S. Customary units, for $T_{cr} < T_i \le 1{,}500°F$, $W = 1 - 0.000909(T_i - T_{cr})$. If T_i exceeds the upper temperature for which an allowable stress value is listed in Appendix A for the base metal, the value for W is the responsibility of the designer.

Table 304.1.1 Values of Coefficient Y for $t < D/6$

Material	Temperature, °C (°F)							
	482 (900) and Below	510 (950)	538 (1,000)	566 (1,050)	593 (1,100)	621 (1,150)	649 (1,200)	677 (1,250) and Above
Ferritic steels	0.4	0.5	0.7	0.7	0.7	0.7	0.7	0.7
Austenitic steels	0.4	0.4	0.4	0.4	0.5	0.7	0.7	0.7
Nickel alloys UNS Nos. N06617, N08800, N08810, and N08825	0.4	0.4	0.4	0.4	0.4	0.4	0.5	0.7
Gray iron	0.0	...	...	...	...	...	...	...
Other ductile metals	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4

two sections stiffened in accordance with UG-29. As an exception, for pipe with $D_o/t < 10$, the value of S to be used in determining P_{a2} shall be the lesser of the following values for pipe material at design temperature:

(a) 1.5 times the stress value from Table A-1 or Table A-1M of this Code, or

(b) 0.9 times the yield strength tabulated in ASME BPVC, Section II, Part D, Table Y-1 for materials listed therein

(The symbol D_o in ASME BPVC, Section VIII is equivalent to D in this Code.)

304.2 Curved and Mitered Segments of Pipe

304.2.1 Pipe Bends. The minimum required thickness, t_m, of a bend, after bending, in its finished form, shall be determined in accordance with eqs. (2) and (3c)

$$t = \frac{PD}{2[(SEW/I) + PY]} \tag{3c}$$

where at the intrados (inside bend radius)

$$I = \frac{4(R_1/D) - 1}{4(R_1/D) - 2} \tag{3d}$$

and at the extrados (outside bend radius)

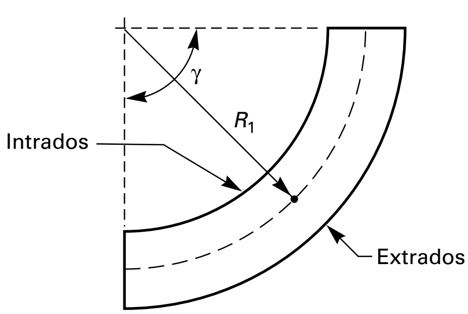
$$I = \frac{4(R_1/D) + 1}{4(R_1/D) + 2} \tag{3e}$$

and at the sidewall on the bend centerline radius, $I = 1.0$, and where

R_1 = bend radius of welding elbow or pipe bend

Thickness variations from the intrados to the extrados and along the length of the bend shall be gradual. The thickness requirements apply at the mid-span of the bend, $\gamma/2$, at the intrados, extrados, and bend centerline radius. The minimum thickness at the end tangents shall not be less than the requirements of para. 304.1 for straight pipe (see Figure 304.2.1).

Figure 304.2.1 Nomenclature for Pipe Bends



304.2.2 Elbows. Manufactured elbows not in accordance with para. 303 shall be qualified as required by para. 304.7.2 or designed in accordance with para. 304.2.1, except as provided in para. 328.4.2(b)(6).

304.2.3 Miter Bends. An angular offset of 3 deg or less (angle α in Figure 304.2.3) does not require design consideration as a miter bend. Acceptable methods for pressure design of multiple and single miter bends are given in (a) and (b) below.

(a) Multiple Miter Bends. The maximum allowable internal pressure shall be the lesser value calculated from eqs. (4a) and (4b). These equations are not applicable when θ exceeds 22.5 deg.

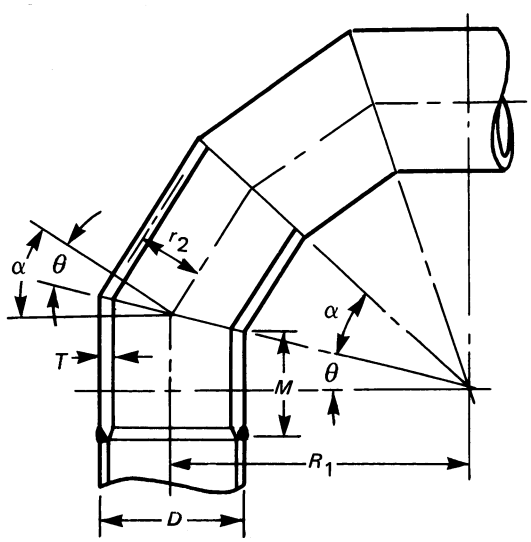
$$P_m = \frac{SEW(T - c)}{r_2}\left(\frac{T - c}{(T - c) + 0.643 \tan\theta\sqrt{r_2(T - c)}}\right) \tag{4a}$$

$$P_m = \frac{SEW(T - c)}{r_2}\left(\frac{R_1 - r_2}{R_1 - 0.5r_2}\right) \tag{4b}$$

(b) Single Miter Bends

(1) The maximum allowable internal pressure for a single miter bend with angle θ not greater than 22.5 deg shall be calculated by eq. (4a).

Figure 304.2.3 Nomenclature for Miter Bends



(2) The maximum allowable internal pressure for a single miter bend with angle θ greater than 22.5 deg shall be calculated by eq. (4c)

$$P_m = \frac{SEW(T-c)}{r_2}\left(\frac{T-c}{(T-c)+1.25\tan\theta\sqrt{r_2(T-c)}}\right) \quad (4c)$$

(c) The miter pipe wall thickness, T, used in eqs. (4a), (4b), and (4c) shall extend a distance not less than M from the inside crotch of the end miter welds where

M = the larger of $2.5(r_2T)^{0.5}$ or $\tan\theta\ (R_1 - r_2)$

The length of taper at the end of the miter pipe may be included in the distance, M.

(d) The following nomenclature is used in eqs. (4a), (4b), and (4c) for the pressure design of miter bends:

c = same as defined in para. 304.1.1
E = same as defined in para. 304.1.1
P_m = maximum allowable internal pressure for miter bends
R_1 = effective radius of miter bend, defined as the shortest distance from the pipe centerline to the intersection of the planes of adjacent miter joints
r_2 = mean radius of pipe using nominal wall $\overline{T}$
S = same as defined in para. 304.1.1
T = miter pipe wall thickness (measured or minimum in accordance with the purchase specification)
W = same as defined in para. 304.1.1
α = angle of change in direction at miter joint = 2θ
θ = angle of miter cut

For compliance with this Code, the value of R_1 shall be not less than that given by eq. (5)

$$R_1 = \frac{A}{\tan\theta} + \frac{D}{2} \quad (5)$$

where A has the following empirical values:

(1) For SI units

$(T-c)$, mm	A
≤ 13	25
$13 < (T-c) < 22$	$2(T-c)$
≥ 22	$[2(T-c)/3] + 30$

(2) For U.S. Customary units

$(T-c)$, in.	A
≤ 0.5	1.0
$0.5 < (T-c) < 0.88$	$2(T-c)$
≥ 0.88	$[2(T-c)/3] + 1.17$

304.2.4 Curved and Mitered Segments of Pipe Under External Pressure. The wall thickness of curved and mitered segments of pipe subjected to external pressure may be determined as specified for straight pipe in para. 304.1.3.

304.3 Branch Connections

304.3.1 General (20)

(a) Except as provided in (b) below, the requirements in paras. 304.3.2 through 304.3.4 are applicable to the following branch connections:

(1) fittings (tees, extruded outlets, branch outlet fittings in accordance with MSS SP-97, laterals, crosses)

(2) couplings not larger than DN 80 (NPS 3) and unlisted cast or forged branch connection fittings (see para. 300.2) attached to the run pipe by welding

(3) welding the branch pipe directly to the run pipe, with or without added reinforcement, as covered in para. 328.5.4

(b) The rules in paras. 304.3.2 through 304.3.4 are minimum requirements, valid only for branch connections in which (using the nomenclature of Figure 304.3.3)

(1) the run pipe diameter-to-thickness ratio (D_h/T_h) is less than 100 and the branch-to-run diameter ratio (D_b/D_h) is not greater than 1.0

(2) for run pipe with $D_h/T_h \geq 100$, the branch diameter, D_b, is less than one-half the run diameter, D_h

(3) angle β is at least 45 deg

(4) the axis of the branch intersects the axis of the run

(c) Where the provisions of (a) and (b) above are not met, pressure design shall be qualified as required by para. 304.7.2.

(d) Other design considerations relating to branch connections are stated in para. 304.3.5.

304.3.2 Strength of Branch Connections. A pipe having a branch connection is weakened by the opening that must be made in it and, unless the wall thickness of the pipe is sufficiently in excess of that required to sustain the pressure, it is necessary to provide added reinforcement. The amount of reinforcement required to sustain the pressure shall be determined in accordance with para. 304.3.3 or 304.3.4. There are, however, certain branch connections that have adequate pressure strength or reinforcement as constructed. It may be assumed without calculation that a branch connection has adequate strength to sustain the internal and external pressure that will be applied to it if

(a) the branch connection is made with a listed branch type fitting such as an ASME B16.9 or ASME B16.11 tee, or MSS SP-97 branch connection fitting. See para. 303.

(b) the branch connection is made by welding a listed threaded or socket welding coupling or listed half coupling directly to the run in accordance with para. 328.5.4, provided the size of the branch does not exceed DN 50 (NPS 2) nor one-fourth the nominal size of the run. The minimum wall thickness of the coupling anywhere in the reinforcement zone (if threads are in the zone, wall thickness is measured from root of thread to minimum outside diameter) shall be not less than that of the unthreaded branch pipe. In no case shall a coupling or half coupling have a rating less than Class 3000 in accordance with ASME B16.11.

(c) the branch connection utilizes an unlisted branch connection fitting (see para. 300.2), provided the fitting is made from materials listed in Table A-1 or Table A-1M and provided that the branch connection is qualified as required by para. 304.7.2.

304.3.3 Reinforcement of Welded Branch Connections. Added reinforcement is required to meet the criteria in (b) and (c) when it is not inherent in the components of the branch connection. Sample problems illustrating the calculations for branch reinforcement are shown in Appendix H.

(a) Nomenclature. The nomenclature below is used in the pressure design of branch connections. It is illustrated in Figure 304.3.3, which does not indicate details for construction or welding. Some of the terms defined in Appendix J are subject to further definitions or variations, as follows:

b = subscript referring to branch

d_1 = effective length removed from pipe at branch. For branch intersections where the branch opening is a projection of the branch pipe inside diameter (e.g., pipe-to-pipe fabricated branch), $d_1 = [D_b - 2(T_b - c)]/\sin\beta$

d_2 = "half width" of reinforcement zone
= d_1 or $(T_b - c) + (T_h - c) + d_1/2$, whichever is greater, but in any case not more than D_h

h = subscript referring to run or header

L_4 = height of reinforcement zone outside of run pipe
= $2.5(T_h - c)$ or $2.5(T_b - c) + T_r$, whichever is less

T_b = branch pipe thickness (measured or minimum in accordance with the purchase specification) except for branch connection fittings (see para. 300.2). For such connections the value of T_b for use in calculating L_4, d_2, and A_3 is the thickness of the reinforcing barrel (minimum per purchase specification), provided that the barrel thickness is uniform (see Figure K328.5.4) and extends at least to the L_4 limit (see Figure 304.3.3).

T_r = minimum thickness of reinforcing ring or saddle made from pipe (use nominal thickness if made from plate)
= 0 if there is no reinforcing ring or saddle

t = pressure design thickness of pipe, according to the appropriate wall thickness equation or procedure in para. 304.1. For welded pipe, when the branch does not intersect the longitudinal weld of the run, the basic allowable stress, S, for the pipe may be used in determining t_h for the purpose of reinforcement calculation only. When the branch does intersect the longitudinal weld of the run, the product SEW (of the stress value, S; the appropriate weld joint quality factor, E_j, from Table A-1B; and the weld joint strength reduction factor, W; see para. 302.3.5) for the run pipe shall be used in the calculation. The product SEW of the branch shall be used in calculating t_b.

β = smaller angle between axes of branch and run

(b) Required Reinforcement Area. The reinforcement area, A_1, required for a branch connection under internal pressure is

$$A_1 = t_h d_1 (2 - \sin\beta) \tag{6}$$

For a branch connection under external pressure, area A_1 is one-half the area calculated by eq. (6), using as t_h the thickness required for external pressure.

(c) Available Area. The area available for reinforcement is defined as

$$A_2 + A_3 + A_4 \geq A_1 \tag{6a}$$

These areas are all within the reinforcement zone and are further defined below.

(1) Area A_2 is the area resulting from excess thickness in the run pipe wall

$$A_2 = (2d_2 - d_1)(T_h - t_h - c) \tag{7}$$

(2) Area A_3 is the area resulting from excess thickness in the branch pipe wall

$$A_3 = 2L_4(T_b - t_b - c)/\sin\beta \tag{8}$$

If the allowable stress for the branch pipe wall is less than that for the run pipe, its calculated area must be reduced in the ratio of allowable stress values of the branch to the run in determining its contributions to area A_3.

(3) Area A_4 is the area of other metal provided by welds and properly attached reinforcement. [See (f).] Weld areas shall be based on the minimum dimensions specified in para. 328.5.4, except that larger dimensions may be used if the welder has been specifically instructed to make the welds to those dimensions.

(d) Reinforcement Zone. The reinforcement zone is a parallelogram whose length extends a distance, d_2, on each side of the centerline of the branch pipe and whose width starts at the inside surface of the run pipe (in its corroded condition) and extends beyond the outside surface of the run pipe a perpendicular distance, L_4.

(e) Multiple Branches. When two or more branch connections are so closely spaced that their reinforcement zones overlap, the distance between centers of the openings should be at least $1\frac{1}{2}$ times their average diameter, and the area of reinforcement between any two openings shall be not less than 50% of the total that both require. Each opening shall have adequate reinforcement in accordance with (b) and (c). No part of the metal cross section may apply to more than one opening or be evaluated more than once in any combined area. (Consult PFI Standard ES-7, Minimum Length and Spacing for Branch Connections, for detailed recommendations on spacing of welded nozzles.)

(f) Added Reinforcement

(1) Reinforcement added in the form of a ring or saddle as part of area A_4 shall be of reasonably constant width.

(2) Material used for reinforcement may differ from that of the run pipe provided it is compatible with run and branch pipes with respect to weldability, heat treatment requirements, galvanic corrosion, thermal expansion, etc.

(3) If the allowable stress for the reinforcement material is less than that for the run pipe, its calculated area must be reduced in the ratio of allowable stress values in determining its contribution to area A_4.

(4) No additional credit may be taken for a material having higher allowable stress value than the run pipe.

304.3.4 Reinforcement of Extruded Outlet Headers

(a) The principles of reinforcement stated in para. 304.3.3 are essentially applicable to extruded outlet headers. An extruded outlet header is a length of pipe in which one or more outlets for branch connection have been formed by extrusion, using a die or dies to control the radii of the extrusion. The extruded outlet projects above the surface of the header a distance h_x at least equal to the external radius of the outlet r_x (i.e., $h_x \geq r_x$).

(b) The rules in this paragraph are minimum requirements, valid only within the limits of geometry shown in Figure 304.3.4, and only where the axis of the outlet intersects and is perpendicular to the axis of the header. Where these requirements are not met, or where nonintegral material such as a ring, pad, or saddle has been added to the outlet, pressure design shall be qualified as required by para. 304.7.2.

(c) Nomenclature. The nomenclature used herein is illustrated in Figure 304.3.4. Note the use of subscript x signifying extruded. Refer to para. 304.3.3(a) for nomenclature not listed here.

d_x = the design inside diameter of the extruded outlet, measured at the level of the outside surface of the header. This dimension is taken after removal of all mechanical and corrosion allowances, and all thickness tolerances.

d_2 = half width of reinforcement zone (equal to d_x)

h_x = height of the extruded outlet. This must be equal to or greater than r_x [except as shown in illustration (b) in Figure 304.3.4].

L_5 = height of reinforcement zone

= $0.7\sqrt{D_b T_x}$

r_x = radius of curvature of external contoured portion of outlet, measured in the plane containing the axes of the header and branch

T_x = corroded finished thickness of extruded outlet, measured at a height equal to r_x above the outside surface of the header

(d) Limitations on Radius r_x. The external contour radius, r_x, is subject to the following limitations:

(1) minimum r_x — the lesser of $0.05D_b$ or 38 mm (1.50 in.)

(2) maximum r_x shall not exceed

(-a) for D_b < DN 200 (NPS 8), 32 mm (1.25 in.)

(-b) for $D_b \geq$ DN 200, $0.1D_b$ + 13 mm (0.50 in.)

(3) for an external contour with multiple radii, the requirements of (1) and (2) above apply, considering the best-fit radius over a 45-deg arc as the maximum radius

(4) machining shall not be employed in order to meet the above requirements

(e) Required Reinforcement Area. The required area of reinforcement is defined by

$$A_1 = K t_h d_x \tag{9}$$

where K is determined as follows:

(1) For $D_b/D_h > 0.60$, $K = 1.00$.

(2) For $0.60 \geq D_b/D_h > 0.15$, $K = 0.6 + \frac{2}{3}(D_b/D_h)$.

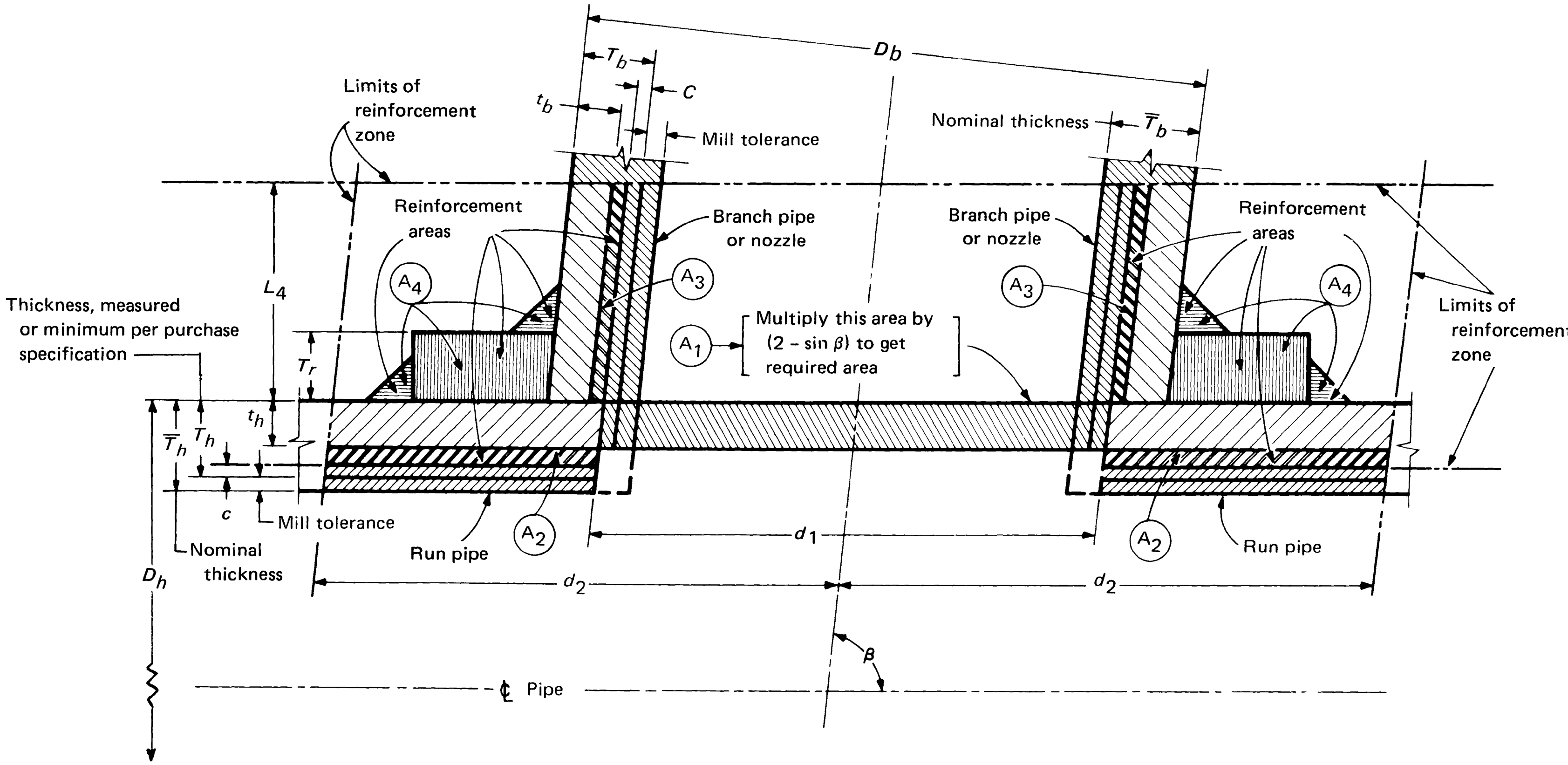
(3) For $D_b/D_h \leq 0.15$, $K = 0.70$.

(f) Available Area. The area available for reinforcement is defined as

$$A_2 + A_3 + A_4 \geq A_1 \tag{9a}$$

These areas are all within the reinforcement zone and are further defined below.

Figure 304.3.3 Branch Connection Nomenclature



GENERAL NOTE: This Figure illustrates the nomenclature of para. 304.3.3. It does not indicate complete welding details or a preferred method of construction. For typical weld details, see Figure 328.5.4D and Figure 328.5.4F.

(1) Area A_2 is the area resulting from excess thickness in the header wall

$$A_2 = (2d_2 - d_x)(T_h - t_h - c) \tag{10}$$

(2) Area A_3 is the area resulting from excess thickness in the branch pipe wall

$$A_3 = 2L_5(T_b - t_b - c) \tag{11}$$

(3) Area A_4 is the area resulting from excess thickness in the extruded outlet lip

$$A_4 = 2r_x[T_x - (T_b - c)] \tag{12}$$

(g) *Reinforcement of Multiple Openings.* The rules of para. 304.3.3(e) shall be followed, except that the required area and reinforcement area shall be as given in this paragraph.

(h) *Identification.* The manufacturer shall establish the design pressure and temperature for each extruded outlet header and shall mark the header with this information, together with the symbol "B31.3" (indicating the applicable Code Section) and the manufacturer's name or trademark.

304.3.5 Additional Design Considerations. The requirements of paras. 304.3.1 through 304.3.4 are intended to ensure satisfactory performance of a branch connection subject only to pressure. The designer shall also consider the following:

(a) In addition to pressure loadings, external forces and movements are applied to a branch connection by thermal expansion and contraction, dead and live loads, and movement of piping terminals and supports. Special consideration shall be given to the design of a branch connection to withstand these forces and movements.

(b) Branch connections made by welding the branch pipe directly to the run pipe should be avoided under the following circumstances:

(1) when branch size approaches run size, particularly if pipe formed by more than 1.5% cold expansion, or expanded pipe of a material subject to work hardening, is used as the run pipe

(2) where repetitive stresses may be imposed on the connection by vibration, pulsating pressure, temperature cycling, etc.

In such cases, it is recommended that the design be conservative and that consideration be given to the use of tee fittings or complete encirclement types of reinforcement.

(c) Adequate flexibility shall be provided in a small line that branches from a large run, to accommodate thermal expansion and other movements of the larger line (see para. 319.6).

(d) If ribs, gussets, or clamps are used to stiffen the branch connection, their areas cannot be counted as contributing to the reinforcement area determined in para. 304.3.3(c) or 304.3.4(f). However, ribs or gussets may be used for pressure-strengthening a branch connection in lieu of reinforcement covered in paras. 304.3.3 and 304.3.4 if the design is qualified as required by para. 304.7.2.

(e) For branch connections that do not meet the requirements of para. 304.3.1(b), integral reinforcement, complete encirclement reinforcement, or other means of reinforcement should be considered.

304.3.6 Branch Connections Under External Pressure. Pressure design for a branch connection subjected to external pressure may be determined in accordance with para. 304.3.1, using the reinforcement area requirement stated in para. 304.3.3(b).

304.4 Closures

304.4.1 General

(a) Closures not in accordance with para. 303 or (b) shall be qualified as required by para. 304.7.2.

(b) For materials and design conditions covered therein, closures may be designed in accordance with rules in ASME BPVC, Section VIII, Division 1, calculated from eq. (13)

$$t_m = t + c \tag{13}$$

where

c = sum of allowances defined in para. 304.1.1

t = pressure design thickness, calculated for the type of closure and direction of loading, shown in Table 304.4.1, except that the symbols used to determine t shall be as follows:

- E = same as defined in para. 304.1.1
- P = design gage pressure
- S = S times W, with S and W as defined in para. 304.1.1

t_m = minimum required thickness, including mechanical, corrosion, and erosion allowance

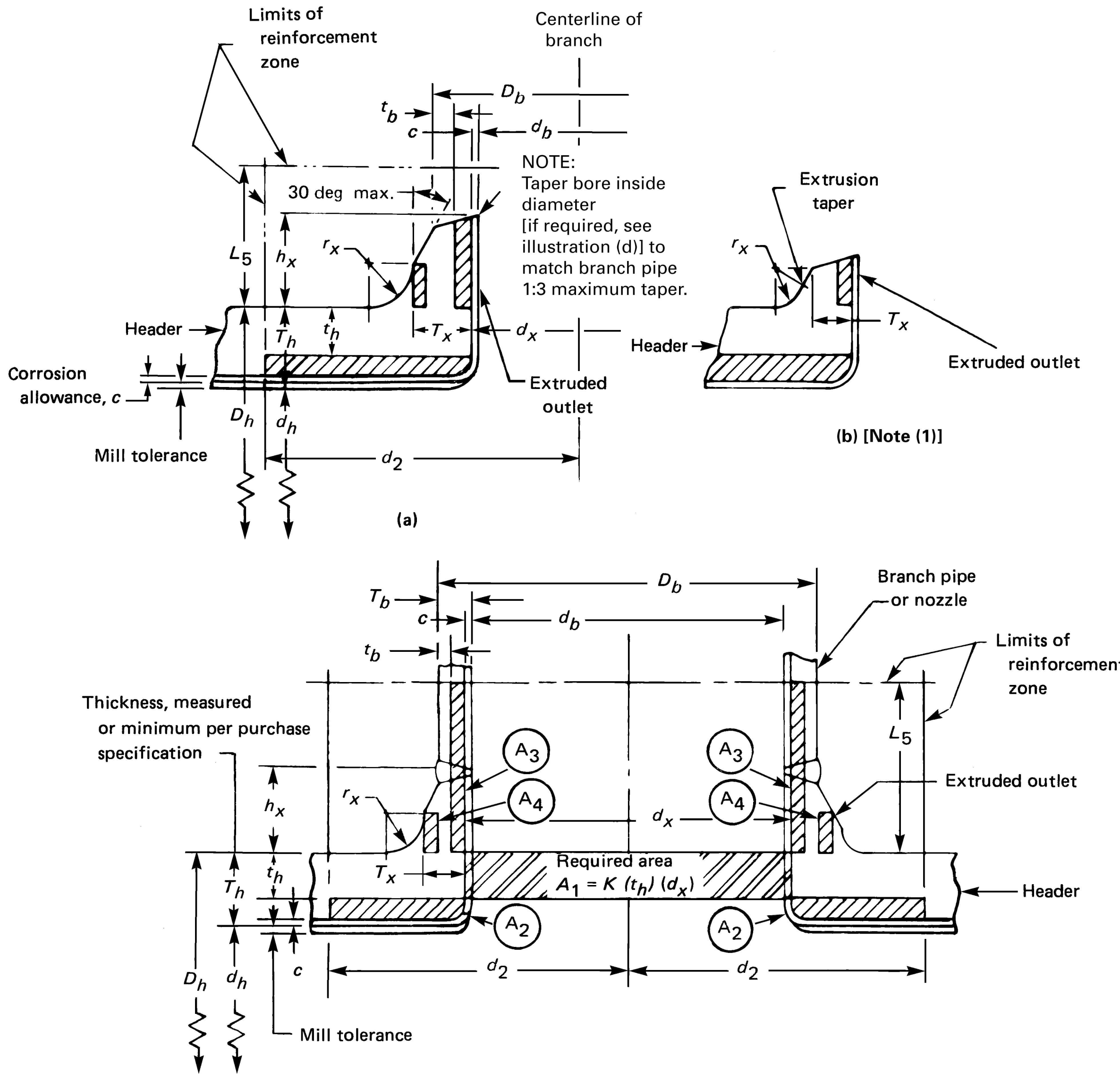
304.4.2 Openings in Closures

(a) The rules in (b) through (g) apply to openings not larger than one-half the inside diameter of the closure as defined in the ASME BPVC, Section VIII, Division 1, UG-36. A closure with a larger opening should be designed as a reducer in accordance with para. 304.6 or, if the closure is flat, as a flange in accordance with para. 304.5.

(b) A closure is weakened by an opening and, unless the thickness of the closure is sufficiently in excess of that required to sustain pressure, it is necessary to provide added reinforcement. The need for and amount of reinforcement required shall be determined in accordance with the subparagraphs below except that it shall be considered that the opening has adequate reinforcement if the outlet connection meets the requirements in para. 304.3.2(b) or 304.3.2(c).

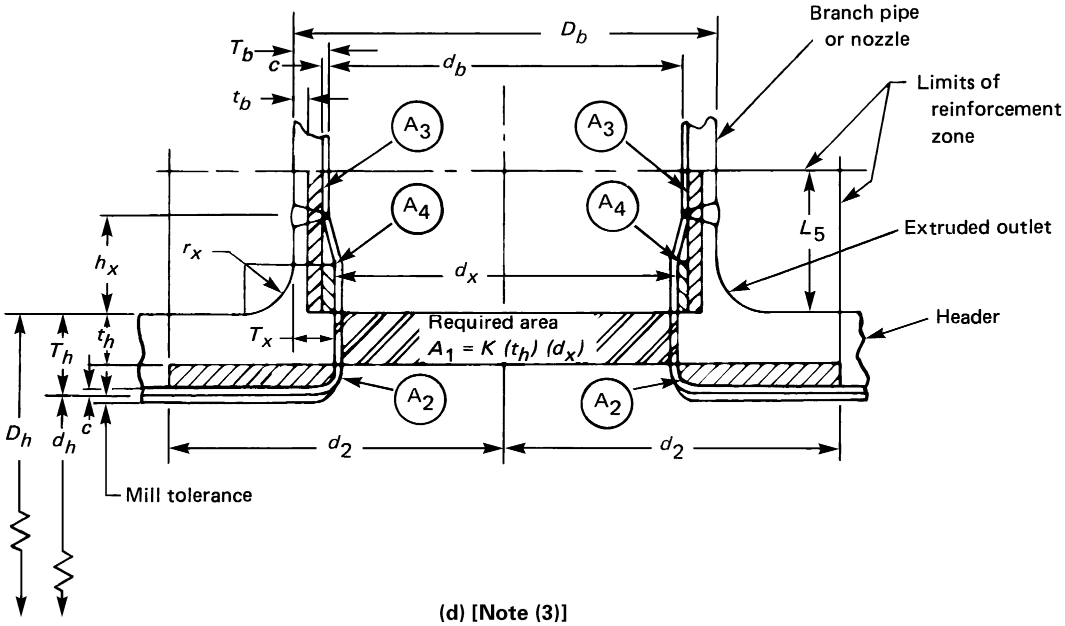
Figure 304.3.4 Extruded Outlet Header Nomenclature

This Figure illustrates the nomenclature of para. 304.3.4. It does not indicate complete details or a preferred method of construction.



(c) [Note (2)]

Figure 304.3.4 Extruded Outlet Header Nomenclature (Cont'd)



(d) [Note (3)]

NOTES:
(1) Illustration to show method of establishing T_x when the taper encroaches on the crotch radius.
(2) Illustration is drawn for condition where K = 1.00.
(3) Illustration is drawn for condition where K = 1.00 and $d_x < d_b$.

Table 304.4.1 ASME BPVC References for Closures

Type of Closure	Concave to Pressure	Convex to Pressure
Ellipsoidal	UG-32(d)	UG-33(d)
Torispherical	UG-32(e)	UG-33(e)
Hemispherical	UG-32(f)	UG-33(c)
Conical (no transition to knuckle)	UG-32(g)	UG-33(f)
Toriconical	UG-32(h)	UG-33(f)
Flat (pressure on either side)	UG-34	

GENERAL NOTE: Paragraph numbers are from ASME BPVC, Section VIII, Division 1.

(c) Reinforcement for an opening in a closure shall be so distributed that reinforcement area on each side of an opening (considering any plane through the center of the opening normal to the surface of the closure) will equal at least one-half the required area in that plane.

(d) The total cross-sectional area required for reinforcement in any given plane passing through the center of the opening shall not be less than that defined in ASME BPVC, Section VIII, Division 1, UG-37 (b), UG-38, and UG-39.

(e) The reinforcement area and reinforcement zone shall be calculated in accordance with para. 304.3.3 or 304.3.4, considering the subscript h and other references to the run or header pipe as applying to the closure. Where the closure is curved, the boundaries of the reinforcement zone shall follow the contour of the closure, and dimensions of the reinforcement zone shall be measured parallel to and perpendicular to the closure surface.

(f) If two or more openings are to be located in a closure, the rules in paras. 304.3.3 and 304.3.4 for the reinforcement of multiple openings apply.

(g) The additional design considerations for branch connections discussed in para. 304.3.5 apply equally to openings in closures.

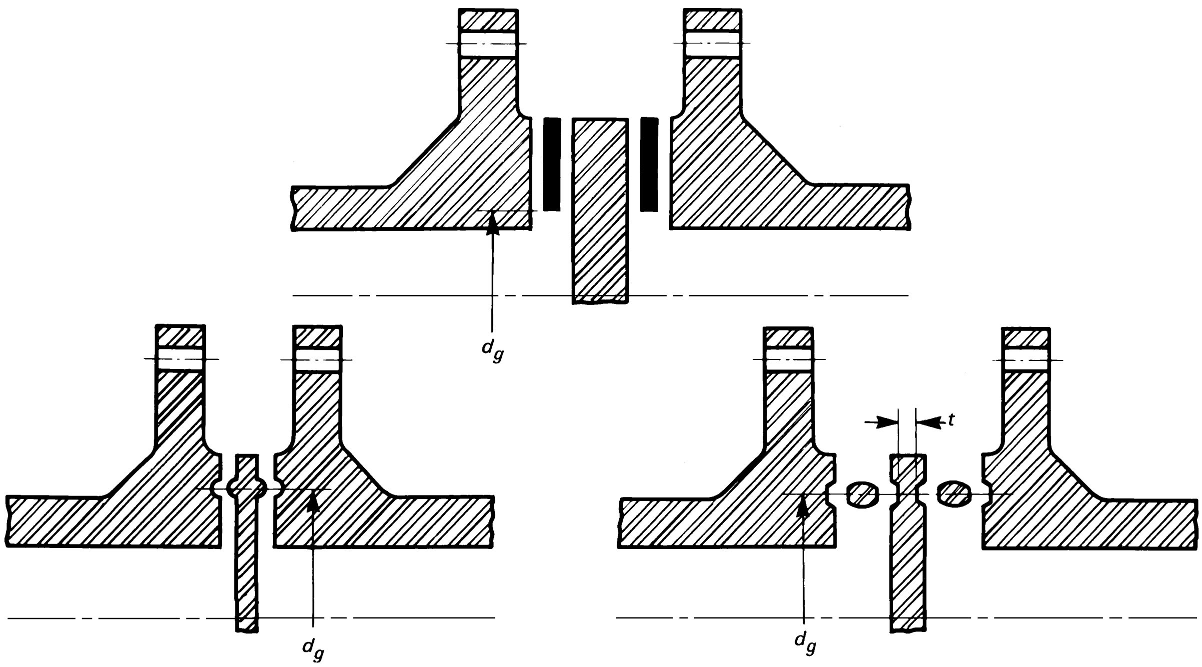
304.5 Pressure Design of Flanges and Blanks

304.5.1 Flanges — General

(a) Flanges not in accordance with para. 303 or (b) or (d) shall be qualified as required by para. 304.7.2.

(b) A flange may be designed in accordance with ASME BPVC, Section VIII, Division 1, Mandatory Appendix 2 (Rules for Bolted Flange Connections with Ring Type Gaskets) or ASME BPVC, Section VIII, Division 2, 4.16 (Design Rules for Flanged Joints), using the allowable stresses and temperature limits of this Code. Nomenclature shall be as defined in Appendix 2, except as follows:

Figure 304.5.3 Blanks



P = design gage pressure
S_a = bolt design stress at atmospheric temperature
S_b = bolt design stress at design temperature
S_f = product SEW [of the stress value, S; the appropriate quality factor, E, from Table A-1A or Table A-1B; and weld joint strength reduction factor in accordance with para. 302.3.5(e)] for flange or pipe material. See para. 302.3.2(e).

(c) The rules in (b) above are not applicable to a flanged joint having a gasket that extends outside the bolts (usually to the outside diameter of the flange).

(d) For flanges that make solid contact outside the bolts, ASME BPVC, Section VIII, Division 1, Appendix Y should be used.

(e) See Section VIII, Division 1, Appendix S, for considerations applicable to bolted joint assembly.

(20) **304.5.2 Blind Flanges**

(a) Blind flanges not in accordance with para. 303 or 304.5.2(b) shall be qualified as required by para. 304.7.2.

(b) A blind flange may be designed in accordance with eq. (14). The minimum thickness, considering the manufacturer's minus tolerance, shall be not less than t_m:

$$t_m = t + c \tag{14}$$

where c is the sum of allowances defined in para. 304.1.1. To calculate t, the rules of ASME BPVC, Section VIII, Division 1, UG-34 may be used with the following changes to the UG-34 nomenclature:

P = internal or external design gage pressure
SE = SEW [product of the basic allowable stress value, S; the appropriate quality factor, E, from Table A-1A or Table A-1B; and the weld joint strength reduction factor, W, in accordance with para. 302.3.5(e)] for flange material [see para. 302.3.2(e)]
t = pressure design thickness, as calculated for the given styles of blind flange, using the appropriate equations for bolted flat cover plates in UG-34

304.5.3 Blanks

(a) Blanks not in accordance with para. 303 or (b) shall be qualified as required by para. 304.7.2.

(b) The minimum required thickness of a permanent blank (representative configurations shown in Figure 304.5.3) shall be calculated in accordance with eq. (15)

$$t_m = d_g \sqrt{\frac{3P}{16SEW}} + c \tag{15}$$

where

c = sum of allowances defined in para. 304.1.1

d_g = inside diameter of gasket for raised or flat face flanges, or the gasket pitch diameter for ring joint and fully retained gasketed flanges
E = same as defined in para. 304.1.1
P = design gage pressure
S = same as defined in para. 304.1.1
W = same as defined in para. 304.1.1

304.6 Reducers

304.6.1 Concentric Reducers

(a) Concentric reducers not in accordance with para. 303 or (b) shall be qualified as required by para. 304.7.2.

(b) Concentric reducers made in a conical or reversed curve section, or a combination of such sections, may be designed in accordance with the rules for conical and toriconical closures stated in para. 304.4.1.

304.6.2 Eccentric Reducers. Eccentric reducers not in accordance with para. 303 shall be qualified as required by para. 304.7.2.

304.7 Pressure Design of Other Components

304.7.1 Listed Components. Other pressure-containing components manufactured in accordance with standards in Table 326.1 may be utilized in accordance with para. 303.

(20) **304.7.2 Unlisted Components.** Pressure design of unlisted components to which the rules elsewhere in para. 304 do not apply shall be based on the pressure design criteria of this Code. The designer shall ensure that the pressure design has been substantiated through one or more of the means stated in (a) through (d). Note that designs are also required to be checked for adequacy of mechanical strength as described in para. 302.5. Documentation showing compliance with this paragraph shall be available for the owner's approval.

(a) extensive, successful service experience under comparable conditions with similarly proportioned components of the same or like material.

(b) experimental stress analysis, such as described in ASME BPVC, Section VIII, Division 2, Annex 5-F. The basic allowable stress from Table A-1 or Table A-1M shall be used in place of the allowable stress, S, in Division 2 where applicable.

(c) proof test in accordance with ASME B16.9, MSS SP-97, or ASME BPVC, Section VIII, Division 1, UG-101. The basic allowable stress from Table A-1 or Table A-1M shall be used in place of the allowable stresses, S and S_2, in Division 1 where applicable.

(d) detailed stress analysis (e.g., finite element method) with results evaluated as described in ASME BPVC, Section VIII, Division 2, Part 5. The basic allowable stress from Table A-1 or Table A-1M shall be used in place of the allowable stress, S, in Division 2 where applicable. Load design factors used in a Division 2 evaluation shall be consistent with the design bases in para. 302.3.2. At design temperatures in the creep range, additional considerations beyond the scope of Division 2 may be necessary.

(e) For any of the above, the designer may interpolate between sizes, wall thicknesses, and pressure classes, and may determine analogies among related materials.

304.7.3 Metallic Components With Nonmetallic Pressure Parts. Components not covered by standards listed in Table 326.1, in which both metallic and nonmetallic parts contain the pressure, shall be evaluated by applicable requirements of para. A304.7.2 as well as those of para. 304.7.2.

304.7.4 Expansion Joints

(a) Metallic Bellows Expansion Joints. The design of bellows type expansion joints shall be in accordance with Appendix X. See also Appendix F, para. F304.7.4 for further design considerations.

(b) Slip Type Expansion Joints

(1) Pressure-containing elements shall be in accordance with para. 318 and other applicable requirements of this Code.

(2) External piping loads shall not impose excessive bending on the joint.

(3) The effective pressure thrust area shall be computed using the outside diameter of the pipe.

(c) Other Types of Expansion Joint. The design of other types of expansion joint shall be qualified as required by para. 304.7.2.

PART 3
FLUID SERVICE REQUIREMENTS FOR PIPING COMPONENTS

305 PIPE

Pipe includes components designated as tube or tubing in the material specification, when intended for pressure service.

305.1 General

Listed pipe may be used in Normal Fluid Service except as stated in paras. 305.2.1 and 305.2.2. Unlisted pipe may be used only as provided in para. 302.2.3.

305.2 Specific Requirements

305.2.1 Pipe for Category D Fluid Service. The following carbon steel pipe may be used only for Category D Fluid Service:

API 5L continuous welded (furnace butt-welded)
ASTM A53, Type F
ASTM A134 made from other than ASTM A285 plate

305.2.2 Pipe Requiring Safeguarding. When used for other than Category D Fluid Service, the following carbon steel pipe shall be safeguarded:

ASTM A134 made from ASTM A285 plate
ASTM A139

305.2.3 Pipe for Severe Cyclic Conditions

(a) Except as limited in (b) through (d), only the following pipe may be used under severe cyclic conditions:

(1) pipe listed in Table A-1A, where $E_c \geq 0.90$,[7] or

(2) pipe listed in Table A-1B, where $E_j \geq 0.90$[7]

(b) For API 5L pipe, only the following materials may be used:

Grade A or B, seamless
Grade A or B, SAW, str. seam, $E_j \geq 0.95$
Grade X42, seamless
Grade X46, seamless
Grade X52, seamless
Grade X56, seamless
Grade X60, seamless

(c) For copper pipe, only ASTM B42 may be used.

(d) For copper alloy pipe, only ASTM B466 may be used.

(e) For aluminum alloy pipe, only ASTM B210 and B241, both in tempers O and H112, may be used.

305.2.4 Elevated Temperature Fluid Service. In Elevated Temperature Fluid Service, all longitudinal or spiral (helical seam) welds in P-No. 4 or P-No. 5 materials shall be examined by 100% radiography or 100% ultrasonic examination. Acceptance criteria are as stated in para. 341.3.2 and in Table 341.3.2, for Normal Fluid Service, unless otherwise specified.

306 FITTINGS, BENDS, MITERS, LAPS, AND BRANCH CONNECTIONS

Fittings, bends, miters, laps, and branch connections may be used in accordance with paras. 306.1 through 306.5. Pipe and other materials used in such components shall be suitable for the manufacturing or fabrication process and the fluid service.

306.1 Pipe Fittings

306.1.1 Listed Fittings. Listed fittings may be used in Normal Fluid Service in accordance with para. 303.

306.1.2 Unlisted Fittings. Unlisted fittings may be used only in accordance with para. 302.2.3.

306.1.3 Specific Fittings

(a) Proprietary welding branch outlet fittings that have been design proof tested successfully as prescribed in ASME B16.9, MSS SP-97, or ASME BPVC, Section VIII, Division 1, UG-101 may be used within their established ratings.

(b) The lap thickness of a proprietary "Type C" lap-joint stub-end buttwelding fitting shall conform to the requirements of para. 306.4.2 for flared laps.

306.1.4 Fittings for Severe Cyclic Conditions

(a) Only the following fittings may be used under severe cyclic conditions:

(1) forged.

(2) wrought, seamless or welded. If welded, requires 100% radiograph of welds in accordance with para. 344.5.1 and Table 341.3.2.

(3) cast, with factor $E_c \geq 0.90$.[7]

(b) Fittings conforming to MSS SP-43, MSS SP-119, and proprietary "Type C" lap-joint stub-end welding fittings shall not be used under severe cyclic conditions.

306.2 Pipe Bends

306.2.1 General

(a) A pipe bend made in accordance with paras. 332.2.1 and 332.2.2, and verified for pressure design in accordance with para. 304.2.1, is suitable for the same service as the pipe from which it is made.

(b) A pipe bend made in accordance with para. 332.2.2, but not meeting the flattening limits of para. 332.2.1, may be qualified for pressure design by para. 304.7.2 and shall not exceed the rating of the straight pipe from which it is made.

306.2.2 Corrugated and Other Bends. Bends of other designs (such as creased or corrugated) shall be qualified for pressure design as required by para. 304.7.2.

306.2.3 Bends for Severe Cyclic Conditions. A pipe bend designed as creased or corrugated shall not be used under severe cyclic conditions.

306.3 Miter Bends

306.3.1 General. Except as stated in para. 306.3.2, a miter bend made in accordance with para. 304.2.3 and welded in accordance with para. 311.1 is suitable for use in Normal Fluid Service.

306.3.2 Miter Bends for Category D Fluid Service. A miter bend that makes a change in direction at a single joint (angle α in Figure 304.2.3) greater than 45 deg, or is welded in accordance with para. 311.1, may be used only for Category D Fluid Service.

306.3.3 Miter Bends for Severe Cyclic Conditions. A miter bend to be used under severe cyclic conditions shall be made in accordance with para. 304.2.3 and welded in accordance with para. 311.1, and shall have an angle α (see Figure 304.2.3) ≤ 22.5 deg.

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[7] See para. 302.3.3.

306.4 Laps

The following requirements do not apply to fittings conforming to para. 306.1, specifically lap-joint stub ends conforming to ASME B16.9, nor to laps integrally hot-forged on pipe ends, except as noted in paras. 306.4.3 and 306.4.4(a).

306.4.1 Fabricated Laps. A fabricated lap is suitable for use in Normal Fluid Service, provided that all of the following requirements are met:

(a) The outside diameter of the lap shall be within the dimensional tolerances of the corresponding ASME B16.9 lap-joint stub end.

(b) The lap thickness shall be at least equal to the nominal wall thickness of the pipe to which it is attached.

(c) The lap material shall have an allowable stress at least as great as that of the pipe.

(d) Welding shall be in accordance with para. 311.1 and fabrication shall be in accordance with para. 328.5.5.

306.4.2 Flared Laps. See para. 308.2.5 for requirements of lapped flanges for use with flared laps. A flared lap is suitable for use in Normal Fluid Service, provided that all of the following requirements are met:

(a) The pipe used shall be of a specification and grade suitable for forming without cracks, surface buckling, or other defects.

(b) The outside diameter of the lap shall be within the dimensional tolerances of the corresponding ASME B16.9 lap-joint stub end.

(c) The radius of fillet shall not exceed 3 mm ($^1\!/\!_8$ in.).

(d) The lap thickness at any point shall be at least 95% of the minimum pipe wall thickness, *T*, multiplied by the ratio of the pipe outside diameter to the diameter at which the lap thickness is measured.

(e) Pressure design shall be qualified as required by para. 304.7.2.

306.4.3 Forged Laps. A lap integrally hot-forged on a pipe end is suitable for Normal Fluid Service only when the requirements of para. 332 are met. Its dimensions shall conform to those for lap-joint stub ends given in ASME B16.9.

306.4.4 Laps for Severe Cyclic Conditions

(a) A forged lap-joint stub end in accordance with para. 306.1 or a lap integrally hot-forged on a pipe end in accordance with para. 306.4.3 may be used under severe cyclic conditions.

(b) A fabricated lap to be used under severe cyclic conditions shall conform to the requirements of para. 306.4.1, except that welding shall be in accordance with para. 311.1. A fabricated lap shall conform to a detail shown in Figure 328.5.5, illustration (d) or (e).

(c) A flared lap is not permitted under severe cyclic conditions.

306.5 Fabricated Branch Connections

The following requirements do not apply to fittings conforming to para. 306.1.

306.5.1 General. A fabricated branch connection made and verified for pressure design in accordance with para. 304.3, and welded in accordance with para. 311.1, is suitable for use in Normal Fluid Service.

306.5.2 Fabricated Branch Connections for Severe Cyclic Conditions. A fabricated branch connection to be used under severe cyclic conditions shall conform to the requirements of para. 306.5.1, except that welding shall be in accordance with para. 311.1, with fabrication limited to a detail equivalent to Figure 328.5.4D, illustration (b) or (d), or to Figure 328.5.4E. (20)

306.6 Thermowells

Thermowells shall comply with ASME PTC 19.3 TW where applicable.

307 VALVES AND SPECIALTY COMPONENTS

The following requirements for valves shall also be met as applicable by other pressure-containing piping components, such as traps, strainers, and separators. See also Appendix F, paras. F301.4 and F307.

307.1 General

307.1.1 Listed Valves. A listed valve is suitable for use in Normal Fluid Service, except as stated in para. 307.2.

307.1.2 Unlisted Valves. Unlisted valves may be used only in accordance with para. 302.2.3. (20)

307.2 Specific Requirements

307.2.1 Bonnet Bolting. A bolted bonnet valve whose bonnet is secured to the body by less than four bolts, or by a U-bolt, may be used only for Category D Fluid Service.

307.2.2 Stem Retention. Valves shall be designed so that the stem seal retaining fasteners (e.g., packing, gland fasteners) alone do not retain the stem. Specifically, the design shall be such that the stem shall not be capable of removal from the valve, while the valve is under pressure, by the removal of the stem seal retainer (e.g., gland) alone.

308 FLANGES, BLANKS, FLANGE FACINGS, AND GASKETS

308.1 General

308.1.1 Listed Components. A listed flange, blank, or gasket is suitable for use in Normal Fluid Service, except as stated elsewhere in para. 308.

Table 308.2.1 Permissible Sizes/Rating Classes for Slip-On Flanges Used as Lapped Flanges

Rating Class	Maximum Flange Size DN	NPS
150	300	12
300	200	8

GENERAL NOTE: Actual thickness of the slip-on flange at the bolt circle shall be at least equal to the minimum required flange thickness for lapped flanges in ASME B16.5.

308.1.2 Unlisted Components. Unlisted flanges, blanks, and gaskets may be used only in accordance with para. 302.2.3.

308.2 Specific Requirements for Flanges

See Appendix F, paras. F308.2 and F312.

308.2.1 Slip-On Flanges

(a) A slip-on flange shall be double-welded as shown in Figure 328.5.2B when the service is

(1) subject to severe erosion, crevice corrosion, or cyclic loading

(2) flammable, toxic, or damaging to human tissue

(3) under severe cyclic conditions

(4) at temperatures below −101°C (−150°F)

(b) The use of slip-on flanges should be avoided where many large temperature cycles are expected, particularly if the flanges are not insulated.

(c) Slip-on Flanges as Lapped Flanges. A slip-on flange may be used as a lapped flange only as shown in Table 308.2.1 unless pressure design is qualified in accordance with para. 304.5.1. A corner radius or bevel shall conform to one of the following as applicable:

(1) For an ASME B16.9 lap joint stub end or a forged lap (see para. 306.4.3), the corner radius shall be as specified in ASME B16.5, Tables 9 and 12, dimension *r*.

(2) For a fabricated lap, the corner bevel shall be at least half the nominal thickness of the pipe to which the lap is attached (see Figure 328.5.5).

(3) For a flared lap see para. 308.2.5.

308.2.2 Expanded-Joint Flanges. A flange having an expanded-joint insert is subject to the requirements for expanded joints in para. 313.

308.2.3 Socket Welding and Threaded Flanges. A socket welding flange is subject to the requirements for socket welds in para. 311.2.2. A threaded flange is subject to the requirements for threaded joints in para. 314.

308.2.4 Flanges for Severe Cyclic Conditions. Unless it is safeguarded, a flange to be used under severe cyclic conditions shall be welding neck conforming to ASME B16.5 or ASME B16.47, or a similarly proportioned flange designed in accordance with para. 304.5.1.

308.2.5 Flanges for Flared Metallic Laps. For a flange used with a flared metallic lap (para. 306.4.2), the intersection of face and bore shall be beveled or rounded approximately 3 mm ($^1/_8$ in.). See also para. 308.2.1(c).

308.3 Flange Facings

The flange facing shall be compatible with the gasket and bolting employed.

308.4 Gaskets

Gaskets shall be selected so that the required seating load is compatible with the flange rating and facing, the strength of the flange, and its bolting. See Appendix F, para. F308.4.

309 BOLTING

Bolting includes bolts, bolt studs, studs, cap screws, nuts, and washers. See also Appendix F, para. F309.

309.1 General

309.1.1 Listed Bolting. Listed bolting is suitable for use in Normal Fluid Service, except as stated elsewhere in para. 309.

309.1.2 Unlisted Bolting. Unlisted bolting may be used only in accordance with para. 302.2.3.

309.1.3 Bolting for Components. Bolting for components conforming to a listed standard shall be in accordance with that standard if specified therein.

309.1.4 Selection Criteria. Bolting selected shall be adequate to seat the gasket and maintain joint tightness under all design conditions.

309.2 Specific Bolting

309.2.1 Low Yield Strength Bolting. Bolting having not more than 207 MPa (30 ksi) specified minimum yield strength shall not be used for flanged joints rated ASME B16.5 Class 400 and higher, nor for flanged joints using metallic gaskets, unless calculations have been made showing adequate strength to maintain joint tightness.

309.2.2 Carbon Steel Bolting. Except where limited by other provisions of this Code, carbon steel bolting may be used with nonmetallic gaskets in flanged joints rated ASME B16.5 Class 300 and lower for bolt metal temperatures at −29°C to 204°C (−20°F to 400°F), inclusive. If these bolts are galvanized, heavy hexagon nuts, threaded to suit, shall be used.

309.2.3 Bolting for Metallic Flange Combinations. Any bolting that meets the requirements of para. 309 may be used with any combination of flange material and facing. If either flange is to the ASME B16.1, ASME B16.24 manufactured from an ASTM B61 or an ASTM B62 casting, MSS SP-42, or MSS SP-51 specification, the bolting material shall be no stronger than low yield strength bolting unless

(a) both flanges have flat faces and a full-face gasket is used, or

(b) sequence and torque limits for bolt-up are specified, with consideration of sustained loads, displacement strains, occasional loads (see paras. 302.3.5 and 302.3.6), and strength of the flanges

309.2.4 Bolting for Severe Cyclic Conditions. Low yield strength bolting (see para. 309.2.1) shall not be used for flanged joints under severe cyclic conditions.

309.3 Tapped Holes

Tapped holes for pressure-retaining bolting in metallic piping components shall be of sufficient depth that the thread engagement will be at least seven-eighths times the nominal thread diameter.

PART 4
FLUID SERVICE REQUIREMENTS FOR PIPING JOINTS

310 GENERAL

Piping joints shall be selected considering joint tightness and mechanical strength under expected service and test conditions of pressure, temperature, and external loading. See para. 302.5.

311 WELDED JOINTS

Joints may be made by welding in any material for which it is possible to qualify welding procedures, welders, and welding operators in conformance with the rules in Chapter V.

311.1 General

Welds shall conform to the following:

(a) Welding shall be in accordance with para. 328.

(b) Preheating and heat treatment shall be in accordance with paras. 330 and 331, respectively.

(c) Examination shall be in accordance with para. 341.4.

(d) Acceptance criteria shall be in accordance with para. 341.3.2.

311.2 Specific Requirements

311.2.1 Backing Rings and Consumable Inserts

(a) If a backing ring is used where the resulting crevice is detrimental (e.g., subject to corrosion, vibration, or severe cyclic conditions), it should be removed and the internal joint face ground smooth. When it is impractical to remove the backing ring in such a case, consideration shall be given to welding without backing rings or to the use of consumable inserts or removable nonmetallic backing rings.

(b) Split backing rings shall not be used under severe cyclic conditions.

311.2.2 Socket Welds (20)

(a) Socket welded joints (para. 328.5.2) should be avoided in any service where crevice corrosion or severe erosion may occur.

(b) Socket welded joints shall conform to the following:

(1) Socket dimensions shall conform to ASME B16.5 for flanges and ASME B16.11 or MSS SP-119 for other socket-welding components.

(2) Weld dimensions shall not be less than those shown in Figures 328.5.2B and 328.5.2C.

(c) Socket welds larger than DN 50 (NPS 2) shall not be used under severe cyclic conditions.

(d) A drain or bypass in a component may be attached by socket welding, provided the socket dimensions conform to ASME B16.5, para. 6.12.3.

311.2.3 Fillet Welds

(a) Fillet welds in accordance with para. 328.5.2 may be used as primary welds to attach socket welding components and slip-on flanges.

(b) Fillet welds may also be used to attach reinforcement and structural attachments, to supplement the strength or reduce stress concentration of primary welds, and to prevent disassembly of joints.

311.2.4 Seal Welds. Seal welds (para. 328.5.3) may be used only to prevent leakage of threaded joints and shall not be considered as contributing any strength to the joints.

312 FLANGED JOINTS

See Appendix F, para. F312.1.

312.1 Joints Using Flanges of Different Ratings

Where flanges of different ratings are bolted together, the rating of the joint shall not exceed that of the lower rated flange. Bolting torque shall be limited so that excessive loads will not be imposed on the lower rated flange in obtaining a tight joint.

Table 314.2.1 Minimum Schedule of Components With External Threads

Fluid Service	Notch-Sensitive Material [Note (1)]	Size Range [Note (2)] DN	NPS	Minimum Schedule [Note (3)]
Normal	Yes	≤40	≤1½	80
		50–150	2–6	40
		>150	>6	None
	No	≤150	≤6	40
		>150	>6	None
Category D	Either	All	All	None

NOTES:
(1) Carbon steel is generally considered to be notch sensitive, whereas stainless steel is generally considered to be not notch sensitive.
(2) For sizes over DN 50 (NPS 2), the joint shall be safeguarded (see Appendix G) for a fluid service that is flammable, toxic, or damaging to human tissue.
(3) Minimum schedules 40 and 80 are listed in ASME B36.10M, which are identical to schedules 40S and 80S listed in ASME B36.19M for DN 150 (NPS 6) and smaller.

312.2 Metal to Nonmetal Flanged Joints

Where a metallic flange is bolted to a nonmetallic flange, both should be flat-faced. A full-faced gasket is preferred. If a gasket extending only to the inner edge of the bolts is used, bolting torque shall be limited so that the nonmetallic flange is not overloaded.

312.3 Flanged Joint Assembly

See para. 335.2.5.

313 EXPANDED JOINTS

(a) Expanded joints shall not be used under severe cyclic conditions. For other services, adequate means shall be provided to prevent separation of the joint. If the fluid is toxic or damaging to human tissue, safeguarding is required.

(b) Consideration shall be given to the tightness of expanded joints when subjected to vibration, differential expansion or contraction due to temperature cycling, or external mechanical loads.

314 THREADED JOINTS

314.1 General

Threaded joints are suitable for Normal Fluid Service except as stated elsewhere in para. 314. They may be used under severe cyclic conditions only as provided in paras. 314.2.1(c) and 314.2.2.

(a) Threaded joints should be avoided in any service where crevice corrosion, severe erosion, or cyclic loading may occur.

(b) When threaded joints are intended to be seal welded, thread sealing compound shall not be used.

(c) Layout of piping employing threaded joints should, insofar as possible, minimize stress on joints, giving special consideration to stresses due to thermal expansion and operation of valves (particularly a valve at a free end). Provision should be made to counteract forces that would tend to unscrew the joints.

(d) Except for specially designed joints employing lens rings or similar gaskets, threaded flanges in which the pipe ends project through to serve as the gasket surface may be used only for Category D Fluid Service.

314.2 Specific Requirements

314.2.1 Taper-Threaded Joints. For joints in which the threads of both mating components conform to ASME B1.20.1 (20)

(a) the minimum thickness of components with external threads shall be the greater of t_m in accordance with para. 304.1.1 and the schedule shown in Table 314.2.1

(b) threaded components shall be checked for adequacy of mechanical strength as described in para. 302.5

(c) threaded components of a specialty nature that are not subject to external moment loading, such as thermowells, may be used under severe cyclic conditions

A coupling having straight threads may be used only for Category D Fluid Service, and only with taper-threaded mating components.

314.2.2 Straight-Threaded Joints. Threaded joints in which the tightness of the joint is provided by a seating surface other than the threads (e.g., a union comprising male and female ends joined with a threaded union nut, or other constructions shown typically in Figure 335.3.3) may be used. If such joints are used under severe cyclic conditions and are subject to external moment loadings, safeguarding is required.

315 TUBING JOINTS

315.1 General

In selecting and applying flared, flareless, and compression type tubing fittings, the designer shall consider the possible adverse effects on the joints of such factors as assembly and disassembly, cyclic loading, vibration, shock, and thermal expansion and contraction.

315.2 Joints Conforming to Listed Standards

Joints using flared, flareless, or compression type tubing fittings covered by listed standards may be used in Normal Fluid Service provided that

(a) the fittings and joints are compatible with the tubing with which they are to be used (considering maximum and minimum wall thickness) and are used within the pressure–temperature limitations of the fitting and the joint

(b) the joints are safeguarded when used under severe cyclic conditions

315.3 Joints Not Conforming to Listed Standards

Joints using flared, flareless, or compression type tubing fittings not listed in Table 326.1 may be used in accordance with para. 315.2 provided that the design is qualified in accordance with para. 304.7.2.

316 CAULKED JOINTS

Caulked joints such as bell type joints shall be limited to Category D Fluid Service and to a temperature not over 93°C (200°F). They shall be used within the pressure–temperature limitations of the joint and pipe. Provisions shall be made to prevent disengagement of joints, to prevent buckling of the piping, and to sustain lateral reactions produced by branch connections or other causes.

317 SOLDERED AND BRAZED JOINTS

317.1 Soldered Joints

Soldered joints shall be made in accordance with the provisions of para. 333 and may be used only in Category D fluid service. Fillet joints made with solder metal are not permitted. The low melting point of solder shall be considered where possible exposure to fire or elevated temperature is involved.

317.2 Brazed and Braze Welded Joints

(a) Brazed and braze welded joints made in accordance with the provisions in para. 333 are suitable for Normal Fluid Service. They shall be safeguarded in fluid services that are flammable, toxic, or damaging to human tissue. They shall not be used under severe cyclic conditions. The melting point of brazing alloys shall be considered where possible exposure to fire is involved.

(b) Fillet joints made with brazing filler metal are not permitted.

318 SPECIAL JOINTS

Special joints are those not covered elsewhere in Chapter II, Part 4, such as bell type and packed gland type joints.

318.1 General

318.1.1 Listed Joints. Joints using listed components are suitable for Normal Fluid Service.

318.1.2 Unlisted Joints. For joints that utilize unlisted components, pressure design shall be qualified as required by para. 304.7.2.

318.2 Specific Requirements

318.2.1 Joint Integrity. Separation of the joint shall be prevented by a means that has sufficient strength to withstand anticipated conditions of service.

318.2.2 Joint Interlocks. Either mechanical or welded interlocks shall be provided to prevent separation of any joint used for a fluid service that is flammable, toxic, or damaging to human tissues, of any joint to be used under severe cyclic conditions, and of any joint exposed to temperatures in the creep range.

318.2.3 Bell and Gland Type Joints. Bell-type and gland-type joints used under severe cyclic conditions shall be safeguarded.

PART 5
FLEXIBILITY AND SUPPORT

319 PIPING FLEXIBILITY

319.1 Requirements

319.1.1 Basic Requirements. Piping systems shall have sufficient flexibility to prevent thermal expansion or contraction or movements of piping supports and terminals from causing

(a) failure of piping or supports from overstress or fatigue

(b) leakage at joints

(c) detrimental stresses or distortion in piping and valves or in connected equipment (e.g., pumps and turbines), resulting from excessive thrusts and moments in the piping

319.1.2 Specific Requirements. In para. 319, concepts, data, and methods are given for determining the requirements for flexibility in a piping system and for assuring that the system meets all of these requirements. In brief, these requirements are that

(a) the computed stress range at any point due to displacements in the system shall not exceed the allowable stress range established in para. 302.3.5

(b) reaction forces computed in para. 319.5 shall not be detrimental to supports or connected equipment

(c) computed movement of the piping shall be within any prescribed limits, and properly accounted for in the flexibility calculations

If it is determined that a piping system does not have adequate inherent flexibility, means for increasing flexibility shall be provided in accordance with para. 319.7.

319.2 Concepts

Concepts characteristic of piping flexibility analysis are covered in the following paragraphs. Special consideration is given to displacements (strains) in the piping system, and to resultant axial, bending, and torsional displacement stress ranges.

319.2.1 Displacement Strains

(a) Thermal Displacements. A piping system will undergo dimensional changes with any change in temperature. If it is constrained from free expansion or contraction by connected equipment and restraints such as guides and anchors, it will be displaced from its unrestrained position.

(b) Restraint Flexibility. If restraints are not considered rigid, their flexibility may be considered in determining displacement stress range and reactions.

(c) Externally Imposed Displacements. Externally caused movement of restraints will impose displacements on the piping in addition to those related to thermal effects. Movements may result from tidal changes (dock piping), wind sway (e.g., piping supported from a tall slender tower), or temperature changes in connected equipment.

Movement due to earth settlement, since it is a single cycle effect, will not significantly influence fatigue life. A displacement stress range greater than that permitted by para. 302.3.5(d) may be allowable if due consideration is given to avoidance of excessive localized strain and end reactions.

(d) Total Displacement Strains. Thermal displacements, reaction displacements, and externally imposed displacements all have equivalent effects on the piping system, and shall be considered together in determining the total displacement strains (proportional deformation) in various parts of the piping system.

319.2.2 Displacement Stresses

(a) Elastic Behavior. Stresses may be considered proportional to the total displacement strains in a piping system in which the strains are well-distributed and not excessive at any point (a balanced system). Layout of systems should aim for such a condition, which is assumed in flexibility analysis methods provided in this Code.

(b) Overstrained Behavior. Stresses cannot be considered proportional to displacement strains throughout a piping system in which an excessive amount of strain may occur in localized portions of the system (an unbalanced system). Operation of an unbalanced system in the creep range may aggravate the deleterious effects due to creep strain accumulation in the most susceptible regions of the system. Unbalance may result from one or more of the following:

(1) highly stressed small size pipe runs in series with large or relatively stiff pipe runs.

(2) a local reduction in size or wall thickness, or local use of material having reduced yield strength (for example, girth welds of substantially lower strength than the base metal).

(3) a line configuration in a system of uniform size in which the expansion or contraction must be absorbed largely in a short offset from the major portion of the run.

(4) variation of piping material or temperature in a line. When differences in the elastic modulus within a piping system will significantly affect the stress distribution, the resulting displacement stresses shall be computed based on the actual elastic moduli at the respective operating temperatures for each segment in the system and then multiplied by the ratio of the elastic modulus at ambient temperature to the modulus used in the analysis for each segment.

Unbalance should be avoided or minimized by design and layout of piping systems, particularly those using materials of low ductility. Many of the effects of unbalance can be mitigated by selective use of cold spring. If unbalance cannot be avoided, the designer shall use appropriate analytical methods in accordance with para. 319.4 to assure adequate flexibility as defined in para. 319.1.

319.2.3 Displacement Stress Range

(a) In contrast with stresses from sustained loads, such as internal pressure or weight, displacement stresses may be permitted to attain sufficient magnitude to cause local yielding in various portions of a piping system. When the system is initially operated at the condition of greatest displacement (highest or lowest temperature, or greatest imposed movement) from its installed condition, any yielding or creep brings about a reduction or relaxation of stress. When the system is later returned to its original condition (or a condition of opposite displacement), a reversal and redistribution of stresses occurs that is referred to as self-springing. It is similar to cold springing in its effects.

(b) While stresses resulting from displacement strains diminish with time due to yielding or creep, the algebraic difference between strains in the extreme displacement condition and the original (as-installed) condition (or any anticipated condition with a greater differential effect) remains substantially constant during any one cycle of operation. This difference in strains produces a corresponding stress differential, the displacement stress range, that is used as the criterion in the design of piping for flexibility. In evaluating systems where supports may be active in some conditions and not others (e.g., pipes lifting off supports), this difference in strains may be influenced by the changing distribution of sustained load. In such cases, the displacement strain range is based on the algebraic difference between the calculated positions of the pipe that define the range. In addition to the displacement strain, each calculated

position shall include the sustained loads present in the condition under evaluation. See para. 302.3.5(d) for the allowable stress range, S_A, and para. 319.4.4(a) for the computed displacement stress range, S_E.

319.2.4 Cold Spring. Cold spring is the intentional deformation of piping during assembly to produce a desired initial displacement and reaction. Cold spring is beneficial in that it serves to balance the magnitude of the reaction under initial and extreme displacement conditions. When cold spring is properly applied there is less likelihood of overstrain during initial operation; hence, it is recommended especially for piping materials of limited ductility. There is also less deviation from as-installed dimensions during initial operation, so that hangers will not be displaced as far from their original settings.

Inasmuch as the service life of a piping system is affected more by the range of stress variation than by the magnitude of stress at a given time, no credit for cold spring is permitted in stress range calculations. However, in calculating the thrusts and moments where actual reactions as well as their range of variations are significant, credit is given for cold spring.

319.3 Properties for Flexibility Analysis

The following paragraphs deal with properties of piping materials and their application in piping flexibility stress analysis.

319.3.1 Thermal Expansion Data

(a) Values for Stress Range. Values of thermal displacements to be used in determining total displacement strains for computing the stress range shall be determined from Appendix C as the algebraic difference between the value at maximum metal temperature and that at the minimum metal temperature for the thermal cycle under analysis.

(b) Values for Reactions. Values of thermal displacements to be used in determining total displacement strains for computation of reactions on supports and connected equipment shall be determined as the algebraic difference between the value at maximum (or minimum) temperature for the thermal cycle under analysis and the value at the temperature expected during installation.

319.3.2 Modulus of Elasticity. The reference modulus of elasticity at 21°C (70°F), E_a, and the modulus of elasticity at maximum or minimum temperature, E_m, shall be taken as the values shown in Appendix C for the temperatures determined in para. 319.3.1(a) or 319.3.1(b). For materials not included in Appendix C, reference shall be made to authoritative source data, such as publications of the National Institute of Standards and Technology.

319.3.3 Poisson's Ratio. Poisson's ratio may be taken as 0.3 at all temperatures for all metals. More accurate and authoritative data may be used if available.

319.3.4 Allowable Stresses (20)

(a) The allowable displacement stress range, S_A, and permissible additive stresses shall be as specified in para. 302.3.5(d) for systems primarily stressed in bending and/or torsion.

(b) The stress intensification factors in ASME B31J have been developed from fatigue tests of representative piping components and assemblies manufactured from ductile ferrous materials using the test procedures in ASME B31J and numerical methods. The allowable displacement stress range is based on tests of carbon and austenitic stainless steels. Caution should be exercised when using eqs. (1a) and (1b) (para. 302.3.5) for allowable displacement stress range for some nonferrous materials (e.g., certain copper and aluminum alloys) for other than low cycle applications.

319.3.5 Dimensions. Nominal thicknesses and outside diameters of pipe and fittings shall be used in flexibility calculations.

319.3.6 Flexibility and Stress Intensification Factors. (20) The flexibility factors, k, and stress intensification factors, i, shall not be less than unity. In the absence of more directly applicable data, the flexibility factor, k, and stress intensification factor, i, shown in ASME B31J shall be used for flexibility calculations described in para. 319.4. Flexibility factors and stress intensification factors for branch connections are defined for in-plane, out-plane, and torsion moments on both the run and branch legs. Branch leg calculations shall use the appropriate branch factor (i.e., k_{ib}, k_{ob}, k_{tb}, i_{ib}, i_{ob}, and i_{tb}), and run leg calculations shall use the appropriate run factor (i.e., k_{ir}, k_{or}, k_{tr}, i_{ir}, i_{or}, and i_{tr}).

Flexibility factors and stress intensification factors may be developed in accordance with ASME B31J, Nonmandatory Appendices B and A, respectively.

For piping components or attachments (such as valves, strainers, anchor rings, or bands) not covered in ASME B31J, suitable stress intensification factors may be assumed by comparison of their significant geometry with that of the components shown. The validity of any assumptions is the responsibility of the designer. If two or more of the geometries shown in ASME B31J are combined, their combined k and i might be significantly different from the values shown. Examples include trunnions on elbows and branch connection fittings welded to anything other than straight pipe.

319.4 Flexibility Analysis

319.4.1 Formal Analysis Not Required. No formal analysis of adequate flexibility is required for a piping system that *(a)* duplicates, or replaces without significant change, a system operating with a successful service record

(b) can readily be judged adequate by comparison with previously analyzed systems

(c) is of uniform size, has no more than two points of fixation, no intermediate restraints, and falls within the limitations of empirical eq. (16)[8]

$$\frac{Dy}{(L - U)^2} \leq K_1 \tag{16}$$

where

D = outside diameter of pipe, mm (in.)

E_a = reference modulus of elasticity at 21°C (70°F), MPa (ksi)

K_1 = 208 000 S_A/E_a, $(\text{mm/m})^2$
= 30 S_A/E_a, $(\text{in./ft})^2$

L = developed length of piping between anchors, m (ft)

S_A = allowable displacement stress range in accordance with eq. (1a), MPa (ksi)

U = anchor distance, straight line between anchors, m (ft)

y = resultant of total displacement strains, mm (in.), to be absorbed by the piping system

319.4.2 Formal Analysis Requirements

(a) Any piping system that does not meet the criteria in para. 319.4.1 shall be analyzed by a simplified, approximate, or comprehensive method of analysis, as appropriate.

(b) A simplified or approximate method may be applied only if used within the range of configurations for which its adequacy has been demonstrated.

(c) Acceptable comprehensive methods of analysis include analytical and chart methods that provide an evaluation of the forces, moments, and stresses caused by displacement strains (see para. 319.2.1).

(d) Comprehensive analysis shall take into account stress intensification factors for any component other than straight pipe. Credit may be taken for the extra flexibility of such a component.

319.4.3 Basic Assumptions and Requirements. Standard assumptions specified in para. 319.3 shall be followed in all cases. In calculating the flexibility of a piping system between anchor points, the system shall be treated as a whole. The significance of all parts of the line and of all restraints introduced for the purpose of reducing moments and forces on equipment or small branch lines, and also the restraint introduced by support friction, shall be recognized. Consider all displacements, as outlined in para. 319.2.1, over the temperature range defined by para. 319.3.1.

319.4.4 Flexibility Stresses (20)

(a) The axial, bending, and torsional displacement stress ranges shall be computed using the reference modulus of elasticity at 21°C (70°F), E_a, except as provided in para. 319.2.2(b)(4), and then combined in accordance with eq. (17) to determine the computed displacement stress range, S_E, which shall not exceed the allowable displacement stress range, S_A, in para. 302.3.5(d). See also eq. (1d) and Appendix S, Example 3 for the greatest computed displacement stress range.

$$S_E = \sqrt{(|S_a| + S_b)^2 + (2S_t)^2} \tag{17}$$

where

A_p = cross-sectional area of pipe; see para. 319.3.5

F_a = axial force range between any two conditions being evaluated

i_a = axial stress intensification factor. In the absence of more-applicable data, i_a = 1.0 for elbows, pipe bends, and miter bends (single, closely spaced, and widely spaced), and $i_a = i_o$ for other components; see also para. 319.3.6.

i_t = torsional stress intensification factor; see para. 319.3.6.

M_t = torsional moment range between any two conditions being evaluated

S_a = axial stress range due to displacement strains
= i_aF_a/A_p

S_b = bending stress range due to displacement strains

S_t = torsional stress range due to displacement strains
= $i_tM_t/2Z$

Z = section modulus of pipe; see para. 319.3.5

(b) The bending stress range, S_b, to be used in eq. (17) for elbows, miter bends, and branch connections (Legs 1, 2, and 3) shall be calculated in accordance with eq. (18), with moments as shown in Figures 319.4.4A and 319.4.4B

$$S_b = \frac{\sqrt{(i_iM_i)^2 + (i_oM_o)^2}}{Z} \tag{18}$$

where

i_i = in-plane stress intensification factor; see para. 319.3.6

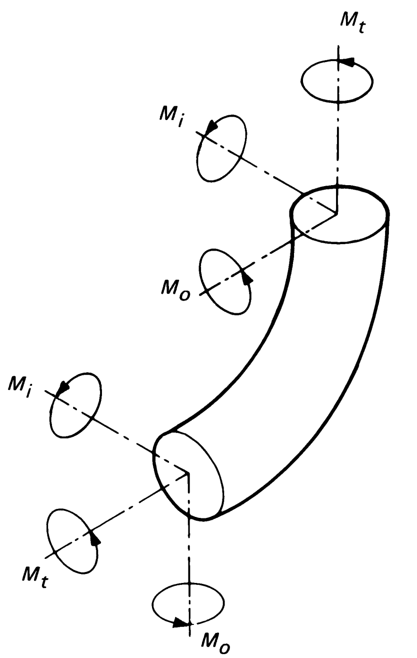
i_o = out-plane stress intensification factor; see para. 319.3.6

M_i = in-plane bending moment range between any two conditions being evaluated

M_o = out-plane bending moment range between any two conditions being evaluated

[8] *WARNING*: No general proof can be offered that this equation will yield accurate or consistently conservative results. It is not applicable to systems used under severe cyclic conditions. It should be used with caution in configurations such as unequal leg U-bends or near-straight "sawtooth" runs, or for large thin-wall pipe ($i \geq 5$), or where extraneous displacements (not in the direction connecting anchor points) constitute a large part of the total displacement. There is no assurance that terminal reactions will be acceptably low, even if a piping system falls within the limitations of eq. (16).

Figure 319.4.4A Moments in Bends



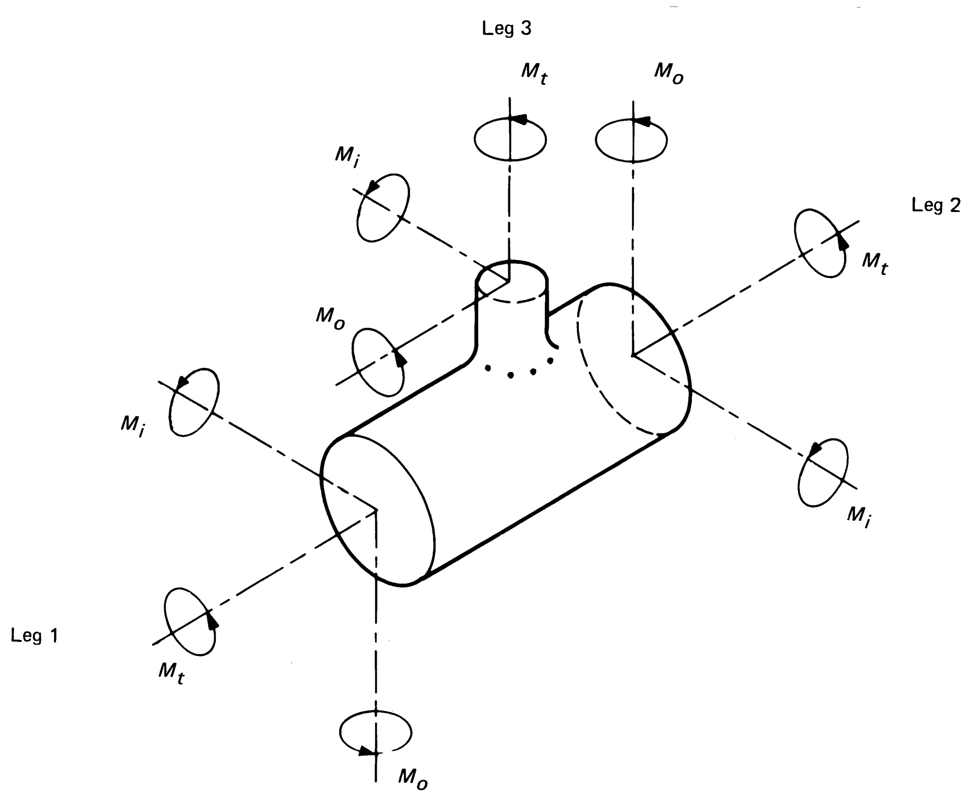
319.5 Reactions

Reaction forces and moments used to design restraints and supports for a piping system, and to evaluate the effects of piping displacement on connected equipment, shall be based on the maximum load from operating conditions, including weight, pressure, and other sustained loads; thermal displacement; and, where applicable, occasional loads. The reactions shall be calculated using the modulus of elasticity at the temperature of the condition, E_m (E_a may be used instead of E_m when it provides a more conservative result). The temperature of the condition may differ in different locations within the piping system.

Where cold spring is used in the piping system, experience has shown that it cannot be fully assured. Therefore, the reactions shall be computed both with the assumption that only two-thirds of the design cold spring is present, and with four-thirds of the design cold spring present.

If it is necessary to determine the reactions at ambient temperature, the designer shall consider loads at that condition, including the design cold spring and self springing of piping. Self springing may occur if the operating stress in the piping system exceeds the yield strength of the material or if the piping operates at temperatures in the creep range of the material.

Figure 319.4.4B Moments in Branch Connections



319.5.1 Maximum Reactions for Simple Systems. For a two-anchor piping system without intermediate restraints, the maximum instantaneous values of reaction forces and moments may be estimated from eqs. (21) and (22).

(a) For Extreme Displacement Conditions, R_m. The temperature for this computation is the maximum or minimum metal temperature defined in para. 319.3.1(b), whichever produces the larger reaction.

$$R_m = R\left(1 - \frac{2C}{3}\right)\frac{E_m}{E_a} \tag{21}$$

where

C = cold-spring factor varying from zero for no cold spring to 1.0 for 100% cold spring. (The factor two-thirds is based on experience showing that specified cold spring cannot be fully assured, even with elaborate precautions.)

E_a = reference modulus of elasticity at 21°C (70°F)

E_m = modulus of elasticity at maximum or minimum metal temperature

R = range of reaction forces or moments (derived from flexibility analysis) corresponding to the full displacement stress range and based on E_a

R_m = estimated instantaneous maximum reaction force or moment at maximum or minimum metal temperature

(b) For Original Condition, R_a. The temperature for this computation is the expected temperature at which the piping is to be assembled.

$R_a = CR$ or C_1R, whichever is greater, where nomenclature is as in para. 319.5.1(a) and

$$C_1 = 1 - \frac{S_h E_a}{S_E E_m} \tag{22}$$

= estimated self-spring or relaxation factor; use zero if value of C_1 is negative

R_a = estimated instantaneous reaction force or moment at installation temperature

S_E = computed displacement stress range (see para. 319.4.4)

S_h = see definition in para. 302.3.5(d)

319.5.2 Maximum Reactions for Complex Systems. For multianchor piping systems and for two-anchor systems with intermediate restraints, eqs. (21) and (22) are not applicable. Each case must be studied to estimate location, nature, and extent of local overstrain, and its effect on stress distribution and reactions.

319.6 Calculation of Movements

Calculations of displacements and rotations at specific locations may be required where clearance problems are involved. In cases where small-size branch pipes attached to stiffer run pipes are to be calculated separately, the linear and angular movements of the junction point must be calculated or estimated for proper analysis of the branch.

319.7 Means of Increasing Flexibility

The layout of piping often provides inherent flexibility through changes in direction, so that displacements produce chiefly bending and torsional strains within prescribed limits. The amount of axial tension or compression strain (which produces large reactions) usually is small.

Where the piping lacks built-in changes of direction, or where it is unbalanced [see para. 319.2.2(b)], large reactions or detrimental overstrain may be encountered. The designer should consider adding flexibility by one or more of the following means: bends, loops, or offsets; swivel joints; corrugated pipe; expansion joints of the bellows or slip-joint type; or other devices permitting angular, rotational, or axial movement. Suitable anchors, ties, or other devices shall be provided as necessary to resist end forces produced by fluid pressure, frictional resistance to movement, and other causes. When expansion joints or other similar devices are provided, the stiffness of the joint or device should be considered in any flexibility analysis of the piping.

320 ANALYSIS OF SUSTAINED LOADS

320.1 Basic Assumptions and Requirements (20)

Sustained conditions may be evaluated by detailed analysis, approximate methods, or simplified means such as span tables. When detailed analysis is performed, the stress due to sustained loads, S_L, shall be computed and combined as described in this paragraph and shall not exceed the allowable described in para. 302.3.5(c). See Appendix S, Example 2 for guidance on loading conditions and support scenarios that result in the greatest S_L for each operating condition being considered. The loads due to weight should be based on the nominal thickness of all system components unless otherwise justified in a more rigorous analysis. Section moduli used to compute the stresses in this paragraph shall be based on nominal pipe dimensions less allowances, i.e., the sum of mechanical (thread or groove depth), internal and external corrosion, and erosion allowances. Areas used to compute the stresses in this paragraph assume nominal pipe dimensions less allowances affecting the inside diameter of the pipe, i.e., the sum of mechanical and internal corrosion and erosion allowances. It is the responsibility of the designer to determine sustained stress indices, I_a, I_i, I_o, and I_t, when a piping component is not explicitly addressed in ASME B31J, e.g., base-ells, reducing elbows, crosses, close proximity fittings, etc., as well as elbows, pipe bends, or miters other than 90 deg or supported by a trunnion. Sustained stress indices shall not be lower than 1.00.

(20) **320.2 Stress Due to Sustained Loads**

The equation for the stress due to sustained loads, such as pressure and weight, S_L, is provided in eq. (23a). Equations for the stress due to sustained bending moments, S_b, are presented in eq. (23b).

$$S_L = \sqrt{(|S_a| + S_b)^2 + (2S_t)^2} \tag{23a}$$

$$S_b = \frac{\sqrt{(I_iM_i)^2 + (I_oM_o)^2}}{Z} \tag{23b}$$

where

I_i = sustained in-plane moment index. In the absence of more-applicable data,[9] I_i is taken as the greater of $0.75i_i$ or 1.00.

I_o = sustained out-plane moment index. In the absence of more-applicable data,[9] I_o is taken as the greater of $0.75i_o$ or 1.00.

M_i = in-plane moment due to sustained loads, e.g., pressure and weight

M_o = out-plane moment due to sustained loads, e.g., pressure and weight

Z = sustained section modulus. Z in eqs. (23b) and (23c), is described in para. 319.4.4 but is computed in this paragraph using nominal pipe dimensions less allowances; see para. 320.1.

The equation for the stress due to sustained torsional moment, S_t, is

$$S_t = \frac{I_tM_t}{2Z} \tag{23c}$$

where

I_t = sustained torsional moment index. In the absence of more-applicable data,[9] I_t is taken as 1.00.

M_t = torsional moment due to sustained loads, e.g., pressure and weight

The equation for the stress due to sustained longitudinal force, S_a, is

$$S_a = \frac{I_aF_a}{A_p} \tag{23d}$$

where

A_p = cross-sectional area of the pipe, considering nominal pipe dimensions less allowances; see para. 320.1

F_a = longitudinal force due to sustained loads, e.g., pressure and weight

I_a = sustained longitudinal force index. In the absence of more-applicable data,[9] I_a is taken as 1.00.

The sustained longitudinal force, F_a, includes the sustained force due to pressure, which is P_jA_f unless the piping system includes an expansion joint that is not designed to carry this force itself, where P_j is the internal operating pressure for the condition being considered, $A_f = \pi d^2/4$, and d is the pipe inside diameter considering pipe wall thickness less applicable allowances; see para. 320.1. For piping systems that contain expansion joints, it is the responsibility of the designer to determine the sustained longitudinal force due to pressure in the piping system.

321 PIPING SUPPORT

321.1 General

The design of support structures (not covered by this Code) and of supporting elements (see definitions of piping and pipe supporting elements in para. 300.2) shall be based on all concurrently acting loads transmitted into such supports. These loads, defined in para. 301, include weight effects, loads introduced by service pressures and temperatures, vibration, wind, earthquake, shock, and displacement strain (see para. 319.2.2).

For piping containing gas or vapor, weight calculations need not include the weight of liquid if the designer has taken specific precautions against entrance of liquid into the piping, and if the piping is not to be subjected to hydrostatic testing at initial construction or subsequent inspections.

321.1.1 Objectives. The layout and design of piping and its supporting elements shall be directed toward preventing the following:

(a) piping stresses in excess of those permitted in this Code

(b) leakage at joints

(c) excessive thrusts and moments on connected equipment (such as pumps and turbines)

(d) excessive stresses in the supporting (or restraining) elements

(e) resonance with imposed or fluid-induced vibrations

(f) excessive interference with thermal expansion and contraction in piping which is otherwise adequately flexible

(g) unintentional disengagement of piping from its supports

[9] The sustained stress or moment factor determined from ASME B31J, Table 1-1, General Note (d) may be considered as more applicable data.

(h) excessive piping sag in piping requiring drainage slope

(i) excessive distortion or sag of piping (e.g., thermoplastics) subject to creep under conditions of repeated thermal cycling

(j) excessive heat flow, exposing supporting elements to temperature extremes outside their design limits

321.1.2 Analysis. In general, the location and design of pipe supporting elements may be based on simple calculations and engineering judgment. However, when a more refined analysis is required and a piping analysis, which may include support stiffness, is made, the stresses, moments, and reactions determined thereby shall be used in the design of supporting elements.

321.1.3 Stresses for Pipe Supporting Elements. Allowable stresses for materials used for pipe supporting elements, except springs, shall be in accordance with para. 302.3.1. Longitudinal weld joint factors, E_j, however, need not be applied to the allowable stresses for welded piping components that are to be used for pipe supporting elements.

321.1.4 Materials

(a) Permanent supports and restraints shall be of material suitable for the service conditions. If steel is cold-formed to a centerline radius less than twice its thickness, it shall be annealed or normalized after forming.

(b) Gray, ductile, and malleable iron may be used for rollers, roller bases, anchor bases, and other supporting elements subject chiefly to compressive loading. Gray iron is not recommended if the piping may be subject to impact-type loading resulting from pulsation or vibration. Ductile and malleable iron may be used for pipe and beam clamps, hanger flanges, clips, brackets, and swivel rings.

(c) Steel of an unknown specification may be used for pipe supporting elements that are not welded directly to pressure-containing piping components. (Compatible intermediate materials of known specification may be welded directly to such components.) Basic allowable stress in tension or compression shall not exceed 82 MPa (12 ksi) and the support temperature shall be within the range of −29°C to 343°C (−20°F to 650°F). For stress values in shear and bearing, see para. 302.3.1(b).

(d) Wood or other materials may be used for pipe supporting elements, provided the supporting element is properly designed, considering temperature, strength, and durability.

(e) Attachments welded or bonded to the piping shall be of a material compatible with the piping and service. For other requirements, see para. 321.3.2.

321.1.5 Threads. Screw threads shall conform to ASME B1.1 unless other threads are required for adjustment under heavy loads. Turnbuckles and adjusting nuts shall have the full length of internal threads engaged. Any threaded adjustment shall be provided with a locknut, unless locked by other means.

321.2 Fixtures

321.2.1 Anchors and Guides

(a) A supporting element used as an anchor shall be designed to maintain an essentially fixed position.

(b) To protect terminal equipment or other (weaker) portions of the system, restraints (such as anchors and guides) shall be provided where necessary to control movement or to direct expansion into those portions of the system that are designed to absorb them. The design, arrangement, and location of restraints shall ensure that expansion joint movements occur in the directions for which the joint is designed. In addition to the other thermal forces and moments, the effects of friction in other supports of the system shall be considered in the design of such anchors and guides.

(c) Piping layout, anchors, restraints, guides, and supports for all types of expansion joints shall be designed in accordance with para. X301.2 of Appendix X.

321.2.2 Inextensible Supports Other Than Anchors and Guides[10]

(a) Supporting elements shall be designed to permit the free movement of piping caused by thermal expansion and contraction.

(b) Hangers include pipe and beam clamps, clips, brackets, rods, straps, chains, and other devices. They shall be proportioned for all required loads. Safe loads for threaded parts shall be based on the root area of the threads.

(c) *Sliding Supports.* Sliding supports (or shoes) and brackets shall be designed to resist the forces due to friction in addition to the loads imposed by bearing. The dimensions of the support shall provide for the expected movement of the supported piping.

321.2.3 Resilient Supports[10]

(a) Spring supports shall be designed to exert a supporting force, at the point of attachment to the pipe, equal to the load as determined by weight balance calculations. They shall be provided with means to prevent misalignment, buckling, or eccentric loading of the springs, and to prevent unintentional disengagement of the load.

(b) Constant-support spring hangers provide a substantially uniform supporting force throughout the range of travel. The use of this type of spring hanger is advantageous at locations subject to appreciable movement with thermal changes. Hangers of this type should be selected so that their travel range exceeds expected movements.

[10] Various types of inextensible (solid) and resilient supports are illustrated in MSS SP-58.

(c) Means shall be provided to prevent overstressing spring hangers due to excessive deflections. It is recommended that all spring hangers be provided with position indicators.

321.2.4 Counterweight Supports. Counterweights shall be provided with stops to limit travel. Weights shall be positively secured. Chains, cables, hangers, rocker arms, or other devices used to attach the counterweight load to the piping shall be subject to the requirements of para. 321.2.2.

321.2.5 Hydraulic Supports. An arrangement utilizing a hydraulic cylinder may be used to give a constant supporting force. Safety devices and stops shall be provided to support the load in case of hydraulic failure.

321.3 Structural Attachments

External and internal attachments to piping shall be designed so that they will not cause undue flattening of the pipe, excessive localized bending stresses, or harmful thermal gradients in the pipe wall. It is important that attachments be designed to minimize stress concentration, particularly in cyclic services.

321.3.1 Nonintegral Attachments. Nonintegral attachments, in which the reaction between the piping and the attachment is by contact, include clamps, slings, cradles, U-bolts, saddles, straps, and clevises. If the weight of a vertical pipe is supported by a clamp, it is recommended to prevent slippage that the clamp be located below a flange, fitting, or support lugs welded to the pipe.

321.3.2 Integral Attachments. Integral attachments include plugs, ears, shoes, plates, trunnions, stanchions, structural shapes, and angle clips, cast on or welded to the piping. The material for integral attachments attached by welding shall be of good weldable quality. [See para. 321.1.4(e) for material requirements.] Preheating, welding, and heat treatment requirements shall be in accordance with Chapter V. Consideration shall be given to the localized stresses induced in the piping component by welding the integral attachment, as well as differential thermal displacement strains between the attachment and the component to which it is attached. Welds shall be proportioned so that the shear stresses meet the requirements of para. 302.3.1(b). If the allowed stress values differ between the piping component and the attachment material, the lower of the two values shall be used. Where postweld heat treatment of the piping is required by para. 331, welds for structural attachments made directly to pressure-containing materials shall be postweld heat treated. Welds for structural attachments not made directly to pressure-containing materials do not require postweld heat treatment.

(a) Integral reinforcement, complete encirclement reinforcement, or intermediate pads of suitable alloy and design may be used to reduce contamination or undesirable heat effects in alloy piping.

(b) Intermediate pads, integral reinforcement, complete encirclement reinforcement, or other means of reinforcement may be used to distribute stresses.

The design of pipe-supporting elements and the local effects on the piping component are the responsibility of the designer. Nonmandatory guidance on the design of supports and attachments may be found as referenced in ASME BPVC, Section VIII, Division 1, Nonmandatory Appendix G, G-9. The designer is cautioned that not all the listed standards and bulletins in G-9 are well suited for use on branch-diameter-to-run-diameter and run-diameter-to-run-thickness ratios typical for pipe support component analyses (e.g., Appendix A of WRC Bulletin 537[11] lists the limitations to WRC Bulletin 537).

321.4 Structural Connections

The load from piping and pipe supporting elements (including restraints and braces) shall be suitably transmitted to a pressure vessel, building, platform, support structure, foundation, or to other piping capable of bearing the load without deleterious effects. See Appendix F, para. F321.4.

PART 6
SYSTEMS

322 SPECIFIC PIPING SYSTEMS

322.3 Instrument Piping

322.3.1 Definition. Instrument piping within the scope of this Code includes all piping and piping components used to connect instruments to other piping or equipment, and control piping used to connect air or hydraulically operated control apparatus. It does not include instruments, or permanently sealed fluid-filled tubing systems furnished with instruments as temperature or pressure responsive devices.

322.3.2 Requirements. Instrument piping shall meet the applicable requirements of the Code and the following:

(a) The design pressure and temperature for instrument piping shall be determined in accordance with para. 301. If more severe conditions are experienced during blowdown of the piping, they may be treated as occasional variations in accordance with para. 302.2.4.

[11] WRC (Welding Research Council) 537-2010, "Precision Equations and Enhanced Diagrams for Local Stresses in Spherical and Cylindrical Shells Due to External Loadings for Implementation of WRC Bulletin 107."

(b) Consideration shall be given to the mechanical strength (including fatigue) of small instrument connections to piping or apparatus (see para. 304.3.5).

(c) Instrument piping containing fluids that are normally static and subject to freezing shall be protected by heat tracing or other heating methods, and insulation.

(d) If it will be necessary to blow down (or bleed) instrument piping containing toxic or flammable fluids, consideration shall be given to safe disposal.

322.6 Pressure-Relieving Systems

Pressure-relieving systems within the scope of this Code shall conform to the following requirements. See also Appendix F, para. F322.6.

322.6.1 Stop Valves in Pressure Relief Piping. If one or more stop valves are installed between the piping being protected and its protective device or devices, or between the protective device or devices and the point of discharge, they shall meet the requirements of (a) and either (b) or (c), below.

(a) A full-area stop valve may be installed on the inlet side of a pressure-relieving device. A full area stop valve may be placed on the discharge side of a pressure-relieving device when its discharge is connected to a common header with other discharge lines from other pressure-relieving devices. Stop valves of less than full area may be used on both the inlet side and discharge side of pressure-relieving devices as outlined herein if the stop valves are of such type and size that the increase in pressure drop will not reduce the relieving capacity below that required, nor adversely affect the proper operation of the pressure-relieving device.

(b) Stop valves to be used in pressure relief piping shall be so constructed or positively controlled that the closing of the maximum number of block valves possible at one time will not reduce the pressure-relieving capacity provided by the unaffected relieving devices below the required relieving capacity.

(c) As an alternative to (b) above, stop valves shall be so constructed and arranged that they can be locked or sealed in either the open or closed position. See Appendix F, para. F322.6.

322.6.2 Pressure Relief Discharge Piping. Discharge lines from pressure-relieving safety devices shall be designed to facilitate drainage. When discharging directly to the atmosphere, discharge shall not impinge on other piping or equipment and shall be directed away from platforms and other areas used by personnel. Reactions on the piping system due to actuation of safety relief devices shall be considered, and adequate strength shall be provided to withstand these reactions.

322.6.3 Pressure-Relieving Devices

(a) Pressure-relieving devices required by para. 301.2.2(a) shall be in accordance with ASME BPVC, Section VIII, Division 1, UG-125(c), UG-126, UG-127, and UG-132 through UG-136, excluding UG-135(e) and UG-136(c). The terms *design pressure*[12] and *piping system* shall be substituted for *maximum allowable working pressure* and *vessel,* respectively, in these paragraphs. The required relieving capacity of any pressure-relieving device shall include consideration of all piping systems that it protects.

(b) Relief set pressure[13] shall be in accordance with Section VIII, Division 1, with the exceptions stated in alternatives (1) and (2), below.

(1) With the owner's approval, the set pressure may exceed the limits in Section VIII, Division 1, provided that the limit on maximum relieving pressure stated in (c) below will not be exceeded.

(2) For a liquid thermal expansion relief device that protects only a blocked-in portion of a piping system, the set pressure shall not exceed the lesser of the system test pressure or 120% of design pressure.

(c) The maximum relieving pressure[14] shall be in accordance with Section VIII, Division 1, with the exception that the allowances in para. 302.2.4(f) are permitted, provided that all other requirements of para. 302.2.4 are also met.

[12] The *design pressure* for pressure relief is the maximum design pressure permitted, considering all components in the piping system.

[13] *Set pressure* is the pressure at which the device begins to relieve, e.g., lift pressure of a spring-actuated relief valve, bursting pressure of a rupture disk, or breaking pressure of a breaking pin device.

[14] *Maximum relieving pressure* is the maximum system pressure during a pressure-relieving event.

Chapter III
Materials

323 GENERAL REQUIREMENTS

Chapter III states limitations and required qualifications for materials based on their inherent properties. Their use in piping is also subject to requirements and limitations in other parts of this Code [see para. 300(d)]. See also para. 321.1.4 for support materials, and Appendix F, para. F323, for precautionary considerations.

323.1 Materials and Specifications

323.1.1 Listed Materials. Any material used in pressure-containing piping components shall conform to a listed specification except as provided in para. 323.1.2.

323.1.2 Unlisted Materials. Unlisted materials may be used provided they conform to a published specification covering chemistry, physical and mechanical properties, method and process of manufacture, heat treatment, and quality control, and otherwise meet the requirements of this Code. See also ASME BPVC, Section II, Part D, Appendix 5. Allowable stresses shall be determined in accordance with the applicable allowable stress basis of this Code or a more conservative basis.

323.1.3 Unknown Materials. Materials of unknown specification shall not be used for pressure-containing piping components.

323.1.4 Reclaimed Materials. Reclaimed pipe and other piping components may be used, provided they are properly identified as conforming to a listed or published specification (para. 323.1.1 or 323.1.2) and otherwise meet the requirements of this Code. Sufficient cleaning and inspection shall be made to determine minimum wall thickness and freedom from imperfections that would be unacceptable in the intended service.

323.2 Temperature Limitations

The designer shall verify that materials that meet other requirements of the Code are suitable for service throughout the operating temperature range.

323.2.1 Upper Temperature Limits, Listed Materials. A listed material may be used at a temperature above the maximum for which a stress value or rating is shown, only if

(a) there is no prohibition in Appendix A or elsewhere in the Code

(b) the designer verifies the serviceability of the material in accordance with para. 323.2.4

323.2.2 Lower Temperature Limits, Listed Materials. Listed materials shall be tested as described in Table 323.2.2 except as exempted by (d) through (j). See Appendix F, para. F323.2.2.

(a) The allowable stress or component rating at any temperature colder than the minimum shown in Table A-1, Table A-1M, or Figure 323.2.2A shall not exceed the stress value or rating at the minimum temperature in Table A-1, Table A-1M, or the component standard.

(b) The stress ratio is used in Figure 323.2.2B to determine the allowable reduction in the impact test exemption temperature. The stress ratio is defined as the maximum of the following:

(1) circumferential pressure stress for the condition under consideration (based on minimum pipe wall thickness less allowances) divided by the basic allowable stress at the condition under consideration.

(2) for piping components with pressure ratings, the pressure for the condition under consideration divided by the pressure rating at the condition under consideration.

(3) combined stress due to pressure, dead loads, live loads, and displacement strain for the condition under consideration divided by the basic allowable stress at the condition under consideration. In calculating this combined stress, the forces and moments in the piping system for these combined sustained loads and displacement strains shall be calculated using nominal dimensions, and the stresses shall be calculated using eqs. (23a) through (23d) with all of the stress indices taken as 1.0 ($I_a = I_i I_o = I_t = 1.0$) and using section properties based on the nominal dimensions less corrosion, erosion, and mechanical allowances. Also see Appendix F, para. F323.2.2.

(c) Minimum impact test exemption temperature reduction may be used only when all of the following apply:

(1) The piping is not in Elevated Temperature Fluid Service.

(2) Local stresses caused by shock loading, thermal bowing, and differential expansion between dissimilar metals (e.g., austenitic welded to ferritic) are less than 10% of the basic allowable stresses at the condition under consideration.

(3) The piping is safeguarded from maintenance loads, e.g., using a valve wheel wrench on a small bore valve.

(d) Impact testing of the base metal is not required if the design minimum temperature is warmer than or equal to the temperature listed in the Min. Temp. column of

Table 323.2.2 Requirements for Low Temperature Toughness Tests for Metals (20)

These Toughness Test Requirements Are in Addition to Tests Required by the Material Specification

	Type of Material	Column A Design Minimum Temperature at or Warmer Than Minimum Temperature in Table A-1, Table A-1M, or Figure 323.2.2A or as Described in Para. 323.2.2(h)		Column B Design Minimum Temperature Colder Than Minimum Temperature in Table A-1, Table A-1M, or Figure 323.2.2A or as Described in Para. 323.2.2(h)
Listed Materials	**1** Gray iron	**A-1** No additional requirements		**B-1** No additional requirements
	2 Malleable and ductile iron; carbon steel in accordance with Note (1)	**A-2** No additional requirements		**B-2** Materials designated in Box 2 shall not be used.
		(a) Base Metal	**(b) Weld Metal [Note (2)]**	
	3 Other carbon steels; low and intermediate alloy steels; and ferritic, martensitic, and duplex stainless steels	**A-3** (a) No additional requirements	**A-3** (b) The weld metal of the welding procedure qualification test coupon shall be impact tested at or below the design minimum temperature when that temperature is less than −18°C (0°F), except when Note (3) or Note (4) is satisfied; impact testing of the weld metal is not required when the classification of the welding consumables according to the filler metal specification requires impact testing at or below the design minimum temperature.	**B-3** Each heat, test unit, or lot of base material as identified in the applicable base metal specification shall be impact tested except when Note (3) or Note (4) is satisfied. When materials are subjected to heat treatment during fabrication, including hot bending or forming and postweld heat treatment such as that required by Table 331.1.1, impact testing shall be performed on material that has been subjected to heat treatment simulating the anticipated heat treatment, including, for postweld heat treatment, at least 80% of the time at temperature. Each welding procedure specification shall be qualified in accordance with Table 323.3.1.
	4 Austenitic stainless steels	**A-4** (a) If (1) carbon content by analysis >0.1% or (2) material is not in solution heat treated condition, then impact test in accordance with para. 323.3 for design minimum temperature <−29°C (−20°F) except as provided in Notes (5) and (6)	**A-4** (b) Weld metal deposits shall be impact tested in accordance with para. 323.3 if design minimum temperature <−29°C (−20°F) except as provided in para. 323.2.2 and in Notes (5) and (6)	**B-4** Base metal and weld metal deposits shall be impact tested in accordance with para. 323.3. See Notes (2), (5), and (6).
	5 Austenitic ductile iron, ASTM A571	**A-5** (a) No additional requirements	**A-5** (b) Welding is not permitted.	**B-5** Base metal shall be impact tested in accordance with para 323.3. Do not use <−196°C (−320°F). Welding is not permitted.
	6 Aluminum, copper, nickel, and their alloys; unalloyed titanium	**A-6** (a) No additional requirements	**A-6** (b) No additional requirements unless filler metal composition is outside the range for base metal composition; then test in accordance with item B-6	**B-6** Designer shall be assured by suitable tests [see Note (7)] that base metal, weld deposits, and HAZ are suitable at the design minimum temperature
Unlisted Materials	**7** An unlisted material shall conform to a published specification. Where composition, heat treatment, and product form are comparable to those of a listed material, requirements for the corresponding listed material shall be met. Other unlisted materials shall be qualified as required in the applicable section of column B.			

NOTES:

(1) Carbon steels conforming to the following are subject to the limitations in Box B-2: plates in accordance with ASTM A36, A283, and A570; pipe in accordance with ASTM A134 when made from these plates; structural shapes in accordance with ASTM A992; and pipe in accordance with ASTM A53 Type F and API 5L Gr. A25 butt weld.

(2) Impact tests that meet the requirements of Table 323.3.1, which are performed as part of the weld procedure qualification, will satisfy all requirements of para. 323.2.2, and need not be repeated for production welds.

(3) See paras. 323.2.2(g) through (i).

Table 323.2.2 Requirements for Low Temperature Toughness Tests for Metals (Cont'd)

NOTES: (Cont'd)

(4) Impact tests are not required when the maximum obtainable Charpy specimen has a width along the notch of less than 2.5 mm (0.098 in.). Under these conditions, and where the stress ratio defined in para. 323.2.2(b) is greater than 0.3, the design minimum temperature shall not be colder than the lower of −48°C (−55°F) or the minimum temperature for the material in Table A-1 or Table A-1M. See also para. 323.2.2(g).

(5) Impact tests are not required when the maximum obtainable Charpy specimen has a width along the notch of less than 2.5 mm (0.098 in.).

(6) For austenitic stainless steels, impact testing is not required if the design minimum temperature is warmer than or equal to −104°C (−155°F), and the stress ratio as defined in para. 323.2.2(b) is 0.3 or less. See also para. 323.2.2(g).

(7) Tests may include tensile elongation, sharp-notch tensile strength (to be compared with unnotched tensile strength), or other tests, conducted at or colder than design minimum temperature. See also para. 323.3.4.

Table A-1, or Table A-1M, except as provided in Table 323.2.2, Box A-4(a) for austenitic stainless steel base material. In some cases, welds will require either impact testing or testing as described in Table 323.2.2, Box B-6 even when the base metal is not required to be tested. See (f) for steels or Table 323.2.2, Box A-6 (b) for other materials.

(e) For carbon steels with a letter designation in the Min. Temp. column of Table A-1 or Table A-1M, the minimum temperature is defined by the applicable curve and Notes in Figure 323.2.2A. If a design minimum temperature–thickness combination is on or above the curve, impact testing exemption requirements described in (d) apply.

(f) For steel materials, impact testing of welds, including those made in manufacturing (e.g., for seam welded pipe and welded tees), is required if either base material is required to be impact tested or if the design minimum temperature is colder than −18°C (0°F), except for manufacturing welds in austenitic stainless steel base materials having a carbon content not exceeding 0.10% and supplied in the solution heat treated condition or as provided in Table 323.2.2, Boxes A-3(b) and A-4(b). For impact testing of production welds, see Table 323.2.2, Note (2).

(g) For steels, impact testing is not required for material (including welds) if the stress ratio as defined in (b) is 0.3 or less, the design minimum temperature is warmer than or equal to −104°C (−155°F), and when (c) applies.

(h) For carbon, low alloy, and intermediate alloy steel materials (including welds) that have not been qualified by impact testing, the minimum temperature from Table A-1, Table A-1M, or Figure 323.2.2A may be reduced to a temperature no colder than −48°C (−55°F) by the temperature reduction provided in Figure 323.2.2B when (c) applies. For carbon, low alloy, and intermediate alloy steel welds that require impact testing in accordance with Table 323.2.2, Box A-3(b), the temperature reduction from Figure 323.2.2B shall be applied to −29°C (−20°F).

(i) For carbon, low alloy, and intermediate alloy steel materials (including welds) that have been qualified by impact testing, the permitted design minimum temperature may be reduced to a temperature no colder than −104°C (−155°F) by the temperature reduction from Figure 323.2.2B when (c) applies.

(j) Impact testing is not required for the following combinations of weld metals and design minimum temperatures:

(1) for austenitic stainless steel base materials having a carbon content not exceeding 0.10%, welded without filler metal, at design minimum temperatures of −104°C (−155°F) and warmer

(2) for austenitic weld metal

(-a) having a carbon content not exceeding 0.10%, and produced with filler metals conforming to AWS A5.4, A5.9, A5.11, A5.14, or A5.22[1] at design minimum temperatures of −104°C (−155°F) and warmer, or

(-b) having a carbon content exceeding 0.10%, and produced with filler metals conforming to AWS A5.4, A5.9, A5.11, A5.14, or A5.22[1] at design minimum temperatures of −48°C (−55°F) and warmer

323.2.3 Temperature Limits, Unlisted Materials. An unlisted material, acceptable under para. 323.1.2, shall be qualified for service at all temperatures within a stated range, from design minimum temperature to design maximum temperature, in accordance with para. 323.2.4.

323.2.4 Verification of Serviceability

(a) When an unlisted material is to be used, or when a listed material is to be used above the highest temperature for which stress values appear in Appendix A, the designer is responsible for demonstrating the validity of the allowable stresses and other limits used in design and of the approach taken in using the material, including the

[1] Titles of referenced AWS standards are as follows:

AWS A5.4/A5.4M, Specification for Stainless Steel Electrodes for Shielded Metal Arc Welding

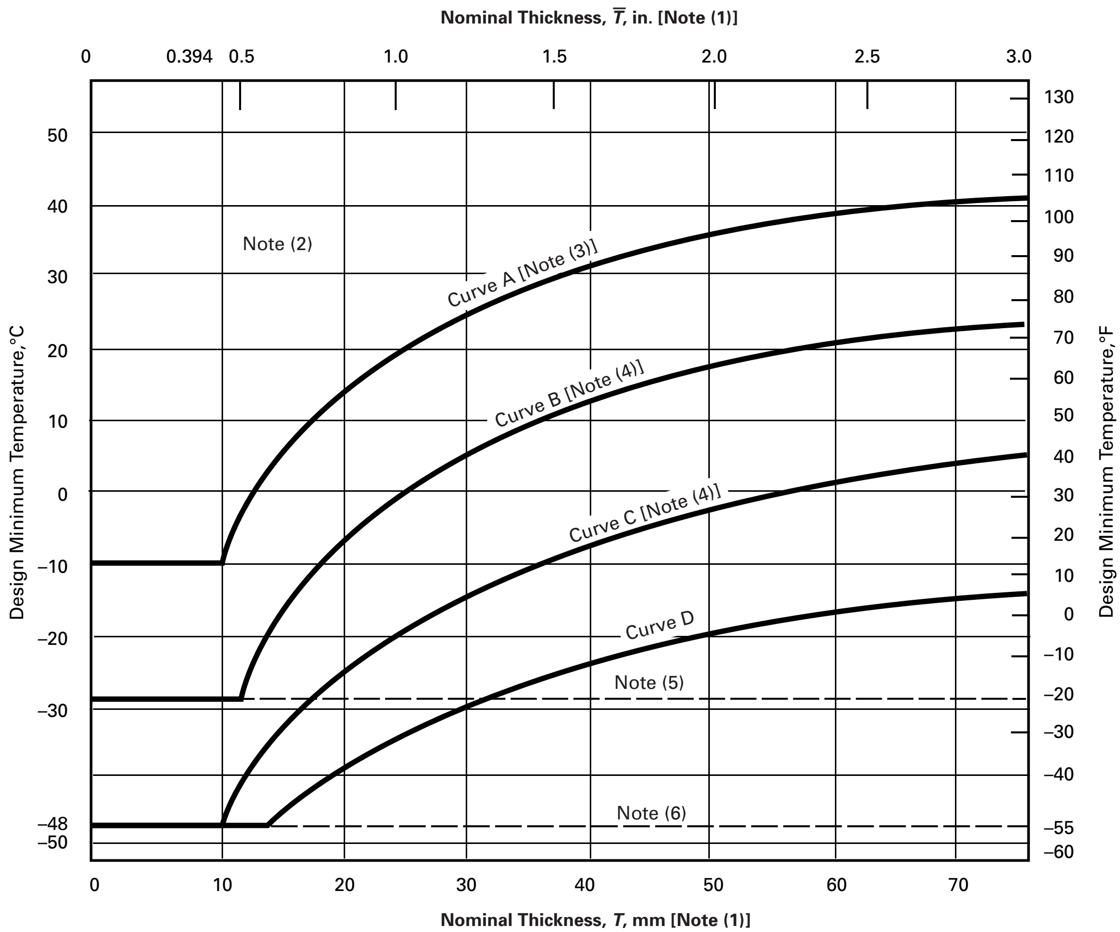
AWS A5.9/A5.9M, Welding Consumables—Wire Electrodes, Strip Electrodes, Wires, and Rods for Arc Welding of Stainless and Heat Resisting Steels—Classification

A5.11/A5.11M, Specification for Nickel and Nickel-Alloy Welding Electrodes for Shielded Metal Arc Welding

A5.14/A5.14M, Specification for Nickel and Nickel-Alloy Bare Welding Electrodes and Rods

A5.22/A5.22M, Specification for Stainless Steel Flux Cored and Metal Cored Welding Electrodes and Rods

Figure 323.2.2A Minimum Temperatures Without Impact Testing for Carbon Steel Materials (See Table A-1 or Table A-1M for Designated Curve for a Listed Material; see Table 323.2.2A for Tabular Values)



NOTES:

(1) For blind flanges and blanks made from materials with a letter designation in the Min. Temp. column of Table A-1 or Table A-1M, $\overline{T}$ shall be $\frac{1}{4}$ of the total thickness, where the total thickness is the thickness of the blind flange or blank including the thickness of the facing(s), if applicable.

(2) Any carbon steel material may be used to a minimum temperature of −29°C (−20°F) for Category D Fluid Service.

(3) X Grades of API 5L, and ASTM A381 materials, may be used in accordance with Curve B if normalized or quenched and tempered.

(4) The following materials may be used in accordance with Curve D if normalized:
  (a) ASTM A516 plate, all grades
  (b) ASTM A671 pipe made from A516 plate, all grades
  (c) ASTM A672 pipe made from A516 plate, all grades

(5) A welding procedure for the manufacture of pipe or components shall include impact testing of welds and HAZ for any design minimum temperature below −29°C (−20°F), except as provided in Table 323.2.2, A-3(b).

(6) Impact testing in accordance with para. 323.3 is required for any design minimum temperature below −48°C (−55°F), except as permitted by Note (3) in Table 323.2.2.

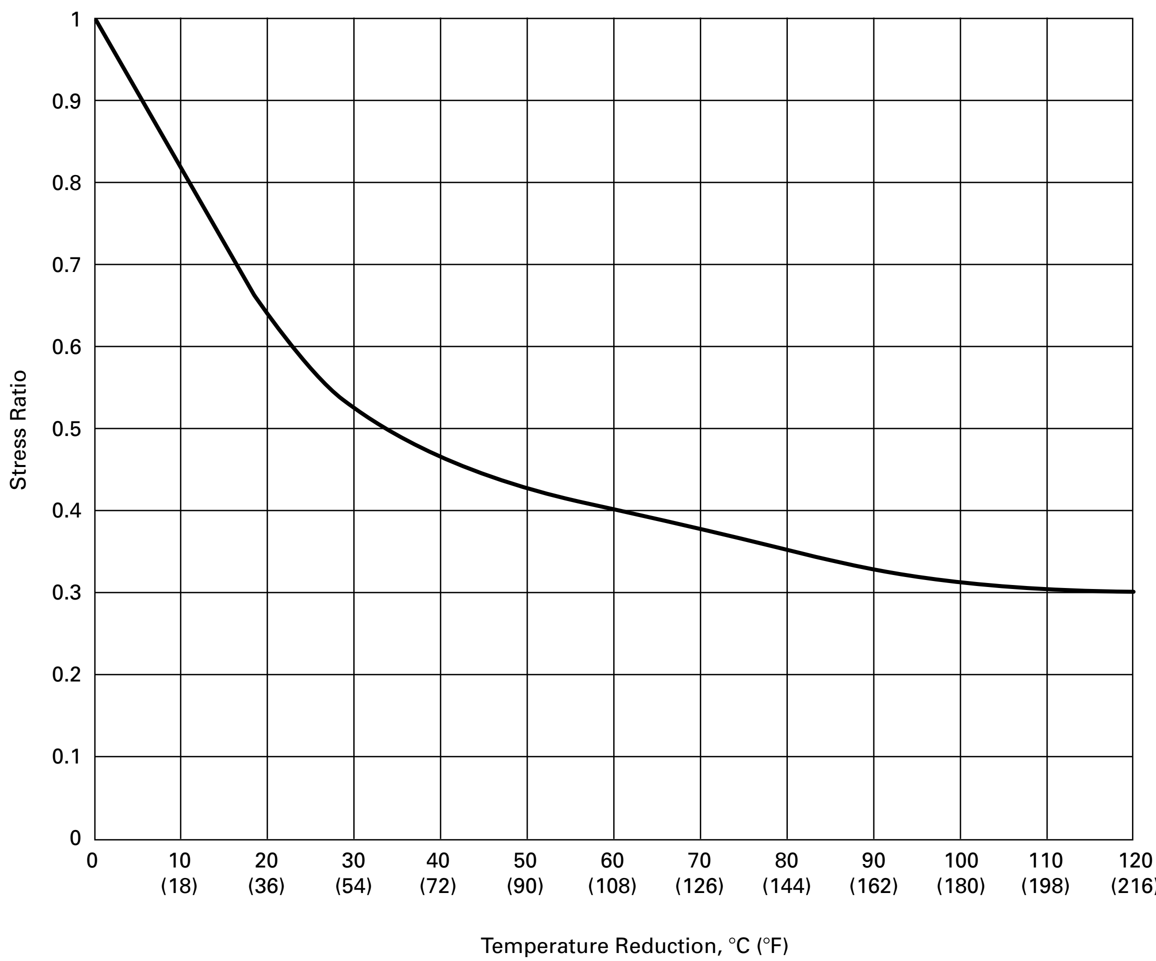
Table 323.2.2A Tabular Values for Minimum Temperatures Without Impact Testing for Carbon Steel Materials (See Figure 323.2.2A for Curves)

Nominal Thickness, $\overline{T}$ [Note (1)]		Lowest Exemption Temperature							
		Curve A [Note (2)]		Curve B [Note (3)]		Curve C [Note (3)]		Curve D	
mm	in.	°C	°F	°C	°F	°C	°F	°C	°F
6.4	0.25	−9.4	15	−28.9	−20	−48.3	−55	−48.3	−55
7.9	0.3125	−9.4	15	−28.9	−20	−48.3	−55	−48.3	−55
9.5	0.375	−9.4	15	−28.9	−20	−48.3	−55	−48.3	−55
10.0	0.394	−9.4	15	−28.9	−20	−48.3	−55	−48.3	−55
11.1	0.4375	−6.7	20	−28.9	−20	−41.7	−43	−48.3	−55
12.7	0.5	−1.1	30	−28.9	−20	−37.8	−36	−48.3	−55
14.3	0.5625	2.8	37	−21.7	−7	−35.0	−31	−45.6	−50
15.9	0.625	6.1	43	−16.7	2	−32.2	−26	−43.9	−47
17.5	0.6875	8.9	48	−12.8	9	−29.4	−21	−41.7	−43
19.1	0.75	11.7	53	−9.4	15	−27.2	−17	−40.0	−40
20.6	0.8125	14.4	58	−6.7	20	−25.0	−13	−38.3	−37
22.2	0.875	16.7	62	−3.9	25	−23.3	−10	−36.7	−34
23.8	0.9375	18.3	65	−1.7	29	−21.7	−7	−35.6	−32
25.4	1.0	20.0	68	0.6	33	−19.4	−3	−34.4	−30
27.0	1.0625	22.2	72	2.2	36	−18.3	−1	−33.3	−28
28.6	1.125	23.9	75	3.9	39	−16.7	2	−32.2	−26
30.2	1.1875	25.0	77	5.6	42	−15.6	4	−30.6	−23
31.8	1.25	26.7	80	6.7	44	−14.4	6	−29.4	−21
33.3	1.3125	27.8	82	7.8	46	−13.3	8	−28.3	−19
34.9	1.375	28.9	84	8.9	48	−12.2	10	−27.8	−18
36.5	1.4375	30.0	86	9.4	49	−11.1	12	−26.7	−16
38.1	1.5	31.1	88	10.6	51	−10.0	14	−25.6	−14
39.7	1.5625	32.2	90	11.7	53	−8.9	16	−25.0	−13
41.3	1.625	33.3	92	12.8	55	−8.3	17	−23.9	−11
42.9	1.6875	33.9	93	13.9	57	−7.2	19	−23.3	−10
44.5	1.75	34.4	94	14.4	58	−6.7	20	−22.2	−8
46.0	1.8125	35.6	96	15.0	59	−5.6	22	−21.7	−7
47.6	1.875	36.1	97	16.1	61	−5.0	23	−21.1	−6
49.2	1.9375	36.7	98	16.7	62	−4.4	24	−20.6	−5
50.8	2.0	37.2	99	17.2	63	−3.3	26	−20.0	−4
52.4	2.0625	37.8	100	17.8	64	−2.8	27	−19.4	−3
54.0	2.125	38.3	101	18.3	65	−2.2	28	−18.9	−2
55.6	2.1875	38.9	102	18.9	66	−1.7	29	−18.3	−1
57.2	2.25	38.9	102	19.4	67	−1.1	30	−17.8	0
58.7	2.3125	39.4	103	20.0	68	−0.6	31	−17.2	1
60.3	2.375	40.0	104	20.6	69	0.0	32	−16.7	2
61.9	2.4375	40.6	105	21.1	70	0.6	33	−16.1	3
63.5	2.5	40.6	105	21.7	71	1.1	34	−15.6	4
65.1	2.5625	41.1	106	21.7	71	1.7	35	−15.0	5
66.7	2.625	41.7	107	22.8	73	2.2	36	−14.4	6
68.3	2.6875	41.7	107	22.8	73	2.8	37	−13.9	7
69.9	2.75	42.2	108	23.3	74	3.3	38	−13.3	8
71.4	2.8125	42.2	108	23.9	75	3.9	39	−13.3	8
73.0	2.875	42.8	109	24.4	76	4.4	40	−12.8	9
74.6	2.9375	42.8	109	25.0	77	4.4	40	−12.2	10
76.2	3.0	43.3	110	25.0	77	5.0	41	−11.7	11

Table 323.2.2A Tabular Values for Minimum Temperatures Without Impact Testing for Carbon Steel Materials (See Figure 323.2.2A for Curves) (Cont'd)

NOTES:
(1) For blind flanges and blanks made from materials with a letter designation in the Min. Temp. column of Table A-1 or Table A-1M, $\overline{T}$ shall be $^1/_4$ of the total thickness, where the total thickness is the thickness of the blind flange or blank including the thickness of the facing(s), if applicable.
(2) X Grades of API 5L, and ASTM A381 materials, may be used in accordance with Curve B if normalized or quenched and tempered.
(3) The following materials may be used in accordance with Curve D if normalized:
  (a) ASTM A516 plate, all grades
  (b) ASTM A671 pipe made from A516 plate, all grades
  (c) ASTM A672 pipe made from A516 plate, all grades

Figure 323.2.2B Reduction in Lowest Exemption Temperature for Steels Without Impact Testing (See Table 323.2.2B for Tabular Values)



GENERAL NOTE: See para. 323.2.2(b) to determine stress ratio.

Table 323.2.2B Tabular Values for Reduction in Lowest Exemption Temperature for Steels Without Impact Testing (See Figure 323.2.2B for Curve and Applicable Notes)

Stress Ratio	Reduction in Exemption Temperature °C	Reduction in Exemption Temperature °F	Stress Ratio	Reduction in Exemption Temperature °C	Reduction in Exemption Temperature °F
1.00	0	0	0.64	20	36
0.99	1	1	0.63	21	37
0.98	1	2	0.62	21	38
0.97	2	3	0.61	22	40
0.96	2	4	0.60	23	41
0.95	3	5	0.59	23	42
0.94	3	6	0.58	24	44
0.93	4	7	0.57	26	46
0.92	4	8	0.56	26	47
0.91	5	9	0.55	27	49
0.90	6	10	0.54	28	51
0.89	6	11	0.53	29	53
0.88	7	12	0.52	31	56
0.87	7	13	0.51	33	59
0.86	8	14	0.50	34	61
0.85	8	15	0.49	36	65
0.84	9	16	0.48	38	68
0.83	9	17	0.47	40	72
0.82	10	18	0.46	42	76
0.81	11	19	0.45	44	80
0.80	11	20	0.44	47	85
0.79	12	21	0.43	50	90
0.78	12	22	0.42	53	96
0.77	13	23	0.41	56	101
0.76	13	24	0.40	60	108
0.75	14	25	0.39	64	115
0.74	14	26	0.38	68	122
0.73	15	27	0.37	72	130
0.72	16	28	0.36	77	138
0.71	16	29	0.35	82	147
0.70	17	30	0.34	87	156
0.69	17	31	0.33	92	166
0.68	18	32	0.32	98	177
0.67	18	33	0.31	104	188
0.66	18	33	0.30	111	200
0.65	19	34	0.30	120	217

derivation of stress data and the establishment of temperature limits.

(b) Data for the development of design limits shall be obtained from a sound scientific program carried out in accordance with recognized technology for both the material and the intended service conditions. Factors to be considered include

(1) applicability and reliability of the data, especially for extremes of the temperature range

(2) resistance of the material to deleterious effects of the fluid service and of the environment throughout the temperature range

(3) determination of allowable stresses in accordance with para. 302.3

323.3 Impact Testing Methods and Acceptance Criteria

323.3.1 General. When impact testing is required by Table 323.2.2, provisions elsewhere in this Code, or the engineering design, it shall be done in accordance with Table 323.3.1 using the testing methods and acceptance criteria described in paras. 323.3.2 through 323.3.5.

323.3.2 Procedure. Impact testing of each product form of material for any specification (including welds in the components) shall be done using procedures and apparatus in accordance with ASTM A370. For material forms that are represented by the ASTM specifications listed below, impact tests shall be conducted in conformance with those requirements as well. When conflicts exist between the specific requirements of this Code and the requirements of those specifications, the requirements of this Code shall take precedence.

Product Form	ASTM Spec. No.
Pipe	A333
Tube	A334
Fittings	A420
Forgings	A350
Castings	A352
Bolting	A320
Plate	A20

GENERAL NOTE: Titles of referenced standards not listed in the Specifications Index for Appendix A are A20 General Requirements for Steel Plates for Pressure Vessels and A370 Test Methods and Definitions for Mechanical Testing of Steel Products.

323.3.3 Test Specimens. Each set of impact test specimens shall consist of three specimen bars. All impact tests shall be made using standard 10 mm (0.394 in.) square cross section Charpy V-notch specimen bars, except when the material shape or thickness does not permit. Charpy impact tests may be performed on specimens of full material thickness, which may be machined to remove surface irregularities. Alternatively, such material may be reduced in thickness to produce the largest possible Charpy subsize specimen. See Table 323.3.4.

323.3.4 Test Temperatures. For all Charpy impact tests, the test temperature criteria in (a) or (b) shall be observed. The test specimens, as well as the handling tongs, shall be cooled for a sufficient length of time to reach the test temperature.

(a) For Materials of Thickness Equal to or Greater Than 10 mm (0.394 in.). Where the largest attainable Charpy V-notch specimen has a width along the notch of at least 8 mm (0.315 in.), the Charpy test using such a specimen shall be conducted at a temperature not higher than the design minimum temperature. Where the largest possible test specimen has a width along the notch less than 8 mm, the test shall be conducted at a temperature lower than the design minimum temperature by the amount shown in Table 323.3.4 for that specimen width.

(b) For Materials With Thickness Less Than 10 mm (0.394 in.). Where the largest attainable Charpy V-notch specimen has a width along the notch of at least 80% of the material thickness, the Charpy test of such a specimen shall be conducted at a temperature not higher than the design minimum temperature. Where the largest possible test specimen has a width along the notch of less than 80% of the material thickness, the test shall be conducted at a temperature lower than the design minimum temperature by an amount equal to the difference (referring to Table 323.3.4) between the temperature reduction corresponding to the actual material thickness and the temperature reduction corresponding to the Charpy specimen width actually tested.

323.3.5 Acceptance Criteria

(a) Minimum Energy Requirements. Except for bolting materials, the applicable minimum energy requirement for carbon and low alloy steels with specified minimum tensile strengths less than 656 MPa (95 ksi) shall be those shown in Table 323.3.5.

(b) Lateral Expansion Requirements. Other carbon and low alloy steels having specified minimum tensile strengths equal to or greater than 656 MPa (95 ksi), all bolting materials, and all high alloy steels (P-Nos. 6, 7, 8, 10H, and 10I) shall have a lateral expansion opposite the notch of not less than 0.38 mm (0.015 in.) for all specimen sizes. The lateral expansion is the increase in width of the broken impact specimen over that of the unbroken specimen measured on the compression side, parallel to the line constituting the bottom of the V-notch (see ASTM A370).

(c) Weld Impact Test Requirements. Where two base metals having different required impact test acceptance criteria are joined by welding, the impact test acceptance criteria shall conform to the requirements of the base material having a specified minimum tensile strength

(20)

Table 323.3.1 Impact Testing Requirements for Metals

<table>
<tr><th colspan="2">Test Characteristics</th><th>Column A
Materials Tested by the Manufacturer [Note (1)] or Those in Table 323.2.2 Requiring Impact Tests Only on Welds</th><th>Column B
Materials Not Tested by the Manufacturer or Those Tested But Heat Treated During or After Fabrication</th></tr>
<tr><td rowspan="3">Tests on Materials</td><td>Number of tests</td><td>A-1 The greater of the number required by
(a) the material specification or
(b) the applicable specification listed in para. 323.3.2 [Note (2)]</td><td>B-1 The number required by the applicable specification listed in para. 323.3.2 [Note (2)]</td></tr>
<tr><td>Location and orientation of specimens</td><td colspan="2">2 As required by the applicable specification listed in para. 323.3.2.</td></tr>
<tr><td>Tests by</td><td>A-3 The manufacturer</td><td>B-3 The fabricator or erector</td></tr>
<tr><td rowspan="4">Tests on Welds in Fabrication or Assembly</td><td>Qualification requirements</td><td colspan="2">4 The supplementary essential variables of ASME BPVC, Section IX, shall apply to the welding procedure qualification.</td></tr>
<tr><td>Extent of testing [Note (3)]</td><td>A-5 Impact tests shall be performed on the weld metal and the heat-affected zone (HAZ) of the procedure qualification test coupon at or below the design minimum temperature and shall meet the acceptance criteria applicable to the base metal in accordance with para. 323.3.</td><td>B-5 If simulated heat treatment is required by Table 323.2.2, item B-3, and materials were supplied without impact test data based on test pieces that were subjected to such heat treatment, the fabricator or erector shall conduct impact tests on material that has been given such heat treatment.</td></tr>
<tr><td>Location and orientation of specimens</td><td colspan="2">6
(a) Weld metal: across the weld, with notch in the weld metal; notch axis shall be normal to material surface, with one face of specimen ≤1.5 mm ($\frac{1}{16}$ in.) from the material surface.
(b) HAZ: across the weld and long enough to locate notch in the HAZ after etching; notch axis shall be approximately normal to material surface and shall include as much as possible of the HAZ in the fracture.</td></tr>
<tr><td>Tests by</td><td colspan="2">7 The fabricator or erector</td></tr>
</table>

NOTES:

(1) A certified report of impact tests performed (after being appropriately heat treated as required by Table 323.2.2, item B-3) by the manufacturer shall be obtained as evidence that the material (including any welds used in its manufacture) meets the requirements of this Code and that

(a) the tests were conducted on specimens representative of the material delivered to and used by the fabricator or erector, or

(b) the tests were conducted on specimens removed from test pieces of the material which received heat treatment separately in the same manner as the material (including heat treatment by the manufacturer) so as to be representative of the finished piping

(2) If welding is used in manufacture, fabrication, or erection, tests of the HAZ will suffice for the tests of the base material.

(3) The test piece shall be large enough to permit preparing three specimens from the weld metal and three from the HAZ (if required) in accordance with para. 323.3. If this is not possible, preparation of additional test pieces is required.

most closely matching the specified minimum tensile strength of the weld metal.

(d) Retests

(1) For Absorbed Energy Criteria. When the average value of the three specimens equals or exceeds the minimum value permitted for a single specimen and the value for more than one specimen is below the required average value, or when the value for one specimen is below the minimum value permitted for a single specimen, a retest of three additional specimens shall be made. The value for each of these retest specimens shall equal or exceed the required average value.

(2) For Lateral Expansion Criterion. If the value of lateral expansion for one specimen in a group of three is below 0.38 mm (0.015 in.) but not below 0.25 mm (0.01 in.), and if the average value for three specimens equals or exceeds 0.38 mm (0.015 in.), a retest of three additional specimens may be made, each of which must equal or exceed the specified minimum value of 0.38 mm (0.015 in.). In the case of heat treated materials, if the required values are not obtained in the retest or if the values in the initial test are below the minimum allowed for retest, the material may be reheat treated and retested. After reheat treatment, a set of three specimens shall be made. For acceptance, the lateral expansion of each of the specimens must equal or exceed the specified minimum value of 0.38 mm (0.015 in.).

(3) For Erratic Test Results. When an erratic result is caused by a defective specimen or there is uncertainty in the test procedure, a retest will be allowed.

Table 323.3.4 Charpy Impact Test Temperature Reduction

Actual Material Thickness [See Para. 323.3.4(b)] or Charpy Impact Specimen Width Along the Notch [Note (1)]		Temperature Reduction Below Design Minimum Temperature	
mm	in.	°C	°F
10 (full size standard bar)	0.394	0	0
9	0.354	0	0
8	0.315	0	0
7.5 (3/4 size bar)	0.295	2.8	5
7	0.276	4.4	8
6.67 (2/3 size bar)	0.262	5.6	10
6	0.236	8.3	15
5 (1/2 size bar)	0.197	11.1	20
4	0.157	16.7	30
3.33 (1/3 size bar)	0.131	19.4	35
3	0.118	22.2	40
2.5 (1/4 size bar)	0.098	27.8	50

GENERAL NOTE: These temperature reduction criteria do not apply when Table 323.3.5 specifies lateral expansion for minimum required values.

NOTE: (1) Straight-line interpolation for intermediate values is permitted.

323.4 Fluid Service Requirements for Materials

323.4.1 General. Requirements in para. 323.4 apply to pressure-containing parts. They do not apply to materials used for supports, gaskets, packing, or bolting. See also Appendix F, para. F323.4.

323.4.2 Specific Requirements

(a) Ductile Iron. Ductile iron shall not be used for pressure containing parts at temperatures below −29°C (−20°F) (except austenitic ductile iron) or above 343°C (650°F). Austenitic ductile iron conforming to ASTM A571 may be used at temperatures below −29°C (−20°F) down to the temperature of the impact test conducted in accordance with that specification but not below −196°C (−320°F).

Valves having bodies and bonnets or covers made of materials conforming to ASTM A395 and meeting the requirements of ASME B16.42 and additional requirements of ASME B16.34 Standard Class, API 594, API 599, or API 609 may be used within the pressure–temperature ratings given in ASME B16.42.

Welding shall not be performed in the fabrication or repair of ductile iron components nor in assembly of such components in a piping system.

(b) Other Cast Irons. The following shall not be used under severe cyclic conditions. If safeguarding is provided against excessive heat and thermal shock and mechanical shock and abuse, they may be used in other services subject to the following requirements:

(1) Gray iron shall not be used above ground within process unit limits in hydrocarbon or other flammable fluid service at temperatures above 149°C (300°F) nor at gage pressures above 1 035 kPa (150 psi). In other locations the pressure limit shall be 2 760 kPa (400 psi).

(2) Malleable iron shall not be used in any fluid service at temperatures below −29°C (−20°F) or above 343°C (650°F) and shall not be used in flammable fluid service at temperatures above 149°C (300°F) nor at gage pressures above 2 760 kPa (400 psi).

(3) High silicon iron (14.5% Si) shall not be used in flammable fluid service. The manufacturer should be consulted for pressure–temperature ratings and for precautionary measures when using this material.

(c) Other Materials

(1) If welding or thermal cutting is performed on aluminum castings, the stress values in Appendix A and component ratings listed in Table 326.1 are not applicable. It is the designer's responsibility to establish such stresses and ratings consistent with the requirements of this Code.

(2) Lead and tin and their alloys shall not be used in flammable fluid services.

323.4.3 Cladding and Lining Materials. Materials with metallic cladding or metallic lining may be used in accordance with the following provisions:

(a) If piping components are made from integrally clad plate conforming to

(1) ASTM A263, Corrosion-Resisting Chromium Steel Clad Plate, Sheet, and Strip

(2) ASTM A264, Stainless Chromium-Nickel Steel Clad Plate, Sheet, and Strip

(3) ASTM A265, Nickel and Nickel-Base Alloy Clad Plate, Sheet, and Strip

Then pressure design in accordance with rules in para. 304 may be based upon the total thickness of base metal and cladding after any allowance for corrosion has been deducted, provided that both the base metal and the cladding metal are acceptable for Code use under para. 323.1, and provided that the clad plate has been shear tested and meets all shear test requirements of the applicable ASTM specification. The allowable stress for each material (base and cladding) shall be taken from Appendix A, or determined in accordance with the rules in para. 302.3, provided, however, that the allowable

Table 323.3.5 Minimum Required Charpy V-Notch Impact Values

Specified Minimum Tensile Strength	Number of Specimens [Note (1)]	Energy [Note (2)] Fully Deoxidized Steels Joules	Energy [Note (2)] Fully Deoxidized Steels ft-lbf	Energy [Note (2)] Other Than Fully Deoxidized Steels Joules	Energy [Note (2)] Other Than Fully Deoxidized Steels ft-lbf
(a) Carbon and Low Alloy Steels					
448 MPa (65 ksi) and less	Average for 3 specimens	18	13	14	10
	Minimum for 1 specimen	14	10	10	7
Over 448 to 517 MPa (75 ksi)	Average for 3 specimens	20	15	18	13
	Minimum for 1 specimen	16	12	14	10
Over 517 but not incl. 656 MPa (95 ksi)	Average for 3 specimens	27	20	...	...
	Minimum for 1 specimen	20	15	...	...
		Lateral Expansion			
656 MPa and over [Note (3)]	Minimum for 3 specimens	0.38 mm (0.015 in.)			
(b) Steels in P-Nos. 6, 7, 8, 10H, and 10I	Minimum for 3 specimens	0.38 mm (0.015 in.)			

NOTES:
(1) See para. 323.3.5(d) for permissible retests.
(2) Energy values in this Table are for standard size specimens. For subsize specimens, these values shall be multiplied by the ratio of the actual specimen width to that of a full-size specimen, 10 mm (0.394 in.).
(3) For bolting of this strength level in nominal sizes M 52 (2 in.) and under, the impact requirements of ASTM A320 may be applied. For bolting over M 52, requirements of this Table shall apply.

stress used for the cladding portion of the design thickness shall never be greater than the allowable stress used for the base portion.

(b) For all other metallic clad or lined piping components, the base metal shall be an acceptable Code material as defined in para. 323.1 and the thickness used in pressure design in accordance with para. 304 shall not include the thickness of the cladding or lining. The allowable stress used shall be that for the base metal at the design temperature. For such components, the cladding or lining may be any material that, in the judgment of the user, is suitable for the intended service and for the method of manufacture and assembly of the piping component.

(c) Except for components designed in accordance with provisions of (a) , fluid service requirements for materials stated in this Code shall not restrict their use as cladding or lining in pipe or other components. Fluid service requirements for the outer material (including those for components and joints) shall govern, except that temperature limitations of both inner and outer materials, and of any bond between them, shall be considered.

(d) Fabrication by welding of clad or lined piping components and the inspection and testing of such components shall be done in accordance with applicable provisions of ASME BPVC, Section VIII, Division 1, UCL-30 through UCL-52, or the provisions of Chapters V and VI of this Code, whichever are more stringent.

323.5 Deterioration of Materials in Service

Selection of material to resist deterioration in service is not within the scope of this Code. See para. 300(c)(6). Recommendations based on experience are presented for guidance in Appendix F, para. F323.

325 MATERIALS — MISCELLANEOUS

325.1 Joining and Auxiliary Materials

When selecting materials such as adhesives, cements, solvents, solders, brazing materials, packing, and O-rings for making or sealing joints, the designer shall consider their suitability for the fluid service. (Consideration should also be given to the possible effects of the joining or auxiliary materials on the fluid handled.)

Chapter IV
Standards for Piping Components

326 DIMENSIONS AND RATINGS OF COMPONENTS

326.1 Dimensional Requirements

326.1.1 Listed Piping Components. Dimensional standards[1] for piping components are listed in Table 326.1. Dimensional requirements contained in specifications listed in Appendix A shall also be considered requirements of this Code.

326.1.2 Unlisted Piping Components. Piping components not listed in Table 326.1 or Appendix A shall meet the pressure design requirements described in para. 302.2.3 and the mechanical strength requirements described in para. 302.5.

326.1.3 Threads. The dimensions of piping connection threads not otherwise covered by a governing component standard or specification shall conform to the requirements of applicable standards listed in Table 326.1 or Appendix A.

326.2 Ratings of Components

326.2.1 Listed Components. The pressure–temperature ratings of components listed in Table 326.1 are accepted for pressure design in accordance with para. 303.

326.2.2 Unlisted Components. The pressure–temperature ratings of unlisted piping components shall conform to the applicable provisions of para. 304.

326.3 Reference Documents

The documents listed in Table 326.1 contain references to codes, standards, and specifications not listed in Table 326.1. Such unlisted codes, standards, and specifications shall be used only in the context of the listed documents in which they appear.

The design, materials, fabrication, assembly, examination, inspection, and testing requirements of this Code are not applicable to components manufactured in accordance with the documents listed in Table 326.1, unless specifically stated in this Code or the listed document.

[1] It is not practical to refer to a specific edition of each standard throughout the Code text. Instead, the approved edition references, along with the names and addresses of sponsoring organizations, are shown in Appendix E.

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Table 326.1 Component Standards

Standard or Specification	Designation
Bolting	
Square, Hex, Heavy Hex, and Askew Head Bolts and Hex, Heavy Hex, Hex Flange, Lobed Head, and Lag Screws (Inch Series)	ASME B18.2.1
Nuts for General Applications: Machine Screw Nuts, Hex, Square, Hex Flange, and Coupling Nuts (Inch Series)	ASME B18.2.2
Continuous Thread Stud, Double-End Stud, and Flange Bolting Stud (Stud Bolt) (Inch Series)	ASME B18.31.2
Metallic Fittings, Valves, and Flanges	
Gray Iron Pipe Flanges and Flanged Fittings: Classes 25, 125, and 250	ASME B16.1
Malleable Iron Threaded Fittings: Classes 150 and 300	ASME B16.3
Gray Iron Threaded Fittings: Classes 125 and 250	ASME B16.4
Pipe Flanges and Flanged Fittings: NPS $^1/_2$ Through NPS 24 Metric/Inch Standard	ASME B16.5
Factory-Made Wrought Buttwelding Fittings	ASME B16.9
Face-to-Face and End-To-End Dimensions of Valves	ASME B16.10
Forged Fittings, Socket-Welding and Threaded	ASME B16.11
Ferrous Pipe Plugs, Bushings, and Locknuts With Pipe Threads	ASME B16.14
Cast Copper Alloy Threaded Fittings: Classes 125 and 250 [Note (1)]	ASME B16.15
Cast Copper Alloy Solder Joint Pressure Fittings	ASME B16.18
Wrought Copper and Copper Alloy Solder-Joint Pressure Fittings	ASME B16.22
Cast Copper Alloy Pipe Flanges, Flanged Fittings, and Valves: Classes 150, 300, 600, 900, 1500, and 2500	ASME B16.24
Cast Copper Alloy Fittings for Flared Copper Tubes	ASME B16.26
Valves — Flanged, Threaded, and Welding End	ASME B16.34
Orifice Flanges	ASME B16.36
Malleable Iron Threaded Pipe Unions: Classes 150, 250, and 300	ASME B16.39
Ductile Iron Pipe Flanges and Flanged Fittings: Classes 150 and 300	ASME B16.42
Large Diameter Steel Flanges: NPS 26 Through NPS 60 Metric/Inch Standard	ASME B16.47
Line Blanks	ASME B16.48
Wrought Copper and Copper Alloy Braze-Joint Pressure Fittings	ASME B16.50
Bioprocessing Equipment [Note (2)]	ASME BPE
Specification for Pipeline and Piping Valves [Note (3)]	API 6D
Flanged Steel Pressure-relief Valves	API 526
Check Valves: Flanged, Lug, Wafer, and Butt-welding	API 594
Metal Plug Valves — Flanged, Threaded, and Welding Ends	API 599
Steel Gate Valves — Flanged and Butt-welding Ends, Bolted Bonnets	API 600
Gate, Globe, and Check Valves for Sizes DN 100 (NPS 4) and Smaller for the Petroleum and Natural Gas Industries	API 602
Corrosion-resistant, Bolted Bonnet Gate Valves — Flanged and Butt-welding Ends	API 603
Metal Ball Valves — Flanged, Threaded, and Welding Ends	API 608
Butterfly Valves: Double-flanged, Lug- and Wafer-type	API 609
Performance of Gasketed Mechanical Couplings for Use in Piping Applications	ASTM F1476
Performance of Fittings for Use with Gasketed Mechanical Couplings Used in Piping Applications	ASTM F1548
Ductile-Iron and Gray-Iron Fittings	AWWA C110
Flanged Ductile-Iron Pipe With Ductile-Iron or Gray-Iron Threaded Flanges	AWWA C115
Steel Pipe Flanges for Waterworks Service, Sizes 4 in. Through 144 in. (100 mm Through 3,600 mm)	AWWA C207
Dimensions for Fabricated Steel Water Pipe Fittings	AWWA C208
Metal-Seated Gate Valves for Water Supply Service	AWWA C500
Standard Finishes for Contact Faces of Pipe Flanges and Connecting-End Flanges of Valves and Fittings	MSS SP-6
Spot Facing for Bronze, Iron, and Steel Flanges	MSS SP-9
Standard Marking System for Valves, Fittings, Flanges, and Unions	MSS SP-25

Table 326.1 Component Standards (Cont'd)

Standard or Specification	Designation
Metallic Fittings, Valves, and Flanges (Cont'd)	
Corrosion-Resistant Gate, Globe, Angle, and Check Valves with Flanged and Butt Weld Ends (Classes 150, 300, & 600)	MSS SP-42
Wrought and Fabricated Butt-Welding Fittings for Low Pressure, Corrosion Resistant Applications [Note (4)]	MSS SP-43
Steel Pipeline Flanges	MSS SP-44
Bypass and Drain Connections	MSS SP-45
Class 150LW Corrosion Resistant Flanges and Cast Flanged Fittings	MSS SP-51
High Pressure Chemical Industry Flanges and Threaded Stubs for Use with Lens Gaskets	MSS SP-65
Gray Iron Gate Valves, Flanged and Threaded Ends	MSS SP-70
Gray Iron Swing Check Valves, Flanged and Threaded Ends	MSS SP-71
Ball Valves with Flanged or Butt-Welding Ends for General Service	MSS SP-72
High-Strength, Wrought, Butt-Welding Fittings	MSS SP-75
Gray Iron Plug Valves, Flanged and Threaded Ends	MSS SP-78
Socket Welding Reducer Inserts	MSS SP-79
Bronze Gate, Globe, Angle, and Check Valves	MSS SP-80
Stainless-Steel or Stainless-Steel-Lined, Bonnetless, Knife Gate Valves with Flanged Ends	MSS SP-81
Class 3000 and 6000 Pipe Unions, Socket Welding and Threaded (Carbon Steel, Alloy Steel, Stainless Steels, and Nickel Alloys)	MSS SP-83
Gray Iron Globe and Angle Valves, Flanged and Threaded Ends	MSS SP-85
Diaphragm Valves	MSS SP-88
Swage(d) Nipples and Bull Plugs	MSS SP-95
Integrally Reinforced Forged Branch Outlet Fittings — Socket Welding, Threaded, and Buttwelding Ends	MSS SP-97
Instrument Valves for Code Applications	MSS SP-105
Cast Copper Alloy Flanges and Flanged Fittings: Class 125, 150, and 300	MSS SP-106
Factory-Made Wrought Belled End Pipe Fittings for Socket-Welding [Note (5)]	MSS SP-119
Refrigeration Tube Fittings — General Specifications	SAE J513
Hydraulic Tube Fittings	SAE J514
Hydraulic Flanged Tube, Pipe, and Hose Connections, 4-Screw Flange Connection Part 1: 3.5 MPa to 35 MPa (Code 61)	SAE J518-1
Hydraulic Flanged Tube, Pipe, and Hose Connections, 4-Screw Flange Connection Part 2: 42 MPa (Code 62)	SAE J518-2
Metallic Pipe and Tubes [Note (6)]	
Welded and Seamless Wrought Steel Pipe	ASME B36.10M
Stainless Steel Pipe	ASME B36.19M
Flanged Ductile-Iron Pipe With Ductile-Iron or Gray-Iron Threaded Flanges	AWWA C115
Thickness Design of Ductile-Iron Pipe	AWWA C150
Ductile-Iron Pipe, Centrifugally Cast	AWWA C151
Steel Water Pipe, 6 in. (150 mm) and Larger	AWWA C200
Miscellaneous	
Unified Inch Screw Threads (UN and UNR Thread Form)	ASME B1.1
Pipe Threads, General Purpose (Inch)	ASME B1.20.1
Dryseal Pipe Threads (Inch)	ASME B1.20.3
Hose Coupling Screw Threads (Inch)	ASME B1.20.7
Metallic Gaskets for Pipe Flanges	ASME B16.20
Nonmetallic Flat Gaskets for Pipe Flanges	ASME B16.21
Buttwelding Ends	ASME B16.25
Surface Texture (Surface Roughness, Waviness, and Lay)	ASME B46.1
Thermowells [Note (7)]	ASME PTC 19.3 TW
Specification for Threading, Gauging, and Thread Inspection of Casing, Tubing, and Line Pipe Threads	API 5B
Rubber-Gasket Joints for Ductile-Iron Pressure Pipe and Fittings	AWWA C111

Table 326.1 Component Standards (Cont'd)

Standard or Specification	Designation
Miscellaneous (Cont'd)	
Grooved and Shouldered Joints [Note (8)]	AWWA C606
Flexible Metal Hose [Notes (9) and (10)]	BS 6501, Part 1
Pipe Hangers and Supports — Materials, Design, Manufacture, Selection, Application, and Installation	MSS SP-58
Standard for Fire Hose Connections	NFPA 1963

GENERAL NOTES:

(a) It is not practical to refer to a specific edition of each standard throughout the Code text. Instead, the approved edition references, along with the names and addresses of the sponsoring organizations, are shown in Appendix E.

(b) Many of the listed standards allow the use of unlisted materials; see para. 323.1.2.

NOTES:

(1) This standard allows straight pipe threads in sizes ≤ DN 15 (NPS $^1/_2$); see last paragraph of para. 314.2.1.

(2) Part DT of ASME BPE covers dimensions and tolerances for stainless steel automatic welding and hygienic clamp tube fittings and process components.

(3) API 6D allows design and calculations for pressure-containing elements to be in accordance with various internationally recognized design codes or standards. Only API 6D valves with design and calculations for pressure-containing elements in accordance with ASME B16.34 are considered a "listed component" for the purpose of this Code.

(4) *Cautionary Note:* See MSS SP-43 for special provisions concerning ratings. (In accordance with MSS SP-43, the pressure ratings for Class CR fittings are 30% of those calculated for straight seamless pipe of *minimum* wall thickness.)

(5) MSS SP-119 includes three classes of fittings: MP, MARINE, and CR. Only the MP class fittings are considered a "Listed Component" for the purpose of this Code. *Cautionary Note*: See MSS SP-119 (Section 5) for special provisions concerning ratings. (In accordance with MSS SP-119, the pressure ratings for MP class fittings are 87.5% of those calculated for straight seamless pipe of *minimum* wall thickness.)

(6) See also Appendix A.

(7) ASME PTC 19.3 TW allows mechanical design of thermowells to be in accordance with various design codes. Only PTC 19.3 TW thermowells with design and calculations for pressure-containing elements in accordance with ASME B31.3 are considered a "listed component" for the purpose of this Code.

(8) For use with this Code, the rated pressure of components covered by this standard shall be based on no greater than one-third the hydrostatic test failure pressure (the pressure at fracture or leakage), rather than one-half the hydrostatic test failure pressure specified in AWWA C606.

(9) Welding and brazing to be in accordance with paras. 328 and 333, respectively, in lieu of the referenced specifications in this standard.

(10) This standard contains recommended materials of construction for certain chemical services; the responsibility for the ultimate selection of material is the responsibility of the Owner and is, therefore, not within the scope of this Code.

Chapter V
Fabrication, Assembly, and Erection

327 GENERAL

Metallic piping materials and components are prepared for assembly and erection by one or more of the fabrication processes covered in paras. 328, 330, 331, 332, and 333. When any of these processes is used in assembly or erection, requirements are the same as for fabrication.

328 WELDING AND BRAZING

Welding and brazing shall conform to the requirements of this Chapter and the applicable requirements of para. 311.2.

328.1 Responsibility

Each employer is responsible for

(a) the welding and brazing performed by personnel of its organization

(b) conducting the qualification tests required to qualify the welding or brazing procedure specifications used by personnel in its organization, except as provided in paras. 328.2.1 and 328.2.2

(c) conducting the qualification tests required to qualify the welders, brazers, and operators, except as provided in para. 328.2.3

328.2 Welding and Brazing Qualification

Welding and brazing procedure specifications (WPSs and BPSs) to be followed in production welding shall be prepared and qualified, and welders, brazers, and operators shall be qualified as required by ASME BPVC, Section IX except as modified by para. 333 for brazing of Category D Fluid Service piping and by the following subparagraphs.

328.2.1 Standard Welding Procedure Specifications. Standard welding procedure specifications published by the American Welding Society and listed in ASME BPVC, Section IX, Appendix E are permitted for Code construction within the limitations established by ASME BPVC, Section IX, Article V.

328.2.2 Procedure Qualification by Others. In order to avoid duplication of effort and subject to the approval of the owner, WPSs and BPSs qualified by a technically competent group or agency may be used provided the following are met:

(a) The procedures meet the requirements of ASME BPVC, Section IX and any additional qualification requirements of this Code.

(b) The employer has qualified at least one welder, brazer, or operator following each WPS or BPS.

(c) The employer's business name shall be shown on each WPS and BPS, and on each qualification record. In addition, qualification records shall be signed and dated by the employer, thereby accepting responsibility for the qualifications performed by others.

328.2.3 Performance Qualification by Others. In order to avoid duplication of effort and subject to the approval of the owner, an employer may accept the performance qualification of a welder, brazer, or operator made by a previous employer. This acceptance is limited to performance qualifications that were made on pipe or tube test coupons. The new employer shall have the WPS or BPS that was followed during qualification or an equivalent WPS or BPS that is within the limits of the essential variables set forth in ASME BPVC, Section IX. An employer accepting such qualification tests shall obtain a copy of the performance qualification test record from the previous employer. The record shall show the name of the employer by whom the welder, brazer, or operator was qualified and the date of that qualification. Evidence shall also be provided that the welder, brazer, or operator has maintained qualification in accordance with QW-322 and QB-322 of ASME BPVC, Section IX, except that this evidence may be provided by an employer responsible for the individual's welding or brazing performance even if not the original qualifying employer. The new employer's business name shall be shown on the qualification record, and it shall be signed and dated by the employer, thereby accepting responsibility for the qualifications performed by others.

328.2.4 Qualification Records. The employer shall maintain copies of the procedure and performance qualification records specified by ASME BPVC, Section IX that shall be available to the Inspector at the location where welding is being done.

328.3 Welding Materials

328.3.1 Electrodes and Filler Metal. Welding electrodes and filler metal, including consumable inserts, shall conform to the requirements of ASME BPVC, Section II, Part C. An electrode or filler metal not conforming to the above may be used provided the WPS and the welders who will follow the WPS have been qualified as required by ASME BPVC, Section IX. Unless otherwise specified by the Designer, welding electrodes and filler metals used shall produce weld metal that complies with the following:

(a) The nominal tensile strength of the weld metal shall equal or exceed the minimum specified tensile strength of the base metals being joined, or the weaker of the two if base metals of two different strengths are being joined.

(b) The nominal chemical analysis of the weld metal shall be similar to the nominal chemical analysis of the major alloying elements of the base metal (e.g., $2^1/_4$% Cr, 1% Mo steels should be joined using $2^1/_4$% Cr, 1% Mo filler metals).

(c) If base metals of different chemical analysis are being joined, the nominal chemical analysis of the weld metal shall be similar to either base metal or an intermediate composition, except as specified below for austenitic steels joined to ferritic steels.

(d) When austenitic steels are joined to ferritic steels, the weld metal shall have a predominantly austenitic microstructure.

(e) For nonferrous metals, the weld metal shall be that recommended by the manufacturer of the nonferrous base metal or by industry associations for that metal.

328.3.2 Weld Backing Material. When backing rings are used, they shall conform to the following:

(a) Ferrous Metal Backing Rings. These shall be of weldable quality. Sulfur content shall not exceed 0.05%.

(b) If two abutting surfaces are to be welded to a third member used as a backing ring and one or two of the three members are ferritic and the other member or members are austenitic, the satisfactory use of such materials shall be demonstrated by welding procedure qualified as required by para. 328.2.

Backing rings may be of the continuous machined or split-band type. Some commonly used types are shown in Figure 328.3.2.

(c) Nonferrous and Nonmetallic Backing Rings. Backing rings of nonferrous or nonmetallic material may be used, provided the designer approves their use and the welding procedure using them is qualified as required by para. 328.2.

328.3.3 Consumable Inserts. Consumable inserts may be used, provided they are of the same nominal composition as the filler metal, will not cause detrimental alloying of the weld metal, and the welding procedure using them is qualified as required by para. 328.2. Some commonly used types are shown in Figure 328.3.2.

328.4 Preparation for Welding

328.4.1 Cleaning. Internal and external surfaces to be thermally cut or welded shall be clean and free from paint, oil, rust, scale, and other material that would be detrimental to either the weld or the base metal when heat is applied.

328.4.2 End Preparation

(a) General

(1) End preparation is acceptable only if the surface is reasonably smooth and true, and slag from oxygen or arc cutting is cleaned from thermally cut surfaces. Discoloration remaining on a thermally cut surface is not considered detrimental oxidation.

(2) End preparation for groove welds specified in ASME B16.25, or any other that meets the WPS, is acceptable. [For convenience, the basic bevel angles of ASME B16.25 and some additional J-bevel angles are shown in Figure 328.4.2, illustrations (a) and (b).]

(b) Circumferential Welds

(1) If component ends are trimmed as shown in Figure 328.3.2, illustration (a) or (b) to fit backing rings or consumable inserts, or as shown in Figure 328.4.3, illustration (a) or (b) to correct internal misalignment, such trimming shall not reduce the finished wall thickness below the required minimum wall thickness, t_m.

(2) Component ends may be bored to allow for a completely recessed backing ring, provided the remaining net thickness of the finished ends is not less than t_m.

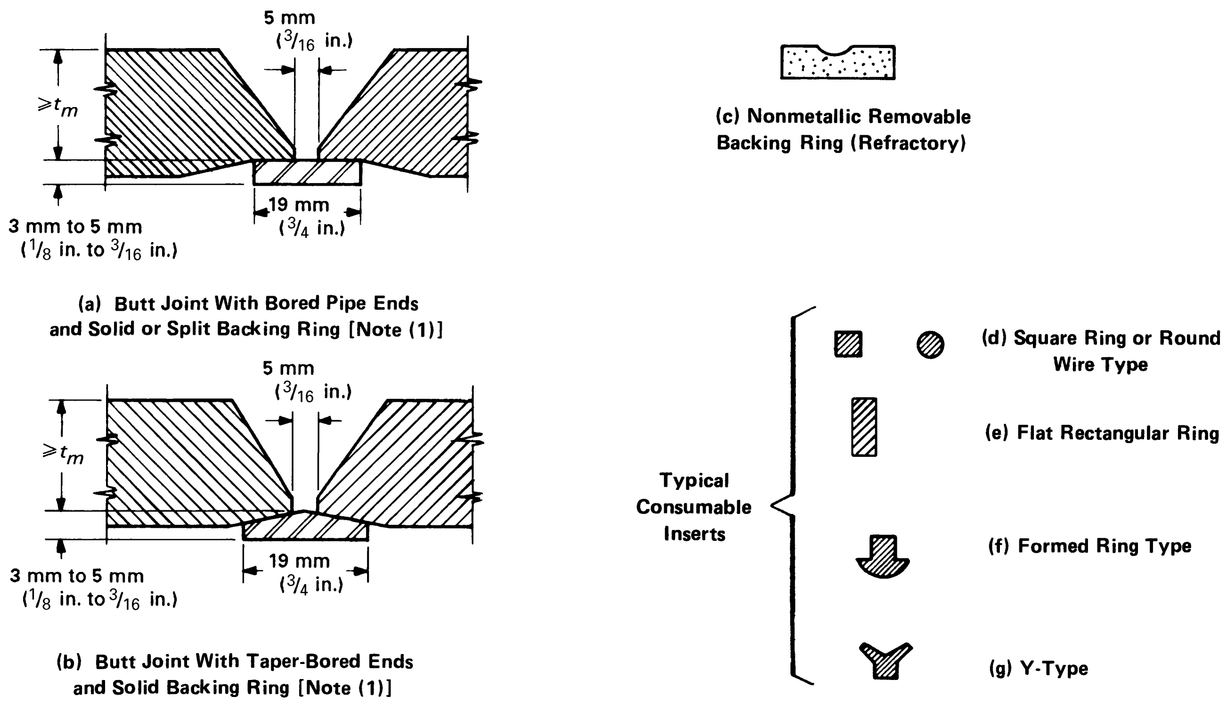
(3) It is permissible to size pipe ends of the same nominal size to improve alignment if wall thickness requirements are maintained.

(4) Where necessary, weld metal may be deposited inside or outside of the component to permit alignment or provide for machining to ensure satisfactory seating of rings or inserts.

(5) When a girth or miter groove weld joins components of unequal wall thickness and one is more than $1^1/_2$ times the thickness of the other, end preparation and geometry shall be in accordance with acceptable designs for unequal wall thickness in ASME B16.25.

(6) Butt-weld fittings manufactured in accordance with ASME B16.9 may be trimmed to produce an angular joint offset in their connections to pipe or to other butt-weld fittings without being subject to design qualifications in accordance with para. 304.7.2, provided the total angular offset produced between the two jointed parts does not exceed 3 deg.

Figure 328.3.2 Typical Backing Rings and Consumable Inserts



(a) Butt Joint With Bored Pipe Ends and Solid or Split Backing Ring [Note (1)]

(b) Butt Joint With Taper-Bored Ends and Solid Backing Ring [Note (1)]

(c) Nonmetallic Removable Backing Ring (Refractory)

(d) Square Ring or Round Wire Type

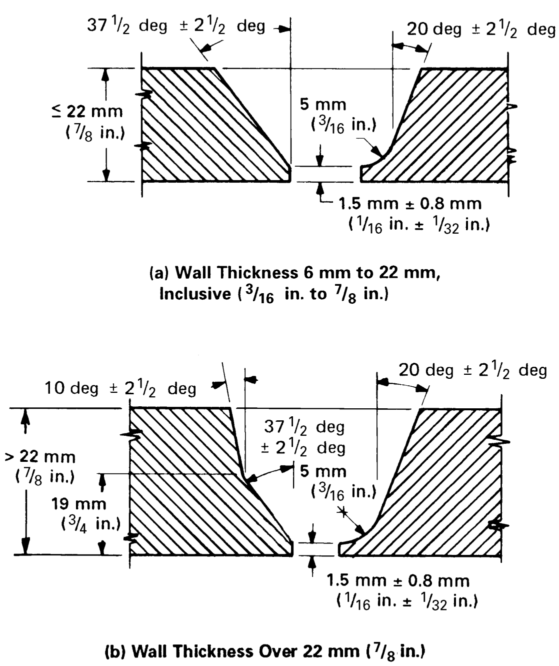
(e) Flat Rectangular Ring

(f) Formed Ring Type

(g) Y-Type

NOTE: (1) Refer to ASME B16.25 for detailed dimensional information on welding ends.

Figure 328.4.2 Typical Butt Weld End Preparation



(a) Wall Thickness 6 mm to 22 mm, Inclusive (3/16 in. to 7/8 in.)

(b) Wall Thickness Over 22 mm (7/8 in.)

328.4.3 Alignment

(a) Circumferential Welds

(1) Inside surfaces of components at ends to be joined in girth or miter groove welds shall be aligned within the dimensional limits in the WPS and the engineering design.

(2) If the external surfaces of the components are not aligned, the weld shall be tapered between them.

(b) Longitudinal Welds. Alignment of longitudinal groove welds (not made in accordance with a standard listed in Table A-1, Table A-1M, or Table 326.1) shall conform to the requirements of para. 328.4.3(a).

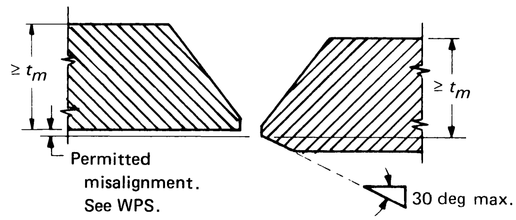
(c) Branch Connection Welds

(1) Branch connections that abut the outside surface of the run pipe shall be contoured for groove welds that meet the WPS requirements [see Figure 328.4.4, illustrations (a) and (b)].

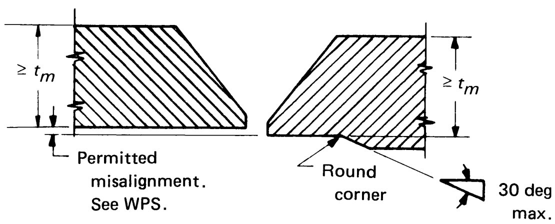
(2) Branch connections that are inserted through a run opening shall be inserted at least as far as the inside surface of the run pipe at all points [see Figure 328.4.4, illustration (c)] and shall otherwise conform to para. 328.4.3(c)(1).

(3) Run openings for branch connections shall not deviate from the required contour more than the dimension *m* in Figure 328.4.4. In no case shall deviations of the shape of the opening cause the root spacing tolerance

Figure 328.4.3 Trimming and Permitted Misalignment



(a) Thicker Pipe Taper-Bored to Align



(b) Thicker Pipe Bored for Alignment

limits in the WPS to be exceeded. Weld metal may be added and refinished if necessary for compliance.

(d) *Spacing.* The root opening of the joint shall be within the tolerance limits in the WPS.

328.5 Welding Requirements

328.5.1 General

(a) Welds, including addition of weld metal for alignment [paras. 328.4.2(b)(4) and 328.4.3(c)(3)], shall be made in accordance with a qualified procedure and by qualified welders or welding operators.

(b) Each qualified welder and welding operator shall be assigned an identification symbol. Unless otherwise specified in the engineering design, each pressure-containing weld or adjacent area shall be marked with the identification symbol of the welder or welding operator. In lieu of marking the weld, appropriate records shall be filed.

(c) Tack welds at the root of the joint shall be made with filler metal equivalent to that used in the root pass. Tack welds shall be made by a qualified welder or welding operator. Tack welds shall be fused with the root pass weld, except that those that have cracked shall be removed. Bridge tacks (above the weld) shall be removed.

(d) Peening is prohibited on the root pass and final pass of a weld.

(e) No welding shall be done if there is impingement on the weld area of rain, snow, sleet, or excessive wind, or if the weld area is frosted or wet.

(f) *Welding End Valves.* The welding sequence and procedure and any heat treatment for a welding end valve shall be such as to preserve the seat tightness of the valve.

328.5.2 Fillet and Socket Welds. (20)

(a) Fillet and socket welds may vary from convex to concave. The size of these welds shall be determined as shown in Figure 328.5.2A.

(b) Minimum attachment weld dimensions for double-welded slip-on flanges, socket welding flanges, and other socket welding components shall be as shown in Figures 328.5.2B and 328.5.2C.

(c) If slip-on flanges are single welded, the weld shall be at the hub, i.e., the X_{min} by X_{min} weld illustrated in Figure 328.5.2B.

328.5.3 Seal Welds. Seal welding shall be done by a qualified welder. Seal welds shall cover all exposed threads.

328.5.4 Welded Branch Connections (20)

(a) Figures 328.5.4A through 328.5.4F show acceptable details of branch connections with and without added reinforcement, in which the branch pipe is connected directly to the run pipe. The illustrations are typical and are not intended to exclude acceptable types of construction not shown.

(b) Figure 328.5.4D shows basic types of weld attachments used in the fabrication of branch connections. The location and minimum size of attachment welds shall conform to the requirements herein. Welds shall be calculated in accordance with para. 304.3.3 but shall be not less than the sizes shown in Figure 328.5.4D. Figure 328.5.4F shows the basic types of attachment welds used with integrally reinforced branch connection fittings. The location and the minimum size of the attachment welds shall conform to the requirements of (i) below.

(c) The nomenclature and symbols used herein, in Figure 328.5.4D, and in Figure 328.5.4F are

$\overline{T}_b$ = nominal thickness of branch

$\overline{T}_h$ = nominal thickness of header

$\overline{T}_m$ = nominal thickness of the branch weld for integrally reinforced branch connection fittings

(1) as specified by the manufacturer of the branch connection fitting

(2) the full depth of the resultant weld groove, after fit-up, if no manufacturer's weld thickness is specified

(3) as documented and specified in the engineering design in accordance with para. 300(c)(3), or

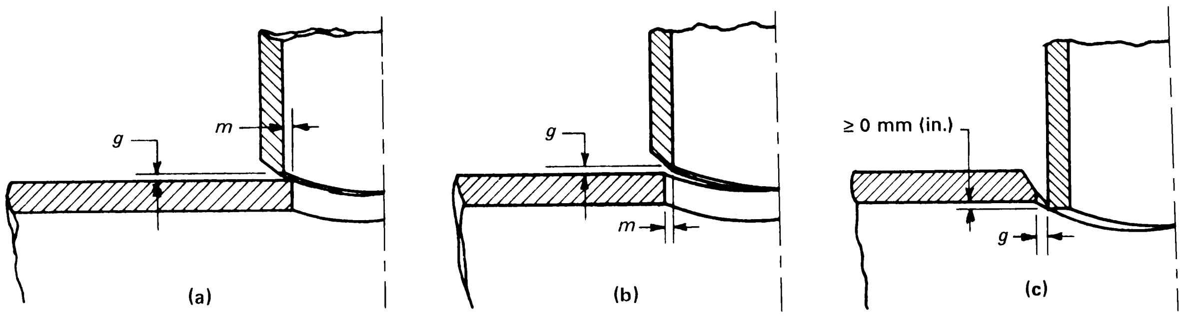
(4) calculated and documented in accordance with the requirements of para. 304.7.2

$\overline{T}_r$ = nominal thickness of reinforcing pad or saddle

t_c = lesser of 0.7 $\overline{T}_b$ or 6 mm (¼ in.)

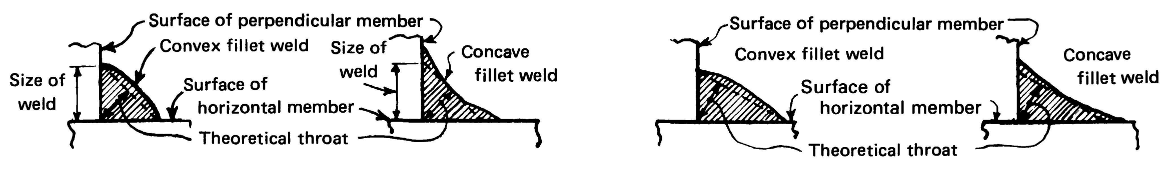
t_{min} = lesser of $\overline{T}_b$ or $\overline{T}_r$

Figure 328.4.4 Preparation for Branch Connections



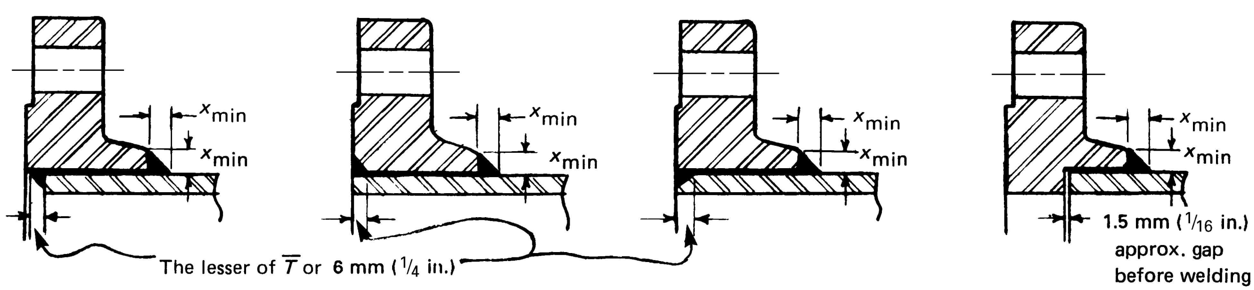
Legend:
g = root gap per welding specification
m = the lesser of 3.2 mm ($^1/_8$ in.) or 0.5 $\overline{T}_b$

Figure 328.5.2A Fillet and Socket Weld Sizes (20)



NOTES:
(1) The size of an equal leg fillet weld is the leg length of the largest inscribed isosceles right triangle (theoretical throat = 0.707 × size).
(2) The size of unequal leg fillet weld is the leg lengths of the largest right triangle that can be inscribed within the weld cross section [e.g., 13 mm × 19 mm ($^1/_2$ in. × $^3/_4$ in.)].

Figure 328.5.2B Minimum Attachment Weld Dimensions for Double-Welded Slip-On and Socket Welding Flanges (20)



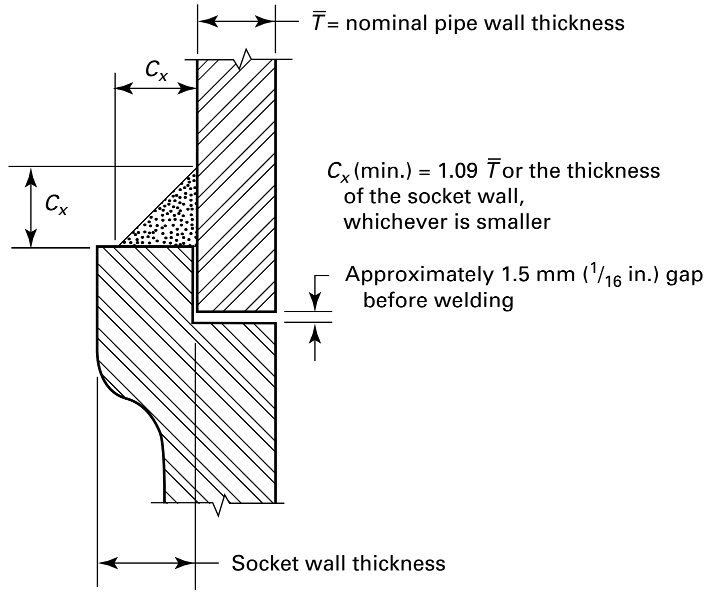
(a) Front and Back Welds

(b) Face and Back Welds

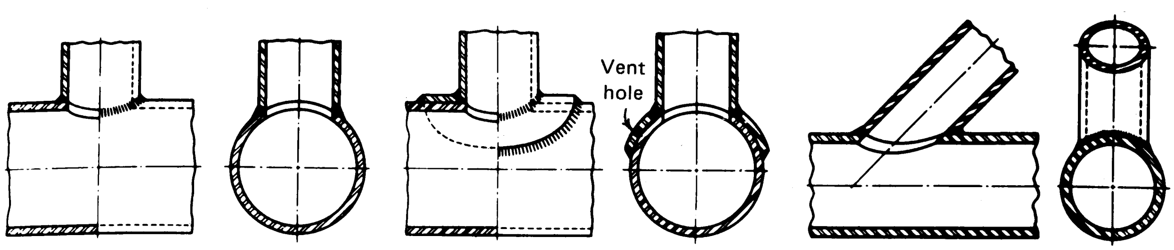
(c) Socket Welding Flange

Legend:
x_{min} = the lesser of 1.4 $\overline{T}$ or the thickness of the hub

(20) **Figure 328.5.2C Minimum Attachment Weld Dimensions for Socket Welding Components Other Than Flanges**



Figures 328.5.4A, B, C Typical Welded Branch Connections



(a) Without Added Reinforcement

(b) With Added Reinforcement

(c) Angular Branch Without Added Reinforcement

(d) Branch connections, including branch connection fittings (see paras. 300.2 and 304.3.2), that abut the outside of the run or that are inserted in an opening in the run shall be attached by fully penetrated groove welds. The welds shall be finished with cover fillet welds having a throat dimension not less than t_c. See Figure 328.5.4D, illustrations (a) and (b).

(e) A reinforcing pad or saddle shall be attached to the branch pipe by either

(1) a fully penetrated groove weld finished with a cover fillet weld having a throat dimension not less than t_c, or

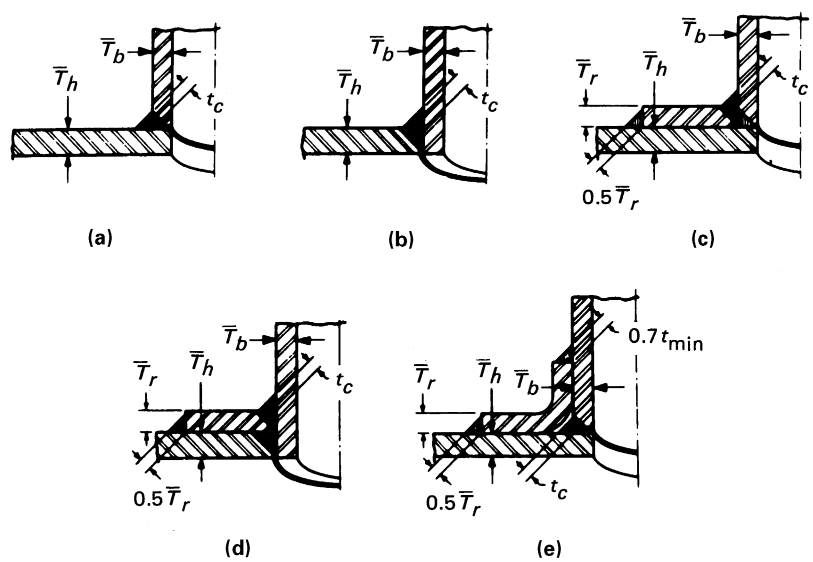
(2) a fillet weld having a throat dimension not less than $0.7t_{min}$. See Figure 328.5.4D, illustration (e).

(f) The outer edge of a reinforcing pad or saddle shall be attached to the run pipe by a fillet weld having a throat dimension not less than 0.5 $\overline{T}_r$. See Figure 328.5.4D, illustrations (c), (d), and (e).

(g) Reinforcing pads and saddles shall have a good fit with the parts to which they are attached. A vent hole shall be provided at the side (not at the crotch) of any pad or saddle to reveal leakage in the weld between branch and run and to allow venting during welding and heat treatment. A pad or saddle may be made in more than one piece if joints between pieces have strength equivalent to pad or saddle parent metal, and if each piece has a vent hole.

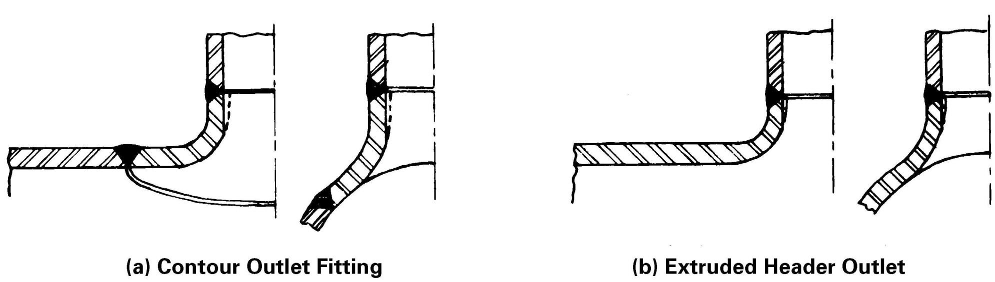
(h) Examination and any necessary repairs of the completed weld between branch and run shall be made before adding a pad or saddle.

Figure 328.5.4D Acceptable Details for Branch Attachment Welds



GENERAL NOTE: These illustrations show minimum acceptable welds. Welds may be larger than those shown here.

Figure 328.5.4E Acceptable Details for Branch Attachments Suitable for 100% Radiography



(i) Figure 328.5.4F shows additional integrally reinforced branch connections typical of MSS SP-97 fittings that abut the outside of the run attached by a full penetration groove weld. The welds shall be finished with cover fillets having a throat dimension not less than t_c. The cover fillet weld shall fill and smoothly transition to the attachment weld and run pipe or fitting.

328.5.5 Fabricated Laps. Figure 328.5.5 shows typical fabricated laps. Fabrication shall be in accordance with the applicable requirements of para. 328.5.4.

328.5.6 Welding for Severe Cyclic Conditions. A welding procedure shall be employed that provides a smooth, regular, fully penetrated inner surface.

328.6 Weld Repair (20)

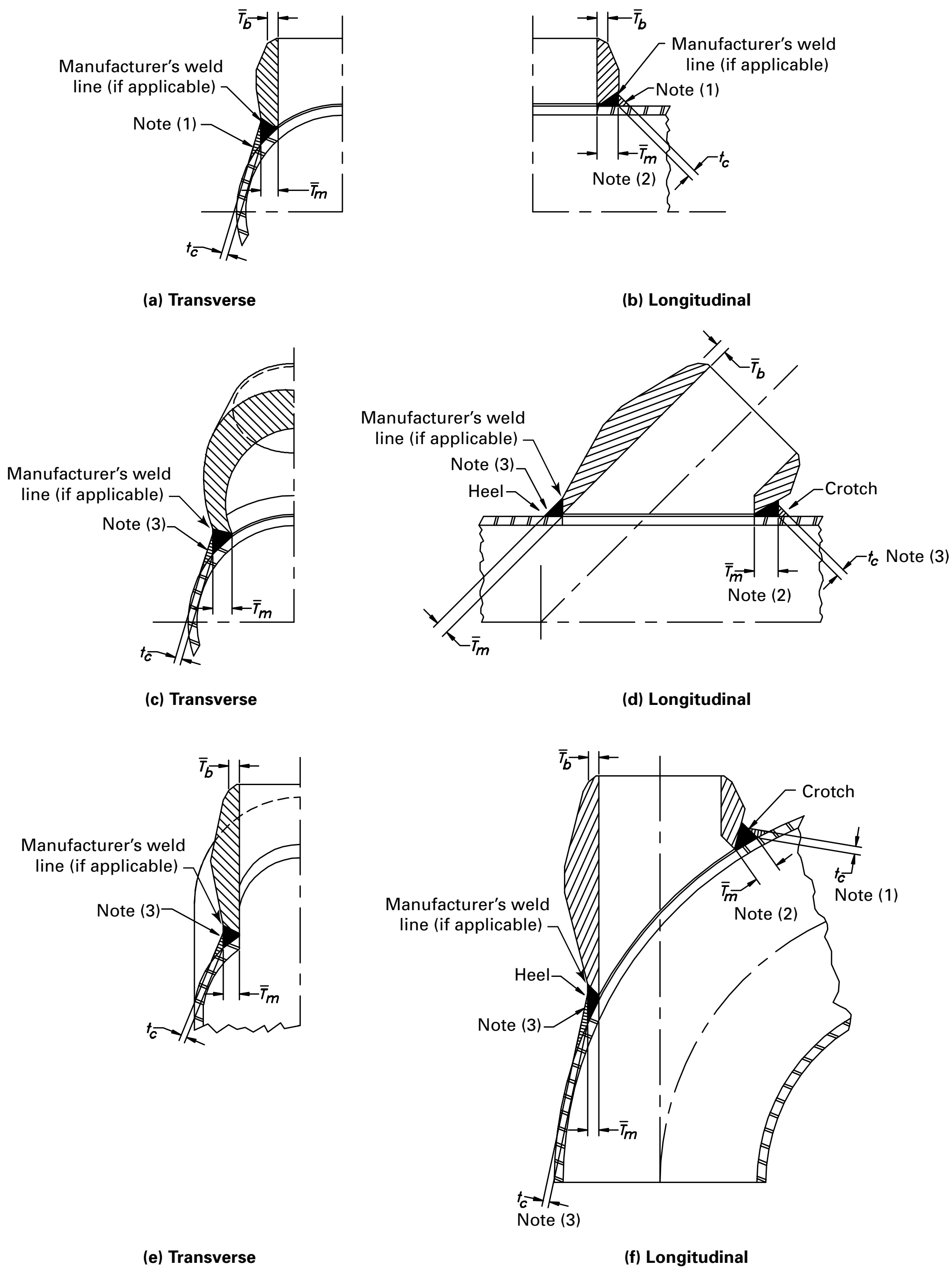
A weld defect to be repaired shall be removed to sound metal. Repair welds shall be made using a welding procedure qualified in accordance with para. 328.2, recognizing that the cavity to be repaired may differ in contour and dimensions from the original joint. Repair welds shall be made by welders or welding operators qualified in accordance with para. 328.2. Preheating and heat treatment shall be as required for the original welding. See also para. 341.3.3.

328.7 Attachment Welds

Structural attachments may be made by complete penetration, partial penetration, or fillet welds.

Low energy capacitor discharge welding may be used for welding temporary attachments (e.g., thermocouples) and permanent nonstructural attachments without

Figure 328.5.4F Acceptable Details for Integrally Reinforced Branch Connections



GENERAL NOTE: Welds shall be in accordance with para. 328.5.4(i).

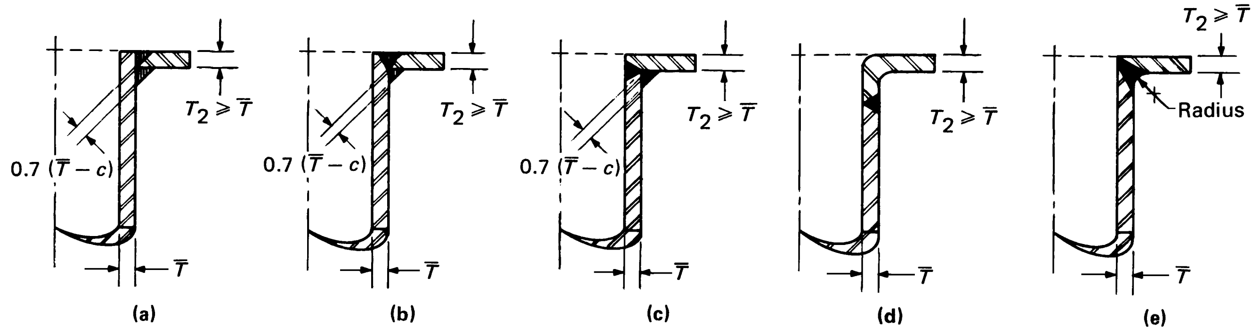
NOTES:

(1) Cover fillet weld shall provide a smooth transition to the run pipe with an equal leg fillet at the longitudinal section to an equal leg fillet, unequal (oblique) leg fillet, or groove butt joint at the transverse section (depending on branch connection size).

(2) Heat treatment requirements shall be in accordance with para. 331.1.3(a).

(3) Cover fillet weld shall provide a smooth transition to the run pipe with an equal leg fillet at the crotch in the longitudinal section to an equal leg fillet, unequal (oblique) leg fillet, or groove butt joint at the transverse section (depending on branch connection size) to nothing at the heel of the branch connection fitting in the longitudinal section.

Figure 328.5.5 Typical Fabricated Laps



GENERAL NOTE: Laps shall be machined (front and back) or trued after welding. Plate flanges in accordance with para. 304.5 or lap joint flanges in accordance with ASME B16.5 may be used. Welds may be machined to radius, as in illustration (e), if necessary to match ASME B16.5 lap joint flanges.

preheat above 10°C (50°F) or subsequent postweld heat treatment on P-No. 1 through P-No. 5B and P-No. 15E materials, provided

(a) a Welding Procedure Specification is prepared, describing the low energy capacitor discharge equipment, the combination of materials to be joined, and the technique of application; qualification of the welding procedure is not required

(b) the energy output of the welding process is limited to 125 W-sec

(c) for P-No. 5A, P-No. 5B, and P-No. 15E materials, the maximum carbon content of the material is 0.15%

(d) after thermocouples are removed, the areas shall be visually examined for evidence of defects to be repaired

330 PREHEATING

(20) ### 330.1 General

The preheat requirements herein apply to all types of welding, including tack welds, repair welds, and seal welds on threaded joints.

The preheating rules in ASME B31P may be used as an alternate.

330.1.1 Requirements. Unless specified otherwise in the engineering design, the minimum preheat temperatures for materials of various P-Numbers are given in Table 330.1.1. The thickness intended in Table 330.1.1 is that of the nominal thickness of the thicker component [as defined in para. 331.1.3(c)]. Higher minimum preheat temperatures may be required by the WPS or by the engineering design.

330.1.2 Unlisted Materials. Preheat requirements for an unlisted material shall be specified in the WPS.

330.1.3 Preheat Temperature Verification

(a) Preheat temperature shall be checked by use of temperature indicating crayons, thermocouple pyrometers, or other suitable means to ensure that the temperature specified in the WPS is obtained prior to and maintained during welding.

(b) Thermocouples may be temporarily attached directly to pressure-containing parts using the low energy capacitor discharge method of welding in accordance with para. 328.7.

330.1.4 Preheat Zone. The preheat zone shall be at or above the specified minimum temperature in all directions from the point of welding for a distance of the larger of 75 mm (3 in.) or 1.5 times the greater nominal thickness.

The base metal temperature for tack welds shall be at or above the specified minimum temperature for a distance not less than 25 mm (1 in.) in all directions from the point of welding.

330.2 Specific Requirements

330.2.1 Different P-No. Materials. When welding two different P-No. materials, the preheat temperature shall be the higher temperature for the material being welded as shown in Table 330.1.1.

330.2.2 Interruption of Welding. After welding commences, the minimum preheat temperature shall be maintained until any required PWHT is performed on P-Nos. 3, 4, 5A, 5B, 6, and 15E, except when all of the following conditions are satisfied:

(a) A minimum of at least 10 mm ($^3/_8$ in.) thickness of weld is deposited or 25% of the welding groove is filled, whichever is less (the weld shall be sufficiently supported to prevent overstressing the weld if the weldment is to be moved or otherwise loaded). Caution is advised that the

Table 330.1.1 Preheat Temperatures

Base Metal P-No. [Note (1)]	Base Metal Group	Greater Material Thickness		Additional Limits [Note (2)]	Required Minimum Temperature	
		mm	in.		°C	°F
1	Carbon steel	≤25	≤1	None	10	50
		>25	>1	%C ≤ 0.30 [Note (3)]	10	50
		>25	>1	%C > 0.30 [Note (3)]	95	200
3	Alloy steel, Cr ≤ ½%	≤13	≤½	SMTS ≤ 450 MPa (65 ksi)	10	50
		>13	>½	SMTS ≤ 450 MPa (65 ksi)	95	200
		All	All	SMTS > 450 MPa (65 ksi)	95	200
4	Alloy steel, ½% < Cr ≤ 2%	All	All	None	120	250
5A	Alloy steel	All	All	SMTS ≤ 414 MPa (60 ksi)	150	300
		All	All	SMTS > 414 MPa (60 ksi)	200	400
5B	Alloy steel	All	All	SMTS ≤ 414 MPa (60 ksi)	150	300
		All	All	SMTS > 414 MPa (60 ksi)	200	400
		>13	>½	%Cr > 6.0 [Note (3)]	200	400
6	Martensitic stainless steel	All	All	None	200 [Note (4)]	400 [Note (4)]
9A	Nickel alloy steel	All	All	None	120	250
9B	Nickel alloy steel	All	All	None	150	300
10I	27Cr steel	All	All	None	150 [Note (5)]	300 [Note (5)]
15E	9Cr–1Mo–V CSEF steel	All	All	None	200	400
...	All other materials	...	...	None	10	50

NOTES:
(1) P-Nos. and Group Nos. from ASME BPVC, Section IX, QW/QB-422.
(2) SMTS = Specified Minimum Tensile Strength.
(3) Composition may be based on ladle or product analysis or in accordance with specification limits.
(4) Maximum interpass temperature 315°C (600°F).
(5) Maintain interpass temperature between 150°C and 230°C (300°F and 450°F).

surface condition prior to cooling should be smooth and free of sharp discontinuities.

(b) For P-Nos. 3, 4, and 5A materials, the weld is allowed to cool slowly to room temperature.

(c) For P-Nos. 5B, 6, and 15E materials, the weld is subjected to an adequate intermediate heat treatment with a controlled rate of cooling. The preheat temperature may be reduced to 95°C (200°F) (minimum) for the purpose of root examination without performing an intermediate heat treatment. Intermediate heat treatment for P-No. 5B or P-No. 15E materials may be omitted when using low-hydrogen electrodes and filler metals classified by the filler metal specification with an optional supplemental diffusible-hydrogen designator of H4 or lower and suitably controlled by maintenance procedures to avoid contamination by hydrogen-producing sources. The surface of the base metal prepared for welding shall be free of contaminants.

(d) After cooling and before welding is resumed, visual examination of the weld shall be performed to assure that no cracks have formed.

(e) Required preheat shall be applied before welding is resumed.

331 HEAT TREATMENT

331.1 General

(20) **331.1.1 Postweld Heat Treatment Requirements**

(a) PWHT shall be in accordance with the material groupings (P-Nos. and Group Nos.) and ranges in Table 331.1.1 except as provided in Table 331.1.2 and Table 331.1.3. The PWHT rules in ASME B31P may be used as an alternate. See Appendix F, para. F331.1. The P-Numbers and Group Numbers are defined in ASME BPVC, Section IX, Table QW/QB-422. (Note that the P-Nos. are also listed in Appendix A.)

(b) The PWHT to be used after production welding shall be specified in the WPS and shall be used in qualifying the welding procedure.

(c) The engineering design shall specify the examination and/or other production quality control (not less than the requirements of this Code) to ensure that the final welds are of adequate quality.

331.1.2 Other Heat Treatments

(a) Heat treatment for bending and forming shall be in accordance with para. 332.4.

(b) See Table 302.3.5 for special heat treatment requirements for longitudinal or spiral (helical seam) welds in Elevated Temperature Fluid Service.

(20) **331.1.3 Definition of Thicknesses Governing PWHT**

(a) The term *control thickness* as used in Table 331.1.1 and Table 331.1.3 is the lesser of

(1) the thickness of the weld

(2) the thickness of the materials being joined at the weld or the thickness of the pressure-containing material if the weld is attaching a nonpressure-containing material to a pressure-containing material.

(b) Thickness of the weld, which is a factor in determining the control thickness, is defined as follows:

(1) groove welds (girth and longitudinal) — the thicker of the two abutting ends after weld preparation, including I.D. machining

(2) fillet welds — the throat thickness of the weld

(3) partial penetration welds — the depth of the weld groove

(4) material repair welds — the depth of the cavity to be repaired

(5) branch welds — the dimension existing in the plane intersecting the longitudinal axes, calculated as indicated for each detail using the thickness through the weld for the details shown in Figure 328.5.4D and Figure 328.5.4F. This thickness shall be computed using the following formulas:

(-a) for Figure 328.5.4D use

$$\text{illustration (a)} = \overline{T}_b + t_c$$

$$\text{illustration (b)} = \overline{T}_h + t_c$$

$$\text{illustration (c)} = \text{greater of } \overline{T}_b + t_c \text{ or } \overline{T}_r + t_c$$

$$\text{illustration (d)} = \overline{T}_h + \overline{T}_r + t_c$$

$$\text{illustration (e)} = \overline{T}_b + t_c$$

(-b) for Figure 328.5.4F use $\overline{T}_m + t_c$ for all illustrations

(c) The term *nominal material thickness* as used in Table 331.1.3 is the thicker of the materials being joined at the weld.

331.1.4 Heating and Cooling. The heating method shall provide the required metal temperature, metal temperature uniformity, and temperature control, and may include an enclosed furnace, local flame heating, electric resistance, electric induction, or exothermic chemical reaction. Above 315°C (600°F), the rate of heating and cooling shall not exceed 335°C/h (600°F/hr) divided by one-half the maximum material thickness in inches at the weld, but in no case shall the rate exceed 335°C/h (600°F/hr). See Table 331.1.1 for cooling rate requirements for P-Nos. 7, 10I, 11A, and 62 materials.

331.1.6 Temperature Verification. Heat treatment (20) temperature shall be checked by thermocouple pyrometers or other suitable methods to ensure that the WPS requirements are met. See para. 328.7 for attachment of thermocouples by the low energy capacitor discharge method of welding.

(a) If used, the heat treatment furnace shall be calibrated such that the PWHT can be controlled within the required temperature range.

(b) Any required PWHT shall be as required by the qualified WPS.

(c) For welds that require PWHT in accordance with Table 331.1.1, the temperature of the material during PWHT shall be within the range specified. However, if specified by the designer, the range may be extended as permitted by Table 331.1.2, provided the lower transformation temperature of the material is not exceeded.

331.2 Specific Requirements

Where warranted by experience or knowledge of service conditions, alternative methods of heat treatment or exceptions to the basic heat treatment provisions of para. 331.1 may be adopted as provided in paras. 331.2.1 and 331.2.2.

(20) **Table 331.1.1 Postweld Heat Treatment**

P-No. and Group No. (ASME BPVC, Section IX, QW/QB-420)	Holding Temperature Range, °C (°F) [Note (1)]	Minimum Holding Time at Temperature for Control Thickness [Note (2)]	
		Up to 50 mm (2 in.)	Over 50 mm (2 in.)
P-No. 1, Group Nos. 1–3	595 to 650 (1,100 to 1,200)	1 h/25 mm (1 hr/in.); 15 min min.	2 hr plus 15 min for each additional 25 mm (in.) over 50 mm (2 in.)
P-No. 3, Group Nos. 1 and 2	595 to 650 (1,100 to 1,200)		
P-No. 4, Group Nos. 1 and 2	650 to 705 (1,200 to 1,300)		
P-No. 5A, Group No. 1	675 to 760 (1,250 to 1,400)		
P-No. 5B, Group No. 1	675 to 760 (1,250 to 1,400)		
P-No. 6, Group Nos. 1–3	760 to 800 (1,400 to 1,475)		
P-No. 7, Group Nos. 1 and 2 [Note (3)]	730 to 775 (1,350 to 1,425)		
P-No. 8, Group Nos. 1–4	PWHT not required unless required by WPS		
P-No. 9A, Group No. 1	595 to 650 (1,100 to 1,200)		
P-No. 9B, Group No. 1	595 to 650 (1,100 to 1,200)		
P-No. 10H, Group No. 1	PWHT not required unless required by WPS. If done, see Note (4).		
P-No. 10I, Group No. 1 [Note (3)]	730 to 815 (1,350 to 1,500)		
P-No. 11A	550 to 585 (1,025 to 1,085) [Note (5)]		
P-No. 15E, Group No. 1	705 to 775 (1,300 to 1,425) [Notes (6) and (7)]	1 h/25 mm (1 hr/in.); 30 min min.	1 h/25 mm (1 hr/in.) up to 125 mm (5 in.) plus 15 min for each additional 25 mm (in.) over 125 mm (5 in.)
P-No. 62	540 to 595 (1,000 to 1,100)	...	See Note (8)
All other materials	PWHT as required by WPS	In accordance with WPS	In accordance with WPS

GENERAL NOTE: The exemptions for mandatory PWHT are defined in Table 331.1.3.

NOTES:

(1) The holding temperature range is further defined in para. 331.1.6(c) and Table 331.1.2.

(2) The control thickness is defined in para. 331.1.3.

(3) Cooling rate shall not be greater than 55°C (100°F) per hour in the range above 650°C (1,200°F), after which the cooling rate shall be sufficiently rapid to prevent embrittlement.

(4) If PWHT is performed after welding, it shall be within the following temperature ranges for the specific alloy, followed by rapid cooling:
Alloys S31803 and S32205 — 1 020°C to 1 100°C (1,870°F to 2,010°F)
Alloy S32550 — 1 040°C to 1 120°C (1,900°F to 2,050°F)
Alloy S32750 — 1 025°C to 1 125°C (1,880°F to 2,060°F)
All others — 980°C to 1 040°C (1,800°F to 1,900°F)

(5) Cooling rate shall be >165°C (300°F)/h to 315°C (600°F)/h.

(6) The minimum PWHT holding temperature may be 675°C (1,250°F) for nominal material thicknesses [see para. 331.1.3(c)] ≤13 mm ($\frac{1}{2}$ in.).

(7) The Ni + Mn content of the filler metal shall not exceed 1.2% unless specified by the designer, in which case the maximum temperature to be reached during PWHT shall be the lower transformation temperature of the filler metal, as determined by analysis and calculation or by test, but not exceeding 800°C (1,470°F). If the 800°C (1,470°F) limit was not exceeded but the lower transformation temperature of the filler metal was exceeded or if the composition of the filler metal is unknown, the weld must be removed and replaced. It shall then be rewelded with compliant filler metal and subjected to a compliant PWHT. If the 800°C (1,470°F) limit was exceeded, the weld and the entire area affected by the PWHT will be removed and, if reused, shall be renormalized and tempered prior to reinstallation. The lower transformation temperature is the steady-state temperature at which the austenite phase transformation occurs.

(8) Heat treat within 14 days after welding. Hold time shall be increased by 1.2 h for each 25 mm (1 in.) over 25 mm (1 in.) thickness. Cool to 425°C (800°F) at a rate ≤280°C (500°F)/h.

Table 331.1.2 Alternate Postweld Heat Treatment Requirements for Carbon and Low Alloy Steels, P-Nos. 1 and 3

Decrease in Specified Minimum Temperature, °C (°F)	Minimum Holding Time at Decreased Temperature, h [Note (1)]
30 (50)	2
55 (100)	4
85 (150) [Note (2)]	10
110 (200) [Note (2)]	20

NOTES:
(1) Times shown apply to thicknesses ≤25 mm (1 in.). Add 15 min/25 mm (15 min/in.) of thickness for control thicknesses >25 mm (1 in.) (see para. 331.1.3).
(2) A decrease >55°C (100°F) below the minimum specified temperature is allowable only for P-No. 1, Group Nos. 1 and 2 materials.

331.2.1 Alternative Heat Treatment. Normalizing, or normalizing and tempering, or annealing may be applied in lieu of the required heat treatment after welding, bending, or forming, provided that the mechanical properties of any affected weld and base metal meet specification requirements after such treatment and that the substitution is approved by the designer.

331.2.2 Exceptions to Basic Requirements. As indicated in para. 331, the basic practices therein may require modification to suit service conditions in some cases. In such cases, the designer may specify more-stringent requirements in the engineering design, including heat treatment and hardness limitations for lesser thickness, or may specify less stringent heat treatment and hardness requirements, including none.

When provisions less stringent than those in para. 331 are specified, the designer must demonstrate to the owner's satisfaction the adequacy of those provisions by comparable service experience, considering service temperature and its effects, frequency and intensity of thermal cycling, flexibility stress levels, probability of brittle failure, and other pertinent factors. In addition, appropriate tests shall be conducted, including WPS qualification tests.

331.2.3 Dissimilar Materials

(a) Heat treatment of welded joints between dissimilar ferritic metals or between ferritic metals using dissimilar ferritic filler metal shall be at the higher of the temperature ranges in Table 331.1.1 for the materials in the joint. This may require the use of material transition joint designs.

(b) Heat treatment of welded joints including both ferritic and austenitic components and filler metals shall be as required for the ferritic material or materials unless otherwise specified in the engineering design.

331.2.4 Delayed Heat Treatment. If a weldment is allowed to cool prior to heat treatment, the rate of cooling shall be controlled or other means shall be used to prevent detrimental effects in the piping.

331.2.5 Partial Heat Treatment. When an entire piping assembly to be heat treated cannot be fitted into the furnace, it is permissible to heat treat in more than one heat, provided there is at least 300 mm (1 ft) overlap between successive heats, and that parts of the assembly outside the furnace are protected from harmful temperature gradients. This method may not be used for austenitizing heat treatments for ferritic materials.

331.2.6 Local Heat Treatment. Welds may be locally (20)
postweld heat treated by heating a circumferential band around the entire component with the weld located in the center of the band. The width of the band heated to the specified temperature range shall be at least three times the wall thickness at the weld of the thickest part being joined. For nozzle and attachment welds, the width of the band heated to the specified temperature range shall extend beyond the nozzle weld or attachment weld on each side at least two times the run pipe thickness, and shall extend completely around the run pipe. Guidance for the placement of thermocouples on circumferential butt welds is provided in AWS D10.10, Sections 5, 6, and 8. Special consideration shall be given to the placement of thermocouples when heating welds adjacent to large heat sinks such as valves or fittings, or when joining parts of different thicknesses. No part of the materials subjected to the heat source shall exceed the lower transformation temperature of the material except as permitted by para. 331.2.1. Particular care must be exercised when the applicable PWHT temperature is close to the material's lower transformation temperature, such as for P-No. 15E materials or when materials of different P-Nos. are being joined. This method may not be used for austenitizing heat treatments.

332 BENDING AND FORMING

332.1 General

Pipe may be bent and components may be formed by any hot or cold method that is suitable for the material, the fluid service, and the severity of the bending or forming process.[1] The finished surface shall be free of cracks and substantially free from buckling. Thickness after bending or forming shall be not less than that required by the design.

[1] For pipe bending, PFI Standard ES-24, Pipe Bending Methods, Tolerances, Process and Material Requirements, may be used as a guide.

Table 331.1.3 Exemptions to Mandatory Postweld Heat Treatment

P-No. and Group No. (ASME BPVC, Section IX, QW/QB-420) [Note (1)]	Control Thickness, mm (in.) [Note (2)]	Type of Weld	Additional Limitations Required for Exemption From PWHT [Notes (3)–(5)]
P-No. 1, all Group Nos.	All	All	A preheat of 95°C (200°F) is applied prior to welding on any nominal material thickness >25 mm (1 in.) Multiple layer welds are used when the nominal material thickness >5 mm ($^3/_{16}$ in.) [Note (6)]
P-No. 3, Group Nos. 1 and 2	≤16 mm ($^5/_8$ in.)	All	A preheat of 95°C (200°F) is applied prior to welding on any nominal material thickness >13 mm ($^1/_2$ in.) A specified carbon content of the base materials ≤0.25% Multiple layer welds are used when the nominal material thickness >5 mm ($^3/_{16}$ in.) [Note (6)]
P-No. 4, Group No. 1	≤16 mm ($^5/_8$ in.)	Groove	Mandatory preheat has been applied Specified carbon content of the base materials ≤0.15% Multiple layer welds are used when the nominal material thickness >5 mm ($^3/_{16}$ in.) [Note (6)]
	≤16 mm ($^5/_8$ in.) except the thickness of a socket weld fitting or flange need not be considered	Socket and fillet welds	Mandatory preheat has been applied Throat thickness of the fillet weld or the socket weld ≤13 mm ($^1/_2$ in.) Specified carbon content of the pipe material ≤0.15% Nominal material thickness of the pipe ≤16 mm ($^5/_8$ in.) Multiple layer welds are used when the nominal material thickness >5 mm ($^3/_{16}$ in.) [Note (6)]
	≤16 mm ($^5/_8$ in.)	Seal welds and non-load-carrying attachments [Note (7)]	Mandatory preheat has been applied Multiple layer welds are used when the nominal material thickness >5 mm ($^3/_{16}$ in.) [Note (6)]
P-No. 5A, Group No. 1	≤16 mm ($^5/_8$ in.)	Groove	Mandatory preheat has been applied Specified carbon content of the base materials ≤0.15% Multiple layer welds are used when the nominal material thickness >5 mm ($^3/_{16}$ in.) [Note (6)]
	≤16 mm ($^5/_8$ in.) except the thickness of a socket weld fitting or flange need not be considered	Socket and fillet welds	Mandatory preheat has been applied Throat thickness of the fillet weld or the socket weld ≤13 mm ($^1/_2$ in.) Specified carbon content of the pipe material ≤0.15% Nominal thickness of the pipe ≤5 mm ($^3/_{16}$ in.) Multiple layer welds are used when the nominal material thickness >5 mm ($^3/_{16}$ in.) [Note (6)]
	≤16 mm ($^5/_8$ in.)	Seal welds and non-load-carrying attachments [Note (7)]	Mandatory preheat has been applied Multiple layer welds are used when the nominal material thickness >5 mm ($^3/_{16}$ in.) [Note (6)]
P-No. 5B, Group No. 1	...	...	No exemptions from PWHT
P-No. 6, Group Nos. 1–3	All	All	Specified carbon content of the base materials ≤0.08% Nominal material thickness ≤10 mm ($^3/_8$ in.) Weld filler metal is A-No. 8, A-No. 9, or F-No. 43 composition [Note (8)]

Table 331.1.3 Exemptions to Mandatory Postweld Heat Treatment (Cont'd)

P-No. and Group No. (ASME BPVC, Section IX, QW/QB-420) [Note (1)]	Control Thickness, mm (in.) [Note (2)]	Type of Weld	Additional Limitations Required for Exemption From PWHT [Notes (3)–(5)]
P-No. 7, Group No. 1	All	All	Specified carbon content of the base materials ≤0.08% Nominal material thickness ≤10 mm ($^3/_8$ in.) Weld filler metal is A-No. 8, A-No. 9, or F-No. 43 composition [Note (8)]
P-No. 7, Group No. 2	...	...	No exemptions from PWHT
P-No. 8, all Group Nos.	All	All	PWHT neither required nor prohibited
P-No. 9A, Group No. 1	All	All	Specified carbon content of the pipe material ≤0.15% Nominal material thickness ≤13 mm ($^1/_2$ in.) Mandatory preheat has been applied
P-No. 9B, Group No. 1	All	All	Nominal material thickness ≤16 mm ($^5/_8$ in.) and the WPS has been qualified using a material of equal or greater thickness than used in the production weld
P-No. 10H, Group No. 1	All	All	PWHT neither required nor prohibited
P-No. 10I, Group No. 1	All	All	PWHT neither required nor prohibited for nominal material thickness ≤13 mm ($^1/_2$ in.)
P-No. 11A	≤50 mm (2 in.)	All	...
P-No. 15E	...	...	No exemptions from PWHT
P-No. 62	...	...	No exemptions from PWHT

NOTES:
(1) If differences with the P-No. listed in Appendix A are found, the P-No. listed in ASME BPVC, Section IX, Table QW/QB-422 applies.
(2) The control thickness is defined in para. 331.1.3.
(3) The nominal material thickness is defined in para. 331.1.3(c).
(4) No exemptions are permitted for PWHTs required by the designer or the WPS.
(5) Additional exemptions for welds made in accordance with para. 328.7 may be taken for the materials addressed.
(6) Single-layer or single-pass welds may be exempted from PWHT, provided the WPS has been qualified using single-pass welds with ±10% heat input and that all other conditions for exemption are met.
(7) Non-load-carrying attachments are defined as items where no pressure loads or significant mechanical loads are transmitted through the attachment to the pipe or pressure-containing material.
(8) The A-Nos. and the F-Nos. are found in ASME BPVC, Section IX, Tables QW-442 and QW-432, respectively.

332.2 Bending

332.2.1 Bend Flattening. Flattening of a bend, the difference between maximum and minimum diameters at any cross section, shall not exceed 8% of nominal outside diameter for internal pressure and 3% for external pressure. Removal of metal shall not be used to achieve these requirements.

332.2.2 Bending Temperature

(a) Cold bending of ferritic materials shall be done at a temperature below the transformation range.

(b) Hot bending shall be done at a temperature above the transformation range and in any case within a temperature range consistent with the material and the intended service.

332.2.3 Corrugated and Other Bends. Dimensions and configuration shall conform to the design qualified in accordance with para. 306.2.2.

332.3 Forming

The temperature range for forming shall be consistent with material, intended service, and specified heat treatment.

(20) ### 332.4 Required Heat Treatment

Heat treatment shall be performed in accordance with para. 331.1.1 when required by para. 332.4.1 or 332.4.2. The process and temperature control methods described in ASME B31P are recommended.

332.4.1 Hot Bending and Forming. After hot bending and forming, heat treatment is required for P-Nos. 3, 4, 5, 6, and 10A materials in all thicknesses. Durations and temperatures shall be in accordance with para. 331.

332.4.2 Cold Bending and Forming. After cold bending and forming, heat treatment is required (for all thicknesses, and with temperature and duration as given in Table 331.1.1) when any of the following conditions exist:

(a) for P-Nos. 1 through 6 materials, where the maximum calculated fiber elongation after bending or forming exceeds 50% of specified basic minimum elongation (in the direction of severest forming) for the applicable specification, grade, and thickness. This requirement may be waived if it can be demonstrated that the selection of pipe and the choice of bending or forming process provide assurance that, in the finished condition, the most severely strained material retains at least 10% elongation.

(b) for any material requiring impact testing, where the maximum calculated fiber elongation after bending or forming will exceed 5%.

(c) when specified in the engineering design.

333 BRAZING AND SOLDERING

333.1 Qualification

333.1.1 Brazing Qualification. The qualification of brazing procedures, brazers, and brazing operators shall be in accordance with para. 328.2. For Category D Fluid Service at design temperature not over 93°C (200°F), such qualification is not required unless specified in the engineering design.

333.1.2 Soldering Qualification. The qualification of solderers shall be in accordance with the requirements of ASTM B828, Standard Practice for Making Capillary Joints by Soldering of Copper and Copper Alloy Tube and Fittings.

333.2 Brazing and Soldering Materials

333.2.1 Brazing Filler Metal and Flux. Brazing filler metal and flux shall comply with AWS A5.8, Specification for Filler Metals for Brazing and Braze Welding, and AWS A5.31, Specification for Fluxes for Brazing and Braze Welding, respectively, or other filler metals and fluxes that have been qualified in accordance with ASME BPVC, Section IX.

333.2.2 Soldering Filler Metal and Flux. Soldering filler metal and flux shall comply with ASTM B32, Standard Specification for Solder Metal, and ASTM B813, Standard Specification for Liquid and Paste Fluxes for Soldering of Copper and Copper Alloy Tube, respectively.

333.3 Preparation and Cleaning

333.3.1 Surface Preparation. The surfaces to be brazed or soldered shall be clean and free from grease, oxides, paint, scale, and dirt of any kind. A suitable chemical or mechanical cleaning method shall be used if necessary to provide a clean wettable surface.

333.3.2 Joint Clearance. The clearance between surfaces to be joined by soldering or brazing shall be no larger than necessary to allow complete capillary distribution of the filler metal.

333.3.3 Flux Removal. Residual flux shall be removed.

335 ASSEMBLY AND ERECTION

335.1 Alignment

(a) Piping Distortions. Any distortion of piping to bring it into alignment for joint assembly that introduces a detrimental strain in equipment or piping components is prohibited.

(b) Cold Spring. Before assembling any joints to be cold sprung, guides, supports, and anchors shall be examined for errors that might interfere with desired movement or lead to undesired movement. The gap or overlap of piping

prior to assembly shall be checked against the drawing and corrected if necessary. Heating shall not be used to help in closing the gap because it defeats the purpose of cold springing.

(c) Flanged Joints. Unless otherwise specified in the engineering design, flanged joints shall be aligned as described in (1) or (2), and (3).

(1) Before bolting, mating gasket contact surfaces shall be aligned to each other within 1 mm in 200 mm ($^1/_{16}$ in./ft), measured across any diameter.

(2) The flanged joint shall be capable of being bolted such that the gasket contact surfaces bear uniformly on the gasket.

(3) Flange bolt holes shall be aligned within 3 mm ($^1/_8$ in.) maximum offset.

335.2 Flanged Joints

335.2.1 Preparation for Assembly. Any damage to the gasket seating surface that would prevent gasket seating shall be repaired, or the flange shall be replaced.

335.2.2 Bolting Torque

(a) In assembling flanged joints, the gasket shall be uniformly compressed to the proper design loading.

(b) Special care shall be used in assembling flanged joints in which the flanges have widely differing mechanical properties. Tightening to a predetermined torque is recommended.

335.2.3 Bolt Length. Bolts shall extend through their nuts such that there is complete thread engagement for the full depth of the nut.

335.2.4 Gaskets. No more than one gasket shall be used between contact faces in assembling a flanged joint.

335.2.5 Flanged Joint Assembly. Assembly requirements for bolted flanged joints and flanged joint assembler qualifications shall be considered in the engineering design. For guidance, see ASME PCC-1, Guidelines for Pressure Boundary Bolted Flange Joint Assembly, and ASME BPVC, Section VIII, Division 1, Nonmandatory Appendix S.

335.3 Threaded Joints

335.3.1 Thread Compound or Lubricant. Any compound or lubricant used on threads shall be suitable for the service temperatures and shall not react unfavorably with either the service fluid or the piping material.

335.3.2 Joints for Seal Welding. A threaded joint to be seal welded shall be made up without thread compound. A joint containing thread compound that leaks during leak testing may be seal welded in accordance with para. 328.5.3, provided all compound is removed from exposed threads.

335.3.3 Straight Threaded Joints. Typical joints using straight threads, with sealing at a surface other than the threads, are shown in Figure 335.3.3, illustrations (a), (b), and (c). Care shall be taken to avoid distorting the seat when incorporating such joints into piping assemblies by welding, brazing, or bonding.

335.4 Tubing Joints

335.4.1 Flared Tubing Joints. The sealing surface of the flare shall be examined for imperfections before assembly and any flare having imperfections shall be rejected.

335.4.2 Flareless and Compression Tubing Joints. Where the manufacturer's instructions call for a specified number of turns of the nut, these shall be counted from the point at which the nut becomes finger tight.

335.5 Caulked Joints

Caulked joints shall be installed and assembled in accordance with the manufacturer's instructions, as modified by the engineering design. Care shall be taken to ensure adequate engagement of joint members.

335.6 Expanded Joints and Special Joints

335.6.1 General. Expanded joints and special joints (as defined in para. 318) shall be installed and assembled in accordance with the manufacturer's instructions, as modified by the engineering design. Care shall be taken to ensure adequate engagement of joint members.

335.6.2 Packed Joints. Where a packed joint is used to absorb thermal expansion, proper clearance shall be provided at the bottom of the socket to permit this movement.

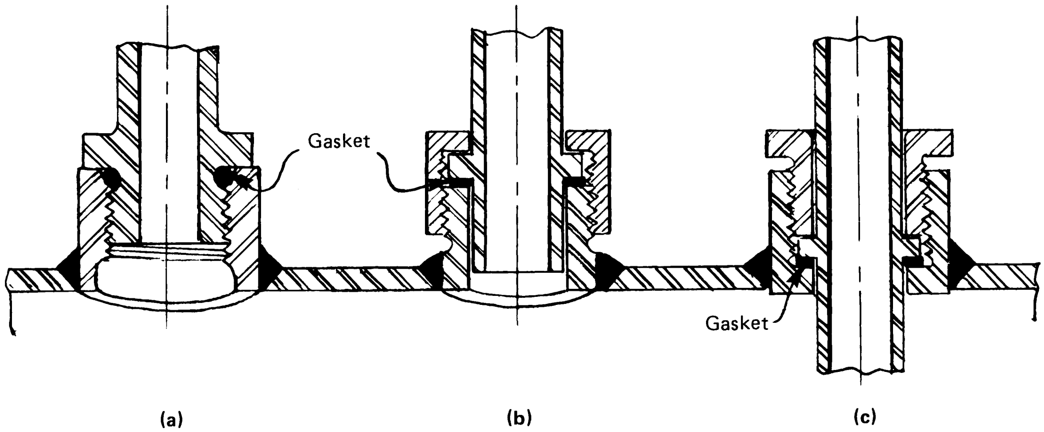
335.9 Cleaning of Piping

This Code does not prescribe mandatory procedures for flushing and cleaning. However, for potential hazards that may result from performing such procedures refer to Appendix F, para. F335.9 for precautionary considerations.

335.10 Identification of Piping

See Appendix F, para. F335.10.

Figure 335.3.3 Typical Threaded Joints Using Straight Threads



GENERAL NOTE: Threads are ASME B1.1 straight threads.

Chapter VI
Inspection, Examination, and Testing

340 INSPECTION

340.1 General

This Code distinguishes between examination (see para. 341) and inspection. Inspection applies to functions performed for the owner by the owner's Inspector or the Inspector's delegates. References in this Code to the "Inspector" are to the owner's Inspector or the Inspector's delegates.

340.2 Responsibility for Inspection

It is the owner's responsibility, exercised through the owner's Inspector, to verify that all required examinations and testing have been completed and to inspect the piping to the extent necessary to be satisfied that it conforms to all applicable examination requirements of the Code and of the engineering design.

340.3 Rights of the Owner's Inspector

The owner's Inspector and the Inspector's delegates shall have access to any place where work concerned with the piping installation is being performed. This includes manufacture, fabrication, heat treatment, assembly, erection, examination, and testing of the piping. They shall have the right to audit any examination, to inspect the piping using any examination method specified by the engineering design, and to review all certifications and records necessary to satisfy the owner's responsibility stated in para. 340.2.

340.4 Qualifications of the Owner's Inspector

(a) The owner's Inspector shall be designated by the owner and shall be the owner, an employee of the owner, an employee of an engineering or scientific organization, or the employee of a recognized insurance or inspection company acting as the owner's agent. The owner's Inspector shall not represent nor be an employee of the piping manufacturer, fabricator, or erector unless the owner is also the manufacturer, fabricator, or erector.

(b) The owner's Inspector shall meet one of the following requirements:

(1) have at least 10 yr of experience in the design, fabrication, or examination of industrial pressure piping. Each 20% of satisfactorily completed work toward an accredited engineering degree shall be considered equivalent to 1 yr of experience, up to 5 yr total.

(2) have a professional engineering registration or nationally recognized equivalent with at least 5 yr of experience in the design, fabrication, or examination of industrial pressure piping.

(3) be a certified welding inspector or a senior certified welding inspector as defined in AWS QC1, Specification for AWS Certification of Welding Inspectors, or nationally recognized equivalent with at least 5 yr of experience in the design, fabrication, or examination of industrial pressure piping.

(4) be an authorized piping inspector as defined in API 570, Piping Inspection Code: In-service Inspection, Rating, Repair, and Alteration of Piping Systems, with at least 5 yr of experience in the design, fabrication, or examination of industrial pressure piping.

(c) In delegating performance of inspection, the owner's Inspector is responsible for determining that a person to whom an inspection function is delegated is qualified to perform that function.

341 EXAMINATION

341.1 General

Examination applies to quality control functions performed by the manufacturer (for components only), fabricator, or erector. Reference in this Code to an examiner is to a person who performs quality control examinations.

341.2 Responsibility for Examination

Inspection does not relieve the manufacturer, the fabricator, or the erector of the responsibility for

(a) providing materials, components, and workmanship in accordance with the requirements of this Code and of the engineering design [see para. 300(b)(3)]

(b) performing all required examinations

(c) preparing suitable records of examinations and tests for the Inspector's use

341.3 Examination Requirements

341.3.1 General. Prior to initial operation, each piping installation, including components and workmanship, shall be examined in accordance with the applicable requirements of para. 341. The type and extent of any additional examination required by the engineering design, and the acceptance criteria to be applied, shall be specified. Joints not included in examinations required by para. 341.4 or by the engineering design are accepted if they pass the leak test required by para. 345.

(a) For P-Nos. 3, 4, 5A, 5B, 5C, and 15E materials, examinations shall be performed after completion of heat treatment. However, examinations need not be repeated on welds or portions of welds that are subjected to additional heat treatments and have not been repaired by welding.

(b) For a welded branch connection, the examination of, and any necessary repairs to, the pressure-containing weld shall be completed before any reinforcing pad or saddle is added.

341.3.2 Acceptance Criteria. Acceptance criteria shall be as stated in the engineering design and shall at least meet the applicable requirements stated below.

(a) *Welds*. See Figure 341.3.2 for typical weld imperfections.

(1) For radiography and visual, see Table 341.3.2.

(2) For magnetic particle, see para. 344.3.2.

(3) For liquid penetrant, see para. 344.4.2.

(4) For ultrasonic, see para. 344.6.2.

(b) *Castings.* Acceptance criteria for castings are specified in para. 302.3.3.

341.3.3 Defective Components and Workmanship. Defects (imperfections of a type or magnitude not acceptable by the criteria specified in para. 341.3.2) shall be repaired, or the defective item or work shall be replaced. Discontinuities detected outside the area required to be examined during weld joint examinations should be evaluated and resolved in a manner acceptable to the owner and designer.

Examination shall be as follows:

(a) When the defective item or work is repaired, the repaired portion of the item or work shall be examined. The examination shall use the same methods and acceptance criteria employed for the original examination. See also para. 341.3.1(a).

(b) When the defective item or work is replaced, the new item or work used to replace the defective item or work shall be examined. The examination shall use any method and applicable acceptance criteria that meet the requirements for the original examination. See also para. 341.3.1(a).

341.3.4 Progressive Sampling for Examination. When required spot or random examination reveals a defect, then

(a) two additional samples of the same kind (if welded or bonded joints, by the same welder, bonder, or operator) from the original designated lot shall be given the same type of examination

(b) if the items examined as required by (a) above are acceptable, the defective item shall be repaired or replaced and reexamined as specified in para. 341.3.3, and all items represented by these two additional samples shall be accepted, but

(c) if any of the items examined as required by (a) above reveals a defect, two further samples of the same kind shall be examined for each defective item found by that sampling

(d) if all the items examined as required by (c) above are acceptable, the defective item(s) shall be repaired or replaced and reexamined as specified in para. 341.3.3, and all items represented by the additional sampling shall be accepted, but

(e) if any of the items examined as required by (c) above reveals a defect, all items represented by the progressive sampling shall be either

(1) repaired or replaced and reexamined as required, or

(2) fully examined and repaired or replaced as necessary, and reexamined as necessary to meet the requirements of this Code

(f) If any of the defective items are repaired or replaced, reexamined, and a defect is again detected in the repaired or replaced item, continued progressive sampling in accordance with (a), (c), and (e) is not required based on the new defects found. The defective item(s) shall be repaired or replaced and reexamined until acceptance as specified in para. 341.3.3. Spot or random examination (whichever is applicable) is then performed on the remaining unexamined joints.

341.4 Extent of Required Examination

341.4.1 Examination — Normal Fluid Service. Piping in Normal Fluid Service shall be examined to the extent specified herein or to any greater extent specified in the engineering design. Acceptance criteria are as stated in para. 341.3.2 and in Table 341.3.2, for Normal Fluid Service unless otherwise specified.

(a) *Visual Examination.* At least the following shall be examined in accordance with para. 344.2:

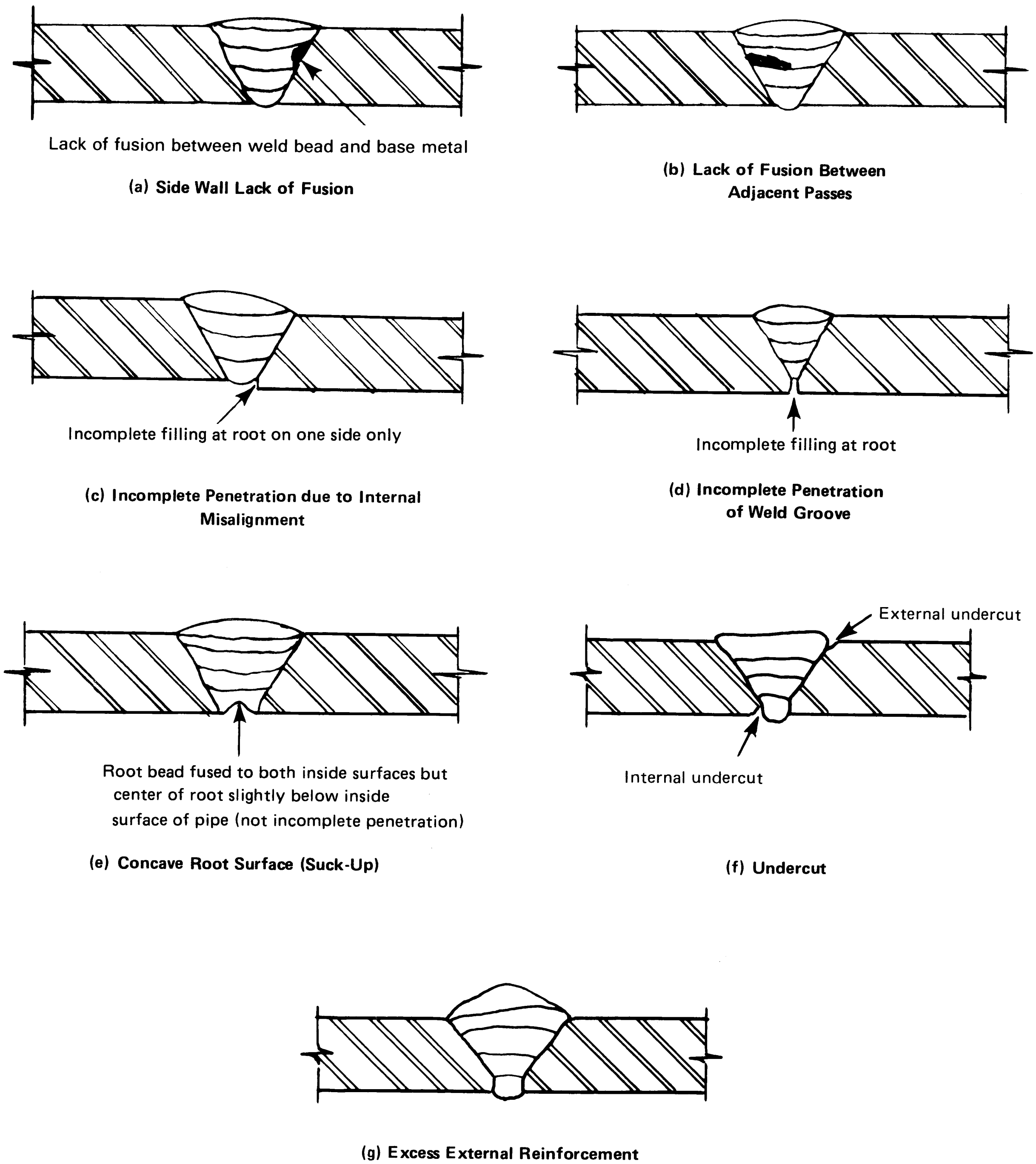
(1) sufficient materials and components, selected at random, to satisfy the examiner that they conform to specifications and are free from defects.

(2) at least 5% of fabrication, as defined in para. 300.2.

(3) 100% of all completed welds, except those in components made in accordance with a listed standard. See para. 341.5.1(a) for examination of longitudinal welds required to have a joint factor, E_j, of 0.90.

(4) random examination of the assembly of threaded, bolted, and other joints to satisfy the examiner that they conform to the applicable requirements of para. 335. When pneumatic testing is to be performed, all threaded, bolted, and other mechanical joints shall be examined.

Figure 341.3.2 Typical Weld Imperfections



(a) Side Wall Lack of Fusion

(b) Lack of Fusion Between Adjacent Passes

(c) Incomplete Penetration due to Internal Misalignment

(d) Incomplete Penetration of Weld Groove

(e) Concave Root Surface (Suck-Up)

(f) Undercut

(g) Excess External Reinforcement

Table 341.3.2 Acceptance Criteria for Welds — Visual and Radiographic Examination

Criteria (A to M) for Types of Welds and for Service Conditions [Note (1)]												
Normal and Category M Fluid Service			Severe Cyclic Conditions			Category D Fluid Service					Examination Methods	
Girth, Miter Groove, and Branch Connection Welds [Note (2)]	Longitudinal Groove Weld [Note (3)]	Fillet Weld [Note (4)]	Girth, Miter Groove, and Branch Connection Welds [Note (2)]	Longitudinal Groove Weld [Note (3)]	Fillet Weld [Note (4)]	Girth and Miter Groove Welds	Longitudinal Groove Weld [Note (3)]	Fillet Weld [Note (4)]	Branch Connection Weld [Note (2)]	Weld Imperfection	Visual	Radiography
A	A	A	A	A	A	A	A	A	A	Crack	✓	✓
A	A	A	A	A	A	C	A	N/A	A	Lack of fusion	✓	✓
B	A	N/A	A	A	N/A	C	A	N/A	B	Incomplete penetration	✓	✓
E	E	N/A	D	D	N/A	N/A	N/A	N/A	N/A	Rounded Indications	...	✓
G	G	N/A	F	F	N/A	N/A	N/A	N/A	N/A	Linear indications	...	✓
H	A	H	A	A	A	I	A	H	H	Undercutting	✓	✓
A	A	A	A	A	A	A	A	A	A	Surface porosity or exposed slag inclusion [Note (5)]	✓	...
N/A	N/A	N/A	J	J	J	N/A	N/A	N/A	N/A	Surface finish	✓	...
K	K	N/A	K	K	N/A	K	K	N/A	K	Concave surface, concave root, or burn-through	✓	✓
L	L	L	L	L	L	M	M	M	M	Weld reinforcement or internal protrusion	✓	...

GENERAL NOTES:
(a) Weld imperfections are evaluated by one or more of the types of examination methods given, as specified in paras. 341.4.1, 341.4.2, 341.4.3, and M341.4, or by the engineering design.
(b) "N/A" indicates the Code does not establish acceptance criteria or does not require evaluation of this kind of imperfection for this type of weld.
(c) Check (✓) indicates examination method generally used for evaluating this kind of weld imperfection.
(d) Ellipsis (...) indicates examination method not generally used for evaluating this kind of weld imperfection.

NOTES:
(1) Criteria given are for required examination. More-stringent criteria may be specified in the engineering design. See also paras. 341.5 and 341.5.3.
(2) Branch connection weld includes pressure containing welds in branches and fabricated laps.
(3) Longitudinal groove weld includes straight and spiral (helical) seam. Criteria are not intended to apply to welds made in accordance with a standard listed in Table A-1, Table A-1M, or Table 326.1. Alternative Leak Test requires examination of these welds; see para. 345.9.
(4) Fillet weld includes socket and seal welds, and attachment welds for slip-on flanges, branch reinforcement, and supports.
(5) These imperfections are evaluated only for welds ≤5 mm ($^3/_{16}$ in.) in nominal thickness.

Criterion Value Notes for Table 341.3.2

Criterion		Acceptable Value Limits [Note (1)]	
Symbol	**Measure**		
A	Extent of imperfection	Zero (no evident imperfection)	
B	Cumulative length of incomplete penetration	≤38 mm (1.5 in.) in any 150 mm (6 in.) weld length or 25% of total weld length, whichever is less	
C	Cumulative length of lack of fusion and incomplete penetration	≤38 mm (1.5 in.) in any 150 mm (6 in.) weld length or 25% of total weld length, whichever is less	
D	Size and distribution of rounded indications	See ASME BPVC, Section VIII, Division 1, Appendix 4 [Note (2)]	
E	Size and distribution of rounded indications	For $\overline{T}_w \leq 6\,\text{mm}$ (¼ in.), limit is same as D [Note (2)] For $\overline{T}_w > 6\,\text{mm}$ (¼ in.), limit is 1.5 × D [Note (2)]	
F	Linear indications		
	Individual length	$\leq \overline{T}_w/3$	
	Individual width	≤2.5 mm (3/32 in.) and $\leq \overline{T}_w/3$	
	Cumulative length	$\leq \overline{T}_w$ in any $12\,\overline{T}_w$ weld length [Note (2)]	
G	Linear indications		
	Individual length	$\leq 2\overline{T}_w$	
	Individual width	≤3 mm (⅛ in.) and $\leq \overline{T}_w/2$	
	Cumulative length	$\leq 4\overline{T}_w$ in any 150 mm (6 in.) weld length [Note (2)]	
H	Depth of undercut	≤1 mm (1/32 in.) and $\leq \overline{T}_w/4$	
	Cumulative length of internal and external undercut	≤38 mm (1.5 in.) in any 150 mm (6 in.) weld length or 25% of total weld length, whichever is less	
I	Depth of undercut	≤1.5 mm (1/16 in.) and ≤[$\overline{T}_w/4$ or 1 mm (1/32 in.)]	
	Cumulative length of internal and external undercut	≤38 mm (1.5 in.) in any 150 mm (6 in.) weld length or 25% of total weld length, whichever is less	
J	Surface roughness	≤12.5 μm (500 μin.) R_a in accordance with ASME B46.1	
K	Depth of surface concavity, root concavity, or burn-through	Total joint thickness, including weld reinforcement, $\geq \overline{T}_w$ [Notes (3) and (4)]	
L	Height of reinforcement or internal protrusion [Note (5)] in any plane through the weld shall be within limits of the applicable height value in the tabulation at right, except as provided in Note (6). Weld metal shall merge smoothly into the component surfaces.	For $\overline{T}_w$, mm (in.)	Height, mm (in.)
		≤6 (¼)	≤1.5 (1/16)
		>6 (¼), ≤13 (½)	≤3 (⅛)
		>13 (½), ≤25 (1)	≤4 (5/32)
		>25 (1)	≤5 (3/16)
M	Height of reinforcement or internal protrusion [Note (5)] as described in L. Note (6) does not apply.	Limit is twice the value applicable for L above	

NOTES:

(1) Where two limiting values are separated by "and," the lesser of the values determines acceptance. Where two sets of values are separated by "or," the larger value is acceptable. $\overline{T}_w$ is the nominal wall thickness of the thinner of two components joined by a butt weld.

Criterion Value Notes for Table 341.3.2 (Cont'd)

NOTES: (Cont'd)

(2) Porosity and inclusions such as slag or tungsten are defined as rounded indications where the maximum length is three times the width or less. These indications may be circular, elliptical, or irregular in shape; may have tails; and may vary in density. Indications where the length is greater than three times the width are defined as linear indications and may also be slag, porosity, or tungsten.

(3) For circumferential groove welded joints in pipe, tube, and headers made entirely without the addition of filler metal, external concavity shall not exceed the lesser of 1 mm ($^1\!/_{32}$ in.) or 10% of the joint nominal thickness. The contour of the concavity shall blend smoothly with the base metal. The total joint thickness, including any reinforcement, shall not be less than the minimum wall thickness, t_m.

(4) For radiography, acceptability may be determined by comparing the density of the image through the affected area to the density through the adjacent base metal ($\overline{T}_w$). If digital radiography is used, brightness comparison may be utilized. A density or brightness darker than the adjacent base metal is cause for rejection.

(5) For groove welds, height is the lesser of the measurements made from the surfaces of the adjacent components; both reinforcement and internal protrusion are permitted in a weld. For fillet welds, height is measured from the theoretical throat, Figure 328.5.2A; internal protrusion does not apply.

(6) For welds in aluminum alloy only, internal protrusion shall not exceed the following values:

(a) 1.5 mm ($^1\!/_{16}$ in.) for thickness ≤2 mm ($^5\!/_{64}$ in.)

(b) 2.5 mm ($^3\!/_{32}$ in.) for thickness >2 mm and ≤6 mm ($^1\!/_4$ in.)

For external reinforcement and for greater thicknesses, see the tabulation for symbol L.

(5) random examination during erection of piping, including checking of alignment, supports, and cold spring.

(6) examination of erected piping for evidence of defects that would require repair or replacement, and for other evident deviations from the intent of the design.

(b) Other Examination

(1) Not less than 5% of circumferential butt and miter groove welds shall be examined fully by random radiography in accordance with para. 344.5 or by random ultrasonic examination in accordance with para. 344.6. The welds to be examined in each designated lot shall include the work product of each welder or welding operator whose welds are part of the lot. The work of welders depositing only tack welds need not be represented as part of the lot. Welds shall also be selected to maximize coverage of intersections with longitudinal joints. When a circumferential weld with an intersecting longitudinal weld(s) is examined, at least the adjacent 38 mm ($1\frac{1}{2}$ in.) of each intersecting weld shall be examined. In-process examination in accordance with para. 344.7 may be substituted for all or part of the radiographic or ultrasonic examination on a weld-for-weld basis if specified in the engineering design or specifically authorized by the Inspector.

(2) Not less than 5% of all brazed joints shall be examined by in-process examination in accordance with para. 344.7, the joints to be examined being selected to ensure that the work of each brazer making the production joints is included.

(c) Certifications and Records. The examiner shall be assured, by examination of certifications, records, and other evidence, that the materials and components are of the specified grades and that they have received required heat treatment, examination, and testing. The examiner shall provide the Inspector with a certification that all the quality control requirements of the Code and of the engineering design have been carried out.

341.4.2 Examination — Category D Fluid Service. Piping and piping elements for Category D Fluid Service as designated in the engineering design shall be visually examined in accordance with para. 344.2 to the extent necessary to satisfy the examiner that components, materials, and workmanship conform to the requirements of this Code and the engineering design. Acceptance criteria are as stated in para. 341.3.2 and in Table 341.3.2, for Category D fluid service, unless otherwise specified.

341.4.3 Examination — Severe Cyclic Conditions. Piping to be used under severe cyclic conditions shall be examined to the extent specified herein or to any greater extent specified in the engineering design. Acceptance criteria are as stated in para. 341.3.2 and in Table 341.3.2, for severe cyclic conditions, unless otherwise specified.

(a) Visual Examination. The requirements of para. 341.4.1(a) apply with the following exceptions:

(1) All fabrication shall be examined.

(2) All threaded, bolted, and other joints shall be examined.

(3) All piping erection shall be examined to verify dimensions and alignment. Supports, guides, and points of cold spring shall be checked to ensure that movement of the piping under all conditions of startup, operation, and shutdown will be accommodated without undue binding or unanticipated constraint.

(b) Other Examination. All circumferential butt and miter groove welds and all fabricated branch connection welds comparable to those shown in Figure 328.5.4E shall be examined by 100% radiography in accordance with para. 344.5, or (if specified in the engineering design) by 100% ultrasonic examination in accordance with para. 344.6. Socket welds and branch connection welds that are not radiographed shall be examined by magnetic particle or liquid penetrant methods in accordance with para. 344.3 or 344.4.

(c) In-process examination in accordance with para. 344.7, supplemented by appropriate nondestructive examination, may be substituted for the examination required in (b) above on a weld-for-weld basis if specified in the engineering design or specifically authorized by the Inspector.

(d) Certification and Records. The requirements of para. 341.4.1(c) apply.

341.4.4 Examination — Elevated Temperature Fluid Service. Piping in Elevated Temperature Fluid Service shall be examined to the extent specified herein or to any greater extent specified in the engineering design. Acceptance criteria are as stated in para. 341.3.2 and in Table 341.3.2, for Normal Fluid Service, unless the requirements for severe cyclic conditions apply or otherwise specified.

(a) Visual Examination. The requirements of para. 341.4.1(a) apply with the following exceptions:

(1) All fabrication shall be examined.

(2) All threaded, bolted, and other joints shall be examined.

(3) All piping erection shall be examined to verify dimensions and alignment. Supports, guides, and points of cold spring shall be checked to ensure that movement of the piping under all conditions of startup, operation, and shutdown will be accommodated without undue binding or unanticipated constraint.

(b) Additional Examination. The examination requirements of para. 341.4.1(b) apply with the following exceptions:

(1) Fabrication for longitudinal and spiral (helical seam) welds in P-No. 4 and P-No. 5 materials, except those in components made in accordance with a listed specification, shall be examined by 100% radiography

in accordance with para. 344.5, or by 100% ultrasonic examination in accordance with para. 344.6.

(2) Socket welds and branch connection welds in P-No. 4 and P-No. 5 materials that are not radiographed or ultrasonically examined shall be examined by magnetic particle or liquid penetrant methods in accordance with para. 344.3 or 344.4.

(c) Additional Examination Required for Autogenous Welds, Without Filler Metal, in Austenitic Stainless Steel and Austenitic High Nickel Alloys. Autogenously welded pipe shall receive nondestructive examination in accordance with the material specification. Autogenously welded expansion joint bellows shall be examined in accordance with para. X302.2.2(c).

(d) Certification and Records. The requirements of para. 341.4.1(c) apply.

341.5 Supplementary Examination

Any of the methods of examination described in para. 344 may be specified by the engineering design to supplement the examination required by para. 341.4. The extent of supplementary examination to be performed and any acceptance criteria that differ from those in para. 341.3.2 shall be specified in the engineering design.

341.5.1 Spot Radiography

(a) Longitudinal Welds. Spot radiography for longitudinal groove welds required to have a weld joint factor E_j of 0.90 requires examination by radiography in accordance with para. 344.5 of at least 300 mm (1 ft) in each 30 m (100 ft) of weld for each welder or welding operator. Acceptance criteria are those stated in Table 341.3.2 for radiography under Normal Fluid Service.

(b) Circumferential Butt Welds and Other Welds. It is recommended that the extent of examination be not less than one shot on one in each 20 welds for each welder or welding operator. Unless otherwise specified, acceptance criteria are as stated in Table 341.3.2 for radiography under Normal Fluid Service for the type of joint examined.

(c) Progressive Sampling for Examination. The provisions of para. 341.3.4 are applicable.

(d) Welds to Be Examined. The locations of welds and the points at which they are to be examined by spot radiography shall be selected or approved by the Inspector.

341.5.2 Hardness Tests. Hardness tests are not required to verify proper heat treatment except as otherwise specified in the engineering design.

341.5.3 Examinations to Resolve Uncertainty. Any method may be used to resolve doubtful indications. Acceptance criteria shall be those for the required examination.

342 EXAMINATION PERSONNEL

342.1 Personnel Qualification and Certification

Personnel performing nondestructive examination to the requirements of this Code shall be qualified and certified for the method to be utilized following a procedure as described in ASME BPVC, Section V, Article 1, T-120(e) or (f).

342.2 Specific Requirement

For in-process examination, the examinations shall be performed by personnel other than those performing the production work.

343 EXAMINATION PROCEDURES

Any examination shall be performed in accordance with a written procedure that conforms to one of the methods specified in para. 344, including special methods (see para. 344.1.2). Procedures shall be written as required in ASME BPVC, Section V, Article 1, T-150. The employer shall make the examination procedures employed available to the Inspector.

344 TYPES OF EXAMINATION

344.1 General

344.1.1 Methods. Except as provided in para. 344.1.2, any examination required by this Code, by the engineering design, or by the Inspector shall be performed in accordance with one of the methods specified herein.

344.1.2 Special Methods. If a method not specified herein is to be used, it and its acceptance criteria shall be specified in the engineering design in enough detail to permit qualification of the necessary procedures and examiners.

344.1.3 Definitions. The following terms apply to any type of examination:

100% examination : complete examination of all of a specified kind of item in a designated lot of piping[1]

random examination[2]*:* complete examination of a percentage of a specified kind of item in a designated lot of piping[1]

[1] A designated lot is that quantity of piping to be considered in applying the requirements for examination in this Code. The quantity or extent of a designated lot should be established by agreement between the contracting parties before the start of work. More than one kind of designated lot may be established for different kinds of piping work. See Pipe Fabrication Institute Standard ES-48, Random Examination, for examples of lot selection.

[2] Random or spot examination will not ensure a fabrication product of a prescribed quality level throughout. Items not examined in a lot of piping represented by such examination may contain defects that further examination could disclose. Specifically, if all radiographically disclosable weld defects must be eliminated from a lot of piping, 100% radiographic examination must be specified.

spot examination[2]*:* a specified partial examination of each of a specified kind of item in a designated lot of piping,[1] e.g., of part of the length of all shop-fabricated welds in a lot of jacketed piping

random spot examination[2]*:* a specified partial examination of a percentage of a specified kind of item in a designated lot of piping[1]

344.2 Visual Examination

344.2.1 Definition. Visual examination is the direct observation of the external and internal portions of components, joints, and other piping elements that are readily accessible or can be exposed to view before, during, or after manufacture, fabrication, assembly, erection, examination, or testing. This examination includes verification of Code and engineering design requirements for materials, components, dimensions, joint preparation, alignment, welding, bonding, brazing, bolting, threading, or other joining method, supports, assembly, and erection.

344.2.2 Method. Visual examination shall be performed in accordance with ASME BPVC, Section V, Article 9. Examination shall be by the direct visual technique. The use of a remote visual technique and the acceptance criteria beyond the requirements of this Code shall be a matter of agreement between contracting parties prior to the start of fabrication.

Records of individual visual examinations are not required except for those of in-process examinations as specified in para. 344.7.

344.3 Magnetic Particle Examination

344.3.1 Method. Examination of castings is covered in para. 302.3.3. Magnetic particle examination of welds and of components other than castings shall be performed in accordance with ASME BPVC, Section V, Article 7.

344.3.2 Acceptance Criteria. Magnetic particle indications are caused by the attraction of the test media to surface or near-surface discontinuities in the area under test. However, all such indications are not necessarily imperfections, since excessive roughness, magnetic permeability variations, etc., may produce nonrelevant indications. Inadvertent accumulation of particles not related to magnetic attraction is classified as a false indication. Indications shall be verified as being relevant, nonrelevant, or false. Additional surface preparation and/or other test methods may be used as needed to verify the relevance of an indication.

An indication of an imperfection may be larger than the imperfection that causes it; however, the size of the indication is the basis for acceptance evaluation. Only indications that have any dimension greater than 1.5 mm ($^1\!/_{16}$ in.) shall be considered relevant.

(a) Indications

(1) A linear indication is one having a length greater than three times its width.

(2) A rounded indication is one of circular or elliptical shape with a length equal to or less than three times its width.

(b) Examination. All surfaces to be examined shall be free of

(1) relevant linear indications

(2) relevant rounded indications >5.0 mm ($^3\!/_{16}$ in.)

(3) four or more relevant rounded indications in a line separated by 1.5 mm ($^1\!/_{16}$ in.) or less, edge to edge

344.4 Liquid Penetrant Examination

344.4.1 Method. Examination of castings is covered in para. 302.3.3. Liquid penetrant examination of welds and of components other than castings shall be performed in accordance with ASME BPVC, Section V, Article 6.

344.4.2 Acceptance Criteria. Liquid penetrant indications are caused by the bleed-out of a visible or fluorescent dye from a surface discontinuity in the area under test. However, all such indications are not necessarily imperfections, since excessive roughness, poor surface preparation, etc., may produce nonrelevant indications. Inadvertent evidence of penetrant not related to actual bleed-out is classified as a false indication. Indications shall be verified as being relevant, nonrelevant, or false. Additional surface preparation and/or other test methods may be used as needed to verify the relevance of an indication.

An indication of an imperfection may be larger than the imperfection that causes it; however, the size of the indication is the basis for acceptance evaluation. Only indications that have any dimension greater than 1.5 mm ($^1\!/_{16}$ in.) shall be considered relevant.

(a) Indications

(1) A linear indication is one having a length greater than three times its width.

(2) A rounded indication is one of circular or elliptical shape with a length equal to or less than three times its width.

(b) Examination. All surfaces to be examined shall be free of

(1) relevant linear indications

(2) relevant rounded indications >5.0 mm ($^3\!/_{16}$ in.)

(3) four or more relevant rounded indications in a line separated by 1.5 mm ($^1\!/_{16}$ in.) or less, edge to edge

344.5 Radiographic Examination

344.5.1 Method. Radiography of castings is covered in para. 302.3.3. Radiography of welds and of components other than castings shall be performed in accordance with ASME BPVC, Section V, Article 2. For the purpose of image quality indicator (IQI) selection, for welds with reinforcement, the thickness used shall be the nominal wall thickness, $\overline{T}_w$, plus the allowable external reinforcement and internal reinforcement (protrusion) combined.

344.5.2 Extent of Radiography

(a) 100% Radiography. This applies only to girth and miter groove welds and to fabricated branch connection welds comparable to Figure 328.5.4E, unless otherwise specified in the engineering design.

(b) Random Radiography. This applies only to girth and miter groove welds.

(c) Spot Radiography. This requires a single exposure radiograph in accordance with para. 344.5.1 at a point within a specified extent of welding. For girth, miter, and branch groove welds, the minimum requirement is

(1) for sizes ≤DN 65 (NPS 2½), a single elliptical exposure encompassing the entire weld circumference

(2) for sizes >DN 65, the lesser of 25% of the inside circumference or 152 mm (6 in.)

For longitudinal welds, the minimum requirement is 152 mm (6 in.) of weld length.

344.6 Ultrasonic Examination

344.6.1 Method. Examination of castings is covered in para. 302.3.3; other product forms are not covered. Ultrasonic examination of welds shall be performed in accordance with ASME BPVC, Section V, Article 4, except that the alternative specified in (a) and (b) below is permitted for basic calibration blocks specified in T-434.2.1 and T-434.3.

(a) When the basic calibration blocks have not received heat treatment in accordance with T-434.1.5, transfer methods shall be used to correlate the responses from the basic calibration block and the component. Transfer is accomplished by noting the difference between responses received from the same reference reflector in the basic calibration block and in the component and correcting for the difference.

(b) The reference reflector may be a V-notch (which must subsequently be removed), an angle beam search unit acting as a reflector, or any other reflector that will aid in accomplishing the transfer.

(c) When the transfer method is chosen as an alternative, it shall be used, at the minimum

(1) for sizes ≤DN 50 (NPS 2), once in each ten welded joints examined

(2) for sizes >DN 50 and ≤DN 450 (NPS 18), once in each 1.5 m (5 ft) of welding examined

(3) for sizes >DN 450, once for each welded joint examined

(d) Each type of material and each size and wall thickness shall be considered separately in applying the transfer method. In addition, the transfer method shall be used at least twice on each type of weld joint.

(e) The reference level for monitoring discontinuities shall be modified to reflect the transfer correction when the transfer method is used.

344.6.2 Acceptance Criteria. Acceptance criteria shall be as described in (a) or (b). (20)

(a) A discontinuity is unacceptable if the amplitude of the indication exceeds the reference level and its length exceeds

(1) 6 mm (¼ in.) for $\overline{T}_w \leq$ 19 mm (¾ in.)

(2) $\overline{T}_w/3$ for 19 mm (¾ in.) $< \overline{T}_w \leq$ 57 mm (2¼ in.)

(3) 19 mm (¾ in.) for $\overline{T}_w >$ 57 mm (2¼ in.)

(b) The fracture-mechanics-based ultrasonic examination acceptance criteria in Appendix R may be used if all requirements of Appendix R are met.

344.7 In-Process Examination

344.7.1 Definition. In-process examination comprises examination of the following, as applicable:

(a) joint preparation and cleanliness

(b) preheating

(c) fit-up, joint clearance, and internal alignment prior to joining

(d) variables specified by the joining procedure, including filler material

(1) (for welding) position and electrode

(2) (for brazing) position, flux, brazing temperature, proper wetting, and capillary action

(e) (for welding) condition of the root pass after cleaning — external and, where accessible, internal — aided by liquid penetrant or magnetic particle examination when specified in the engineering design

(f) (for welding) slag removal and weld condition between passes

(g) appearance of the finished joint

344.7.2 Method. The examination is visual, in accordance with para. 344.2, unless additional methods are specified in the engineering design.

345 TESTING

345.1 Required Leak Test

Prior to initial operation, and after completion of the applicable examinations required by para. 341, each piping system shall be tested to ensure tightness. The test shall be a hydrostatic leak test in accordance with para. 345.4 except as provided herein.

(a) At the owner's option, a piping system in Category D fluid service may be subjected to an initial service leak test in accordance with para. 345.7, in lieu of the hydrostatic leak test.

(b) Where the owner considers a hydrostatic leak test impracticable, either a pneumatic test in accordance with para. 345.5 or a combined hydrostatic–pneumatic test in

accordance with para. 345.6 may be substituted, recognizing the hazard of energy stored in compressed gas.

(c) Where the owner considers both hydrostatic and pneumatic leak testing impracticable, the alternative specified in para. 345.9 may be used if both of the following conditions apply:

(1) a hydrostatic test would

(-a) damage linings or internal insulation

(-b) contaminate a process that would be hazardous, corrosive, or inoperative in the presence of moisture

(-c) require significant support modifications for the hydrostatic test load or

(-d) present the danger of brittle fracture due to low metal temperature during the test

(2) a pneumatic test would

(-a) present an undue hazard of possible release of energy stored in the system or

(-b) present the danger of brittle fracture due to low metal temperature during the test

(d) Unless specified in the engineering design, lines open to the atmosphere, such as vents or drains downstream of the last shutoff valve, need not be leak tested.

345.2 General Requirements for Leak Tests

Requirements in para. 345.2 apply to more than one type of leak test.

345.2.1 Limitations on Pressure

(a) Reduced Test Pressure. If the test pressure would produce a circumferential or longitudinal stress (based on minimum pipe wall thickness) in excess of yield strength at test temperature or is greater than 1.5 times the component rating at test temperature, the test pressure may be reduced to the maximum pressure that will not exceed the lesser of the yield strength or 1.5 times a component rating at test temperature. [See para. 302.3.2.] For metallic bellows expansion joints, see Appendix X, para. X302.2.3(a).

(b) Test Fluid Expansion. If a pressure test is to be maintained for a period of time and the test fluid in the system is subject to thermal expansion, precautions shall be taken to avoid excessive pressure.

(c) Preliminary Pneumatic Test. A preliminary test using air at no more than 170 kPa (25 psi) gage pressure may be made prior to hydrostatic testing to locate major leaks.

345.2.2 Other Test Requirements

(a) Examination for Leaks. The leak test pressure shall be maintained for at least 10 min and then all joints and connections shall be examined for leaks. The test pressure may be reduced to not less than the design pressure while performing this examination.

(b) Heat Treatment. Leak tests shall be conducted after any heat treatment has been completed.

(c) Low Test Temperature. The possibility of brittle fracture shall be considered when conducting leak tests at metal temperatures near the ductile–brittle transition temperature.

345.2.3 Special Provisions for Testing

(a) Piping Components and Subassemblies. Piping components and subassemblies may be tested either separately or as assembled piping.

(b) Flanged Joints. Flanged joints used to connect piping components and subassemblies that have previously been tested, and flanged joints at which a blank or blind is used to isolate equipment or other piping during a test, need not be leak tested in accordance with para. 345.1.

(c) Closure Welds. The final weld connecting piping systems or components that have been successfully tested in accordance with para. 345 need not be leak tested provided the weld is examined in-process in accordance with para. 344.7 and passes with 100% radiographic examination in accordance with para. 344.5 or 100% ultrasonic examination in accordance with para. 344.6.

(d) Instrument Connections. Threaded joints, tubing joints, or a combination of these joints used to connect instruments to previously leak tested piping need not be leak tested in accordance with para. 345.1.

(e) See also Appendix F, para. F345.2.3.

345.2.4 Externally Pressured Piping

(a) Except as provided in (b) below, piping systems subject to external pressure shall be tested at an internal gage pressure 1.5 times the external differential pressure, but not less than 105 kPa (15 psi).

(b) As an alternative to leak testing under internal pressure, piping systems designed for vacuum service only may be subjected to a vacuum leak test method, technique, and acceptance criteria specified by the owner. The vacuum leak test shall be performed following a written procedure complying with the applicable technical requirements of ASME BPVC, Section V, Article 10. Leak-testing personnel shall be qualified and certified as required by ASME BPVC, Section V, Article 1, T-120(e) or (f).

345.2.5 Jacketed Piping

(a) The internal line shall be leak tested on the basis of the internal or external design pressure, whichever results in a higher test pressure. This test must be performed before the jacket is completed if it is necessary to provide visual access to joints of the internal line as required by para. 345.3.1.

(b) The jacket shall be leak tested in accordance with para. 345.1 based on the jacket design conditions. The test pressure is permitted to be lower when so specified in the engineering design.

345.2.6 Repairs or Additions After Leak Testing. If repairs or additions are made following the leak test, the affected piping shall be retested, except that for minor repairs or additions the owner may waive retest requirements when precautionary measures are taken to assure sound construction.

345.2.7 Test Records. Records shall be made of each piping system during the testing, including

(a) date of test
(b) identification of piping system tested
(c) test fluid
(d) test pressure
(e) certification of results by examiner

These records need not be retained after completion of the test if a certification by the Inspector that the piping has satisfactorily passed pressure testing as required by this Code is retained.

345.3 Preparation for Leak Test

345.3.1 Joints Exposed

(a) Except as provided in (b) and (c) below, all joints, welds (including structural attachment welds to pressure-containing components), and bonds shall be left uninsulated and exposed for examination during leak testing.

(b) Joints previously tested in accordance with this Code may be insulated or covered.

(c) At the owner's option, joints in Category D Fluid Service that are subject to a hydrostatic leak test (para. 345.4) or an initial service leak test (para. 345.7) may be insulated and have protective weather sheathing installed prior to leak testing. Consideration shall be given to increasing the test period to allow time for possible leakage to pass through the insulation and weather sheathing.

(d) All joints may be primed and painted prior to leak testing unless a sensitive leak test (para. 345.8) is required.

345.3.2 Temporary Supports. Piping designed for vapor or gas shall be provided with additional temporary supports, if necessary, to support the weight of test liquid.

345.3.3 Piping With Expansion Joints

(a) Unrestrained expansion joints depend on external main anchors to resist pressure thrust forces. Except as limited in (c), a piping system containing unrestrained expansion joints shall be leak tested without any temporary restraints in accordance with para. 345 up to 150% of the expansion joint design pressure. If the required test pressure exceeds 150% of the expansion joint design pressure and the main anchors are not designed to resist the pressure thrust forces at the required test pressure, for that portion of the test when the pressure exceeds 150% of the expansion joint design pressure, the expansion joint shall either be temporarily removed or temporary restraints shall be added to resist the pressure thrust forces.

(b) Self-restrained metallic bellows expansion joints (i.e., tied, hinged, pressure balanced, etc.) have restraint hardware designed to resist the pressure thrust forces. Except as limited in (c), a piping system containing self-restrained expansion joints shall be leak tested in accordance with para. 345. A self-restrained expansion joint previously shop tested by the manufacturer in accordance with Appendix X may be excluded from the system to be leak tested, except when a sensitive leak test in accordance with para. 345.8 is required. Restraint hardware for all types of expansion joints shall be designed for the pressure thrust forces at the test pressure.

(c) When a metallic bellows expansion joint is installed in the piping system subject to a leak test and the leak test pressure determined in accordance with para. 345 exceeds the pressure of the test performed by the manufacturer in accordance with Appendix X, the required leak test pressure shall be reduced to the manufacturer's test pressure.

345.3.4 Limits of Tested Piping. Equipment that is not to be tested shall be either disconnected from the piping or isolated by blinds or other means during the test. A valve may be used provided the valve (including its closure mechanism) is suitable for the test pressure.

345.4 Hydrostatic Leak Test

345.4.1 Test Fluid. The fluid shall be water unless there is the possibility of damage due to freezing or to adverse effects of water on the piping or the process (see para. F345.4.1). In that case another suitable nontoxic liquid may be used. If the liquid is flammable, its flash point shall be at least 49°C (120°F), and consideration shall be given to the test environment.

345.4.2 Test Pressure. Except as provided in para. 345.4.3, the hydrostatic test pressure at every point in a metallic piping system shall be as follows:

(a) not less than 1.5 times the design pressure.

(b) when the design temperature is greater than the test temperature, the minimum test pressure, at the point under consideration, shall be calculated using eq. (24).

$$P_T = 1.5\, P S_T / S \tag{24}$$

where

P = internal design gage pressure
P_T = minimum test gage pressure
S = allowable stress at component design temperature for the prevalent pipe material; see Table A-1 or Table A-1M
S_T = allowable stress at test temperature for the prevalent pipe material; see Table A-1 or Table A-1M

(c) in those cases where the piping system may not include pipe itself, any other component in the piping system, other than pipe-supporting elements and bolting, may be used to determine the S_T/S ratio based on the applicable allowable stresses obtained from Table A-1 or Table A-1M. In those cases where the piping system may be made up of equivalent lengths of more than one material, the S_T/S ratio shall be based on the minimum calculated ratio of the included materials.

345.4.3 Hydrostatic Test of Piping With Vessels as a System[3]

(a) Where the test pressure of piping attached to a vessel is the same as or less than the test pressure for the vessel, the piping may be tested with the vessel at the piping test pressure.

(b) Where the test pressure of the piping exceeds the vessel test pressure, and it is not considered practicable to isolate the piping from the vessel, the piping and the vessel may be tested together at the vessel test pressure, provided the owner approves and the vessel test pressure is not less than 77% of the piping test pressure calculated in accordance with para. 345.4.2(b).

345.5 Pneumatic Leak Test

345.5.1 Precautions. Pneumatic testing involves the hazard of released energy stored in compressed gas. Particular care must therefore be taken to minimize the chance of brittle failure during a pneumatic leak test. Test temperature is important in this regard and must be considered when the designer chooses the material of construction. See para. 345.2.2(c) and Appendix F, paras. F323.4 and F345.5.1.

345.5.2 Pressure Relief Device. A pressure relief device shall be provided, having a set pressure not higher than the test pressure plus the lesser of 345 kPa (50 psi) or 10% of the test pressure.

345.5.3 Test Fluid. The gas used as test fluid, if not air, shall be nonflammable and nontoxic.

345.5.4 Test Pressure. The test pressure shall be not less than 1.1 times the design pressure and shall not exceed the lesser of

(a) 1.33 times the design pressure

(b) the pressure that would exceed 90% of the pressure described in para. 345.2.1(a)

345.5.5 Procedure. The pressure shall be gradually increased until a gage pressure that is the lesser of one-half the test pressure or 170 kPa (25 psi) is attained, at which time a preliminary check shall be made, including examination of joints in accordance with para. 341.4.1(a). Thereafter, the pressure shall be gradually increased in steps until the test pressure is reached, holding the pressure at each step long enough to equalize piping strains. The pressure shall then be reduced to the design pressure before examining for leakage in accordance with para. 345.2.2(a).

345.6 Hydrostatic–Pneumatic Leak Test

If a combination hydrostatic–pneumatic leak test is used, the requirements of para. 345.5 shall be met, and the pressure in the liquid filled part of the piping shall not exceed the limits stated in para. 345.4.2.

345.7 Initial Service Leak Test

This test is applicable only to piping in Category D Fluid Service, at the owner's option. See para. 345.1(a).

345.7.1 Test Fluid. The test fluid is the service fluid.

345.7.2 Procedure. During or prior to initial operation, the pressure shall be gradually increased in steps until the operating pressure is reached, holding the pressure at each step long enough to equalize piping strains. A preliminary check shall be made as described in para. 345.5.5 if the service fluid is a gas or vapor.

345.7.3 Examination for Leaks. The examination for leaks required by para. 345.2.2(a) shall be conducted while the system is at operating pressure. It is permissible to omit examination for leaks of joints and connections previously tested in accordance with this Code.

345.8 Sensitive Leak Test

345.8.1 Precautions. The precautions described in para. 345.5.1 shall be considered when applicable.

345.8.2 Method. The test shall be the Bubble Test — Direct Pressure Technique in accordance with ASME BPVC, Section V, Article 10, Mandatory Appendix I or another leak test method that has a demonstrated sensitivity not less than 10^{-3} std mL/s under test conditions.

When the Bubble Test — Direct Pressure Technique is used

(a) the test pressure shall be at least the lesser of 105 kPa (15 psi) or 25% of the design pressure.

(b) the pressure shall be gradually increased until a gage pressure equal to the lesser of one-half the test pressure or 170 kPa (25 psi) is attained, at which time a preliminary check shall be made. Then the pressure shall be gradually increased in steps until the test pressure is reached, the pressure being held long enough at each step to equalize piping strains.

345.9 Alternative Leak Test

The following procedures and leak test method may be used only under the conditions stated in para. 345.1(c).

[3] The provisions of para. 345.4.3 do not affect the pressure test requirements of any applicable vessel code.

345.9.1 Examination of Welds. Welds, including those used in the manufacture of welded pipe and fittings, that have not been subjected to hydrostatic or pneumatic leak tests in accordance with this Code, shall be examined as follows:

(a) Circumferential, longitudinal, and spiral (helical seam) groove welds shall be 100% radiographed in accordance with para. 344.5 or 100% ultrasonically examined in accordance with para. 344.6.

(b) All welds, including structural attachment welds, not covered in (a) above, shall be examined using the liquid penetrant method (para. 344.4) or, for magnetic materials, the magnetic particle method (para. 344.3).

345.9.2 Flexibility Analysis. A flexibility analysis of the piping system shall have been made in accordance with the requirements of para. 319.4.2(b), if applicable, or paras. 319.4.2(c) and 319.4.2(d).

345.9.3 Test Method. The system shall be subjected to a sensitive leak test in accordance with para. 345.8.

346 RECORDS

346.2 Responsibility

It is the responsibility of the piping designer, the manufacturer, the fabricator, and the erector, as applicable, to prepare the records required by this Code and by the engineering design.

346.3 Retention of Records

Unless otherwise specified by the engineering design, the following records shall be retained for at least 5 yr after the record is generated for the project:

(a) examination procedures
(b) examination personnel qualifications
(c) examination reports

Chapter VII
Nonmetallic Piping and Piping Lined With Nonmetals

A300 GENERAL STATEMENTS

(a) Chapter VII pertains to nonmetallic piping and to piping lined with nonmetals.

(b) The organization, content, and paragraph designations of this Chapter correspond to those of the first six Chapters (the base Code). The prefix A is used.

(c) Provisions and requirements of the base Code apply only as stated in this Chapter.

(d) Metallic piping that provides the pressure containment for a nonmetallic lining shall conform to the requirements of Chapters I through VI, and to those in Chapter VII not limited to nonmetals.

(e) This Chapter makes no provision for piping to be used under severe cyclic conditions.

(f) With the exceptions stated above, Chapter I applies in its entirety.

PART 1
CONDITIONS AND CRITERIA

A301 DESIGN CONDITIONS

Paragraph 301 applies in its entirety, with the exception of paras. 301.2 and 301.3. See below.

A301.2 Design Pressure

Paragraph 301.2 applies in its entirety, except that references to paras. A302.2.4 and A304 replace references to paras. 302.2.4 and 304, respectively.

A301.3 Design Temperature

Paragraph 301.3 applies with the following exceptions.

A301.3.1 Design Minimum Temperature. Paragraph 301.3.1 applies; but see para. A323.2.2, rather than para. 323.2.2.

A301.3.2 Uninsulated Components. The component design temperature shall be the fluid temperature, unless a higher temperature will result from solar radiation or other external heat sources.

A302 DESIGN CRITERIA

Paragraph A302 states pressure–temperature ratings, stress criteria, design allowances, and minimum design values, together with permissible variations of these factors as applied to the design of piping.

A302.1 General

The designer shall be satisfied as to the adequacy of the nonmetallic material and its manufacture, considering at least the following:

(a) tensile, compressive, flexural, and shear strength, and modulus of elasticity, at design temperature (long term and short term)

(b) creep rate at design conditions

(c) design stress and its basis

(d) ductility and plasticity

(e) impact and thermal shock properties

(f) temperature limits

(g) transition temperature — melting and vaporization

(h) porosity and permeability

(i) testing methods

(j) methods of making joints and their efficiency

(k) possibility of deterioration in service

A302.2 Pressure–Temperature Design Criteria

A302.2.1 Listed Components Having Established Ratings. Paragraph 302.2.1 applies, except that reference to Table A326.1 replaces reference to Table 326.1.

A302.2.2 Listed Components Not Having Specific Ratings. Nonmetallic piping components for which design stresses have been developed in accordance with para. A302.3, but which do not have specific pressure–temperature ratings, shall be rated by rules for pressure design in para. A304, within the range of temperatures for which stresses are shown in Appendix B, modified as applicable by other rules of this Code.

Piping components that do not have allowable stresses or pressure–temperature ratings shall be qualified for pressure design as required by para. A304.7.2.

A302.2.3 Unlisted Components. Paragraph 302.2.3 applies, except that references to Table A326.1 and paras. A304 and A323 replace references to Table 326.1 and paras. 304 and 323, respectively.

A302.2.4 Allowances for Pressure and Temperature Variations

(a) Nonmetallic Piping. Allowances for variations of pressure or temperature, or both, above design conditions are not permitted. The most severe conditions of coincident pressure and temperature shall be used to determine the design conditions for a piping system. See paras. 301.2 and 301.3.

(b) Metallic Piping With Nonmetallic Lining. Allowances for pressure and temperature variations provided in para. 302.2.4 are permitted only if the suitability of the lining material for the increased conditions is established through prior successful service experience or tests under comparable conditions.

A302.2.5 Rating at Junction of Different Services. When two services that operate at different pressure–temperature conditions are connected, the valve segregating the two services shall be rated for the more severe service condition.

A302.3 Allowable Stresses and Other Design Limits

A302.3.1 General

(a) Table B-1 contains hydrostatic design stresses (HDS). Tables B-2 and B-3 provide listings of specifications that meet the criteria of paras. A302.3.2(b) and A302.3.2(c), respectively. Tables B-4 and B-5 contain allowable pressures. These HDS values, allowable stress criteria, and pressures shall be used in accordance with the Notes to Appendix B, and may be used in design calculations (where the allowable stress S means the appropriate design stress) except as modified by other provisions of this Code. Use of hydrostatic design stresses for calculations other than pressure design has not been verified. The bases for determining allowable stresses and pressures are outlined in para. A302.3.2.

(b) The stresses and allowable pressures are grouped by materials and listed for stated temperatures. Straight-line interpolation between temperatures is permissible.

A302.3.2 Bases for Allowable Stresses and Pressures[1]

(a) Thermoplastics. The method of determining HDS is described in ASTM D2837. HDS values are given in Table B-1 for those materials and temperatures for which sufficient data have been compiled to substantiate the determination of stress.

(b) Reinforced Thermosetting Resin (Laminated). The design stress (DS) values for materials listed in Table B-2 shall be one-tenth of the minimum tensile strengths specified in ASTM C582 and are valid only in the temperature range from −29°C (−20°F) through 82°C (180°F).

(c) Reinforced Thermosetting Resin and Reinforced Plastic Mortar (Filament Wound and Centrifugally Cast). The hydrostatic design basis stress (HDBS) values for materials listed in Table B-3 shall be obtained by the procedures in ASTM D2992 and are valid only at 23°C (73°F). HDS shall be obtained by multiplying the HDBS by a service (design) factor[2] selected for the application, in accordance with procedures described in ASTM D2992, within the following limits:

(1) When using the cyclic HDBS, the service (design) factor F shall not exceed 1.0.

(2) When using the static HDBS, the service (design) factor F shall not exceed 0.5.

(d) Other Materials. Allowable pressures in Tables B-4 and B-5 have been determined conservatively from physical properties of materials conforming to the listed specifications, and have been confirmed by extensive experience. Use of other materials shall be qualified as required by para. A304.7.2.

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[1] Titles of ASTM Specifications and AWWA Standards referenced herein are as follows:

ASTM C14, Concrete Sewer, Storm Drain, and Culvert Pipe

ASTM C301, Method of Testing Vitrified Clay Pipe

ASTM C582, Contact-Molded Reinforced Thermosetting Plastic (RTP) Laminates for Corrosion Resistant Equipment

ASTM D2321, Practice for Underground Installation of Thermoplastic Pipe for Sewers and Other Gravity-Flow Applications

ASTM D2837, Test Method for Obtaining Hydrostatic Design Basis for Thermoplastic Pipe Materials or Pressure Design Basis for Thermoplastic Pipe Products

ASTM D2992, Practice for Obtaining Hydrostatic or Pressure Design Basis for "Fiberglass" (Glass-Fiber-RTR) Pipe and Fittings

ASTM D3839, Underground Installation of Fiberglass Pipe

AWWA C900, Polyvinyl Chloride (PVC) Pressure Pipe and Fabricated Fittings, 4 In. Through 60 In. (100 mm Through 1,500 mm)

AWWA C950, Glass-Fiber-Reinforced Thermosetting Resin Pressure Pipe

[2] The service (design) factor, F, should be selected by the designer after evaluating fully the service conditions and the engineering properties of the specific material under consideration. Aside from the limits in paras. A302.3.2(c)(1) and A302.3.2(c)(2), it is not the intent of this Code to specify service (design) factors.

A302.3.3 Limits of Calculated Stresses Due to Sustained Loads[1]

(a) Internal Pressure Stresses. Limits of stress due to internal pressure are covered in para. A304.

(b) External Pressure Stresses. Stresses due to uniform external pressure shall be considered safe when the wall thickness of the component and its means of stiffening have been qualified as required by para. A304.7.2.

(c) External Loading Stresses. Design of piping under external loading shall be based on the following:

(1) Thermoplastic Piping. ASTM D2321 or AWWA C900.

(2) Reinforced Thermosetting Resin (RTR) and Reinforced Plastic Mortar (RPM) Piping. ASTM D3839 or Appendix A of AWWA C950.

(3) Strain and possible buckling shall be considered when determining the maximum allowable deflection in (1) or (2) above, but in no case shall the allowable diametral deflection exceed 5% of the pipe inside diameter.

(4) Nonmetallic piping not covered in (1) or (2) above shall be subjected to a crushing or three-edge bearing test in accordance with ASTM C14 or C301; the allowable load shall be 25% of the minimum value obtained.

A302.3.4 Limits of Calculated Stresses Due to Occasional Loads

(a) Operation

(1) For other than RTR and RPM piping, the sum of stresses in any component in a piping system due to sustained loads, such as pressure and weight, and of the stresses produced by occasional loads, such as wind or earthquake, shall not exceed the limits in the applicable part of para. A302.3.3.

(2) For RTR and RPM piping, the sum of stresses due to operating loads plus stresses due to occasional loads may be as much as 1.33 times the limits in the applicable part of para. A302.3.3.

(3) Wind and earthquake forces need not be considered as acting concurrently.

(b) Test. Stresses due to test conditions are not subject to the limitations in para. A302.3.3. It is not necessary to consider other occasional loads, such as wind and earthquake, as occurring concurrently with test loads.

A302.4 Allowances

Paragraph 302.4 applies in its entirety.

PART 2
PRESSURE DESIGN OF PIPING COMPONENTS

A303 GENERAL

Paragraph 303 applies, except that references to Table A326.1 and para. A302.2.1 replace references to Table 326.1 and para. 302.2.1. For nonmetallic components, reference to para. A304 replaces reference to para. 304.

A304 PRESSURE DESIGN OF PIPING COMPONENTS

A304.1 Straight Pipe

A304.1.1 General

(a) The required thickness of straight sections of pipe shall be determined by eq. (25).

$$t_m = t + c \tag{25}$$

The minimum thickness T for the pipe selected, considering manufacturer's minus tolerance, shall be not less than t_m.

(b) The following nomenclature is used in the equations for pressure design of straight pipe:

c = the sum of mechanical allowances (thread or groove depth) plus corrosion and erosion allowance. For threaded components, the nominal thread depth (dimension h of ASME B1.20.1 or equivalent) shall apply. For machined surfaces or grooves where the tolerance is not specified, the tolerance shall be assumed to be 0.5 mm (0.02 in.) in addition to the specified depth of the cut.
D = outside diameter of pipe
F = service (design) factor. See para. A302.3.2(c).
P = internal design gage pressure
S = design stress from applicable Table in Appendix B
T = pipe wall thickness (measured or minimum in accordance with the purchase specification)
t = pressure design thickness, as calculated in accordance with para. A304.1.2 for internal pressure or as determined in accordance with para. A304.1.3 for external pressure
t_m = minimum required thickness, including mechanical, corrosion, and erosion allowances

A304.1.2 Straight Nonmetallic Pipe Under Internal Pressure. The internal pressure design thickness, t, shall be not less than that calculated by one of the following equations, using stress values listed in or derived from the appropriate table in Appendix B:

(a) *Thermoplastic Pipe* [see para. A302.3.2(a)]

$$t = \frac{PD}{2S + P}(\text{Table B-1}) \tag{26a}$$

(b) *RTR (Laminated) Pipe* [see para. A302.3.2(b)][3]

$$t = \frac{PD}{2S + P}(\text{Table B-2}) \tag{26b}$$

(c) *RTR (Filament Wound) and RPM (Centrifugally Cast) Pipe* [see para. A302.3.2(c)][3]

$$t = \frac{PD}{2SF + P}(\text{Table B-3}) \tag{26c}$$

A304.1.3 Straight Pipe Under External Pressure

(a) *Nonmetallic Pipe.* The external pressure design thickness, t, shall be qualified as required by para. A304.7.2.

(b) *Metallic Pipe Lined With Nonmetals*

(1) The external pressure design thickness, t, for the base (outer) material shall be determined in accordance with para. 304.1.3.

(2) The external pressure design thickness, t, for the lining material shall be qualified as required by para. A304.7.2.

A304.2 Curved and Mitered Segments of Pipe

A304.2.1 Pipe Bends. The minimum required thickness, t_m, of a bend, after bending, shall be determined as for straight pipe in accordance with para. A304.1.

A304.2.2 Elbows. Manufactured elbows not in accordance with para. A303 shall be qualified as required by para. A304.7.2.

A304.2.3 Miter Bends. Miter bends shall be qualified as required by para. A304.7.2.

A304.3 Branch Connections

A304.3.1 General. A pipe having a branch connection is weakened by the opening that must be made in it and, unless the wall thickness of the pipe is sufficiently in excess of that required to sustain the pressure, it is necessary to provide added reinforcement. The amount of reinforcement shall be qualified as required by para. A304.7.2 except as provided in para. A304.3.2.

A304.3.2 Branch Connections Using Fittings. It may be assumed without calculation that a branch connection has adequate strength to sustain the internal and external pressure that will be applied to it if it utilizes a fitting (a tee, lateral, or cross) in accordance with para. A303.

[3] The internal design pressure thickness, t, shall not include any thickness of the pipe wall reinforced with less than 20% by weight of reinforcing fibers.

A304.3.3 Additional Design Considerations. The requirements of paras. A304.3.1 and A304.3.2 are intended to assure satisfactory performance of a branch connection subjected only to internal or external pressure. The designer shall also consider paras. 304.3.5(a), (c), and (d).

A304.4 Closures

Closures not in accordance with para. A303 shall be qualified as required by para. A304.7.2.

A304.5 Pressure Design of Nonmetallic Flanges

A304.5.1 General

(a) Flanges not in accordance with para. A303 or (b) or (d) shall be qualified as required by para. A304.7.2.

(b) Flanges for use with flat ring gaskets may be designed in accordance with ASME BPVC, Section VIII, Division 1, Appendix 2, except that the allowable stresses and temperature limits of this Code shall govern. Nomenclature shall be as defined in ASME BPVC, except for the following:

P = design gage pressure
S_a = bolt design stress at atmospheric temperature[4]
S_b = bolt design stress at design temperature[4]
S_f = allowable stress for flange material from Table B-1, B-2, or B-3

(c) The rules in (b) above are not applicable to a flanged joint having a gasket that extends outside the bolts (usually to the outside diameter of the flange).

(d) For flanges that make solid contact outside the bolts, ASME BPVC, Section VIII, Division 1, Appendix Y should be used.

A304.5.2 Blind Flanges. Blind flanges not in accordance with para. A303 may be designed in accordance with para. 304.5.2, except that allowable stress, S, shall be taken from Tables in Appendix B. Otherwise, they shall be qualified as required by para. A304.7.2.

A304.6 Reducers

Reducers not in accordance with para. A303 shall be qualified as required by para. A304.7.2.

A304.7 Pressure Design of Other Components

A304.7.1 Listed Components. Other pressure containing components, manufactured in accordance with standards in Table A326.1 but not covered elsewhere in para. A304, may be utilized in accordance with para. A303.

A304.7.2 Unlisted Components. Pressure design of unlisted components and joints, to which the rules elsewhere in para. A304 do not apply, shall be based on calculations consistent with the design criteria of this Code.

[4] Bolt design stresses shall not exceed those in Table A-2 or Table A-2M.

Calculations shall be substantiated by one or both of the means stated in (a) and (b) below, considering applicable ambient and dynamic effects in paras. 301.4 through 301.11.

(a) extensive, successful service experience under comparable design conditions with similarly proportioned components made of the same or like material

(b) performance test under design conditions including applicable dynamic and creep effects, continued for a time period sufficient to determine the acceptability of the component or joint for its design life

For (a) or (b) above, the designer may interpolate between sizes, wall thicknesses, and pressure classes, and may determine analogies among related materials.

A304.7.3 Nonmetallic Components With Metallic Pressure Parts. Components not covered by standards in Table A326.1, in which both nonmetallic and metallic parts contain the pressure, shall be evaluated by applicable requirements of para. 304.7.2 as well as those of para. A304.7.2.

PART 3
FLUID SERVICE REQUIREMENTS FOR PIPING COMPONENTS

A305 PIPE

Listed pipe may be used in Normal Fluid Service, subject to the limitations of the pressure-containing material and para. A323.4. Unlisted pipe may be used only in accordance with para. A302.2.3.

A306 FITTINGS, BENDS, MITERS, LAPS, AND BRANCH CONNECTIONS

General. Fittings, bends, miters, laps, and branch connections may be used in accordance with paras. A306.1 through A306.5. Pipe and other materials used in such components shall be suitable for the manufacturing process and the fluid service.

A306.1 Pipe Fittings

A306.1.1 Listed Fittings. Listed fittings may be used in Normal Fluid Service subject to limitations on materials.

A306.1.2 Unlisted Fittings. Unlisted fittings may be used only in accordance with para. A302.2.3.

A306.2 Pipe Bends

A306.2.1 General. A bend made in accordance with para. A332 and verified for pressure design in accordance with para. A304.2.1 shall be suitable for the same service as the pipe from which it is made.

A306.2.2 Corrugated and Other Bends. Bends of other designs (such as creased or corrugated) shall be qualified for pressure design as required by para. A304.7.2.

A306.3 Miter Bends

Except as specified in para. 306.3.2, a miter bend that conforms to para. A304.2.3 may be used in Normal Fluid Service.

A306.4 Fabricated or Flared Laps

The following requirements do not apply to fittings conforming to para. A306.1.

A306.4.1 Fabricated Laps

(a) The requirements in paras. 306.4.1(a) and (b) shall be met.

(b) Lap material shall be suitable for the service conditions. Pressure design shall be qualified as required by para. A304.7.2.

A306.4.2 Flared Laps. Flared laps shall not be used in nonmetallic piping.

A306.5 Fabricated Branch Connections

The following requirements do not apply to fittings conforming to para. A306.1.

A306.5.1 General. A fabricated branch connection made by bonding the branch pipe directly to the header pipe, with or without added reinforcement as stated in para. 328.5.4, and shown in Figure 328.5.4, may be used in Normal Fluid Service, provided that pressure design is qualified as required by para. A304.7.2.

A306.5.2 Specific Requirements. Fabricated branch connections shall be made as specified in para. A328.5.

A307 VALVES AND SPECIALTY COMPONENTS

Paragraph 307 applies in its entirety, except that in para. 307.1.2 references to paras. A302.2.3 and A304.7.2 replace references to paras. 302.2.3 and 304.7.2, respectively.

A308 FLANGES, BLANKS, FLANGE FACINGS, AND GASKETS

A308.1 General

Paragraph 308.1 applies, except that in para. 308.1.2 reference to para. A302.2.3 replaces reference to para. 302.2.3.

A308.2 Nonmetallic Flanges

A308.2.1 General

(a) Flanges shall be adequate, with suitable facing, gasketing, and bolting, to develop the full rating of the joint and to withstand expected external loadings.

(b) The designer should consult the manufacturer for ratings of flanges.

A308.2.2 Threaded Flanges. Threaded flanges are subject to the requirements for threaded joints in para. A314.

A308.3 Flange Facings

Paragraph 308.3 applies in its entirety.

A308.4 Limitations on Gaskets

See also Appendix F, para. F308.4.

A308.4.1 Lining Used as Facing or Gasket. Lining material extended over the flange face and used as a gasket shall conform to para. 308.4.

A309 BOLTING

Bolting includes bolts, bolt studs, studs, cap screws, nuts, and washers. See Appendix F, para. F309.

A309.1 General

Paragraph 309.1 applies in its entirety.

A309.2 Specific Bolting

Any bolting that meets the requirements of para. 309.1 may be used with any combination of flange materials and flange facings. Joint assembly shall conform to the requirements of para. A335.2.

A309.3 Tapped Holes in Nonmetallic Components

Tapped holes for pressure-retaining bolting in piping components may be used provided pressure design is qualified as required by para. A304.7.2.

PART 4
FLUID SERVICE REQUIREMENTS FOR PIPING JOINTS

A310 GENERAL

Paragraph 310 applies in its entirety.

A311 BONDED JOINTS IN PLASTICS

A311.1 General

Bonding shall be in accordance with para. A328 and examination shall be in accordance with para. A341.4.1 for use in Normal Fluid Service, subject to the limitations of the material.

A311.2 Specific Requirements

A311.2.1 Fillet Bonds. A fillet bond may be used only in conjunction with a qualified hot gas welding procedure for bonding (see para. A328.5.2).

A311.2.2 Seal Bonds. A seal bond may be used only to prevent leakage of a threaded joint and only if it has been demonstrated that there will be no deleterious effect on the materials bonded.

A311.2.3 Joints Limited to Category D Fluid Service. Joints that have been examined in accordance with para. 341.4.2 may be used only for Category D Fluid Service.

A312 FLANGED JOINTS

The designer should consult the manufacturer for ratings of flanged joints in nonmetallic piping and in piping lined with nonmetals.

A313 EXPANDED JOINTS

Paragraph 313 applies in its entirety.

A314 THREADED JOINTS

A314.1 General

A threaded joint is suitable for use in Normal Fluid Service, subject to the limitations of the material and requirements elsewhere in para. A314. A joint conforming to para. 314.1(d) shall not be used.

A314.2 Specific Requirements

A314.2.1 Thermoplastic Piping

(a) Polyethylene (PE) pipe and tubing shall not be joined by threaded joints.

(b) Threaded joints in other thermoplastic piping shall conform to all of the following:

(1) The pipe wall shall be at least as thick as Schedule 80 as defined in ASTM D1785.

(2) Threads shall be NPT, and shall conform to ASME B1.20.1 or ASTM F1498.

(3) Threads shall conform to applicable standards in Table A326.1.

(4) A suitable thread sealant shall be used.

A314.2.2 Reinforced Thermosetting Resin Piping. Threaded joints in reinforced thermosetting resin (RTR) piping shall conform to the following:

(a) External threads shall be factory cut or molded on special thick-walled pipe ends.

(b) Matching internal threads shall be factory cut or molded in the fittings.

(c) Threading of plain ends of RTR pipe is not permitted, except where such threads are limited to the function of a mechanical lock to matching internal threads factory cut or molded in the bottom portions of fittings with deep sockets.

(d) Factory cut or molded threaded nipples, couplings, or adapters, bonded to plain-end RTR pipe and fittings, may be used where it is necessary to provide connections to threaded metallic piping.

A314.2.3 Reinforced Plastic Mortar Piping. Threaded joints are not permitted in reinforced plastic mortar (RPM) piping.

A315 TUBING JOINTS

Paragraph 315 applies in its entirety, subject to material limitations, exclusion of 315.2(b) regarding severe cyclic conditions, and replacement of references to Table 326.1 and para. 304.7.2 with references to Table A326.1 and para. A304.7.2, respectively.

A316 CAULKED JOINTS

Paragraph 316 applies in its entirety.

A318 SPECIAL JOINTS

Special joints are those not covered elsewhere in Chapter VII, Part 4, such as bell type and packed gland type joints.

A318.1 General

Paragraph 318.1 applies in its entirety, except that, in para. 318.1.2, reference to para. A304.7.2 replaces reference to para. 304.7.2.

A318.2 Specific Requirements

Paragraph 318.2 applies with the exception of para. 318.2.3.

A318.3 Piping Lined With Nonmetals

A318.3.1 Welding of Metallic Piping

(a) General. Joints made in accordance with the rules in para. A329.1 may be used in Normal Fluid Service, subject to material limitations.

(b) Specific Requirements. Welds shall be limited to those that do not affect the serviceability of the lining.

A318.3.2 Flared Linings

(a) General. Flared ends of linings made in accordance with the rules in para. A329.2 may be used in Normal Fluid Service, subject to material limitations.

(b) Specific Requirements. Flaring shall be limited to applications that do not affect the serviceability of the lining.

A318.4 Flexible Elastomeric Sealed Joints

Flexible elastomeric seals conforming to the following may be used in Normal Fluid Service, subject to material limitations:

(a) Seals for joints in thermoplastic piping shall conform to ASTM D3139.

(b) Seals for joints in RTR and RPM piping shall conform to ASTM D4161.

PART 5
FLEXIBILITY AND SUPPORT

A319 FLEXIBILITY OF NONMETALLIC PIPING

A319.1 Requirements

A319.1.1 Basic Requirements. Piping systems shall be designed to prevent thermal expansion or contraction, pressure expansion, or movement of piping supports and terminals from causing

(a) failure of piping or supports from overstrain or fatigue

(b) leakage at joints

(c) detrimental stresses or distortion in piping or in connected equipment (e.g., pumps), resulting from excessive thrusts and moments in the piping

A319.1.2 Specific Requirements

(a) In para. A319, guidance, concepts, and data are given to assist the designer in assuring adequate flexibility in piping systems. No specific stress-limiting criteria or methods of stress analysis are presented, since stress–strain behavior of most nonmetals differs considerably from that of metals covered by para. 319 and is less well defined for mathematical analysis.

(b) Piping systems should be designed and laid out so that flexural stresses resulting from displacement due to expansion, contraction, and other movement are minimized. This concept requires special attention to supports, terminals, and other restraints, as well as to the techniques outlined in para. A319.7. See also para. A319.2.2(b).

(c) Further information on design of thermoplastic piping can be found in PPI Technical Report TR-21.

A319.2 Concepts

A319.2.1 Displacement Strains. The concepts of strain imposed by restraint of thermal expansion or contraction, and by external movement, described in para. 319.2.1, apply in principle to nonmetals. Nevertheless, the assumption that stresses throughout the piping systems can be predicted from these strains because of fully elastic behavior of the piping materials is not always valid.

(a) In thermoplastics piping, displacement strains are not likely to produce immediate failure but may result in detrimental distortion. Progressive deformation may occur upon repeated thermal cycling or on prolonged exposure to elevated temperature.

(b) In brittle piping (e.g., porcelain and glass) and some RTR and RPM piping, the materials show rigid behavior and develop high displacement stresses up to the point of sudden breakage due to overstrain.

(c) RTR and RPM piping are assumed to display linear elastic behavior, having displacement stresses proportional to displacement strains.

A319.2.2 Displacement Stresses

(a) Elastic Behavior. The assumption that displacement strains will produce proportional stress over a sufficiently wide range to justify an elastic stress analysis is not always valid for nonmetals. RTR and RPM piping shall be designed for linear elastic behavior, having displacement stresses proportional to displacement strains. In brittle piping, strains initially will produce relatively large elastic stresses. The total displacement strain must be kept small, however, since overstrain results in failure rather than plastic deformation. In thermoplastic piping, strains generally will produce stresses of the overstrained (plastic) type, even at relatively low values of total displacement strain. If a method of flexibility analysis that assumes elastic behavior is selected for thermoplastic piping, the designer shall demonstrate its validity for the piping system under consideration and shall establish safe limits for computed stresses.

(b) Overstrained Behavior. Stresses cannot be considered proportional to displacement strains throughout a piping system in which an excessive amount of strain may occur in localized portions of the piping [an unbalanced system; see para. 319.2.2(b)] or in which elastic behavior of the piping material cannot be assumed. Overstrain shall be minimized by system layout and excessive displacements shall be minimized by special joints or expansion devices (see para. A319.7).

A319.2.3 Cold Spring. Cold spring is the intentional deformation of piping during assembly to produce a desired initial displacement or reaction. Cold spring may be beneficial in serving to balance the magnitude of the reaction under initial and extreme displacement conditions. When cold spring is properly applied, there is less likelihood of overstrain during initial operation. There is also less deviation from as-installed dimensions during initial operation, so that hangers will not be displaced as far from their original settings. No credit for cold spring is permitted in stress range calculations, or in calculating thrusts and moments.

A319.3 Properties for Flexibility Analysis

A319.3.1 Thermal Expansion Data. Appendix C lists coefficients of thermal expansion for several nonmetals. More precise values in some instances may be obtainable from manufacturers of components. If these values are to be used in stress analysis, the thermal displacements shall be determined as stated in para. 319.3.1.

A319.3.2 Modulus of Elasticity. Appendix C lists representative data on the tensile modulus of elasticity, E, for several nonmetals as obtained under typical laboratory rate of strain (loading) conditions. More precise values of the short-term and working estimates of effective moduli of elasticity for given conditions of loading and temperature may be obtainable from the manufacturer. For materials and temperatures not listed, refer to ASTM or PPI documents, or to manufacturer's data.

(a) Because of their viscoelasticity, the effective moduli of thermoplastics under actual conditions of use will depend on both the specific course of the strain (or load) with time and the specific characteristics of the thermoplastic.

(b) The modulus may also vary with the orientation of the specimen. Because the reinforcement plays a significant role in developing the physical properties for RTR and RPM piping, the modulus may vary with the type and orientation of the reinforcement.

A319.3.3 Poisson's Ratio. Poisson's ratio varies widely depending upon material and temperature. For that reason, simplified formulas used in stress analysis for metals may not be valid for nonmetals. For RTR and RPM piping, Poisson's ratio varies with the orientation of the reinforcement.

A319.3.4 Dimensions. Nominal thicknesses and outside diameters of pipe and fittings shall be used in flexibility calculations.

A319.4 Analysis

A319.4.1 Formal Analysis Not Required. No formal analysis is required for a piping system that

(a) duplicates, or replaces without significant change, a system operating with a successful service record

(b) can readily be judged adequate by comparison with previously analyzed systems, or

(c) is laid out with a conservative margin of inherent flexibility, or employs joining methods or expansion joint devices, or a combination of these methods, in accordance with manufacturers' instructions

A319.4.2 Formal Analysis Requirements. For a piping system that does not meet the above criteria, the designer shall demonstrate adequate flexibility by simplified, approximate, or comprehensive stress analysis, using a method that can be shown to be valid for the specific case. If substantially elastic behavior can be demonstrated for the piping system [see para. A319.2.2(a)], methods outlined in para. 319.4 may be applicable.

A319.5 Reactions

Paragraph 319.5 may be applicable if a formal stress analysis can be shown to be valid for the specific case.

A319.6 Movements

Special attention shall be given to movement (displacement or rotation) of piping with respect to supports and points of close clearance. Movements of the run pipe at the junction of a small branch connection shall be considered in determining the need for flexibility in the branch pipe.

A319.7 Means of Increasing Flexibility

Piping layout often provides adequate inherent flexibility through changes in direction, wherein displacements produce chiefly bending and torsional strains of low magnitude. The amount of tension or compression strain (which can produce larger reactions) usually is small.

Where piping lacks inherent flexibility or is unbalanced, additional flexibility shall be provided by one or more of the following means: bends, loops, or offsets; swivel or flexible joints; corrugated, bellows, or slip-joint expansion joints; or other devices permitting angular, rotational, or axial movement. Suitable anchors, ties, or other devices shall be provided as necessary to resist end forces produced by fluid pressure, frictional resistance to movement, and other causes.

A321 PIPING SUPPORT

Paragraph 321 applies in its entirety.

A321.5 Supports for Nonmetallic Piping

(20) **A321.5.1 General.** In addition to other applicable requirements of para. 321, supports, guides, and anchors shall be selected and applied to comply with the principles and requirements of para. A319 and the following:

(a) Piping shall be supported, guided, and anchored in such a manner as to prevent damage to the piping. Point loads and narrow areas of contact between piping and supports shall be avoided. Suitable padding, compatible with the piping material, shall be placed between piping and supports where damage to piping may occur. Local stresses at points of support, including clamping forces, shall be considered.

(b) Valves and equipment that would transmit excessive loads to the piping shall be independently supported to prevent such loads.

(c) Consideration shall be given to mechanical guarding in traffic areas.

(d) Manufacturers' recommendations for support shall be considered.

A321.5.2 Supports for Thermoplastic, RTR, and RPM Piping. (20)

(a) Supports shall be spaced to avoid excessive sag or deformation at the design temperature and within the design life of the piping system.

(b) Decreases in the modulus of elasticity with increasing temperature and creep of material with time shall be considered when applicable.

(c) The thermal expansion of the piping system shall be considered in the design and location of supports.

(d) Where axial restraint is required, positive stops, such as shear collars, shall be provided as axial restraint. Frictional forces from clamping pressure shall not be considered as an anchor mechanism unless the support/anchor is specifically recommended for this purpose by the manufacturer.

A321.5.3 Supports for Brittle Piping. Brittle piping, such as glass, shall be well supported but free of hindrance to expansion or other movement. Not more than one anchor shall be provided in any straight run without an expansion joint.

PART 6
SYSTEMS

A322 SPECIFIC PIPING SYSTEMS

A322.3 Instrument Piping

Paragraph 322.3 applies in its entirety, except that references to paras. A301 and A302.2.4 replace references to paras. 301 and 302.2.4, respectively.

A322.6 Pressure-Relieving Systems

Paragraph 322.6 applies in its entirety, except for para. 322.6.3. See para. A322.6.3.

A322.6.3 Overpressure Protection. Paragraph 322.6.3 applies, except that maximum relieving pressure shall be in accordance with para. A302.2.4.

PART 7
MATERIALS

A323 GENERAL REQUIREMENTS

A323.1 Materials and Specifications

Paragraph 323.1 applies except for para. 323.1.4. See para. A323.1.4.

A323.1.4 Reclaimed Materials. Reclaimed piping components may be used, provided they are properly identified as conforming to a listed or published specification (see para. 323.1.1) and otherwise meet the requirements of this Code. The user shall verify that components are suitable for the intended service. Sufficient cleaning, examination, and testing shall be performed to determine the minimum available wall thickness and freedom from any of the following to an extent that would be unacceptable in the intended service:

(a) imperfections
(b) reduction of mechanical properties, or
(c) absorption of deleterious substances

A323.2 Temperature Limitations

The designer shall verify that materials that meet other requirements of the Code are suitable for service throughout the operating temperature range. Also see the Notes for Tables B-1 through B-5 in Appendix B.

A323.2.1 Upper Temperature Limits, Listed Materials

(a) Except as provided in (b) below, a listed material shall not be used at a design temperature higher than the maximum for which a stress value or rating is shown, or higher than the maximum recommended temperature in Table A323.4.2C for RTR materials and in Table A323.4.3 for thermoplastics used as linings.

(b) A listed material may be used at a temperature higher than the maximum stated in (a) above if there is no prohibition in Appendix B or elsewhere in the Code, and if the designer verifies the serviceability of the material in accordance with para. 323.2.4.

A323.2.2 Lower Temperature Limits, Listed Materials

(a) Materials for use at design minimum temperatures below certain limits must usually be tested to determine that they have suitable toughness for use in Code piping. Table A323.2.2 sets forth those requirements.

(b) When materials are qualified for use at temperatures below the minimum temperature listed in Appendix B, the allowable stresses or pressures shall not exceed the values for the lowest temperatures shown.

(c) See also the recommended limits in Table A323.4.2C for reinforced thermosetting resin pipe and in Table A323.4.3 for thermoplastics used as linings.

A323.2.3 Temperature Limits, Unlisted Materials. Paragraph 323.2.3 applies.

A323.2.4 Verification of Serviceability. When an unlisted material is to be used, or when a listed material is to be used above or below the limits in Appendix B, Table A323.4.2C, or Table A323.4.3, the designer shall comply with the requirements of para. 323.2.4.

A323.4 Fluid Service Requirements for Nonmetallic Materials

A323.4.1 General

(a) Nonmetallic materials shall be safeguarded against excessive temperature, shock, vibration, pulsation, and mechanical abuse in all fluid services.

(b) Requirements in para. A323.4 apply to pressure-containing parts. They do not apply to materials used for supports, gaskets, or packing. See also Appendix F, para. FA323.4.

A323.4.2 Specific Requirements

(a) *Thermoplastics*

(1) They shall not be used in flammable fluid service above ground, unless all of the following are met:

(-a) The size of the piping does not exceed DN 25 (NPS 1).

(-b) Owner's approval is obtained.

(-c) Safeguarding in accordance with Appendix G is provided.

(-d) The precautions of Appendix F, paras. F323.1(a) through F323.1(c) are considered.

(2) They shall be safeguarded when used in other than Category D Fluid Service.

(3) PVC and CPVC shall not be used in compressed air or other compressed gas service.

(b) *Reinforced Plastic Mortars (RPM) Piping.* This piping shall be safeguarded when used in other than Category D Fluid Service.

(c) *Reinforced Thermosetting Resins (RTR) Piping.* This piping shall be safeguarded when used in toxic or flammable fluid services. Table A323.4.2C gives the recommended temperature limits for reinforced thermosetting resins.

(d) *Borosilicate Glass and Porcelain*

(1) They shall be safeguarded when used in toxic or flammable fluid services.

(2) They shall be safeguarded against large, rapid temperature changes in fluid services.

A323.4.3 Piping Lined With Nonmetals

(a) *Metallic Piping Lined With Nonmetals.* Fluid service requirements for the base (outer) material in para. 323.4 govern except as stated in (d) below.

Table A323.2.2 Requirements for Low Temperature Toughness Tests for Nonmetals

Type of Material	Column A At or Above Listed Minimum Temperature	Column B Below Listed Minimum Temperature
Listed nonmetallic materials	No added requirement	The designer shall have test results at or below the lowest expected service temperature which assure that the materials and bonds will have adequate toughness and are suitable at the design minimum temperature.
Unlisted materials	An unlisted material shall conform to a published specification. Where composition, properties, and product form are comparable to those of a listed material, requirements for the corresponding listed material shall be met. Other unlisted materials shall be qualified as required in Column B.	

GENERAL NOTE: These requirements are in addition to the requirements of the material specification.

Table A323.4.2C Recommended Temperature Limits for Reinforced Thermosetting Resin Pipe

Materials		Recommended Temperature Limits			
		Minimum		Maximum	
Resin	Reinforcing	°C	°F	°C	°F
Epoxy	Glass fiber	−29	−20	149	300
Phenolic	Glass fiber	−29	−20	149	300
Furan	Carbon	−29	−20	93	200
Furan	Glass fiber	−29	−20	93	200
Polyester	Glass fiber	−29	−20	93	200
Vinyl ester	Glass fiber	−29	−20	93	200

GENERAL NOTE: These temperature limits apply only to materials listed and do not reflect evidence of successful use in specific fluid services at these temperatures. The designer should consult the manufacturer for specific applications, particularly as the temperature limits are approached.

(b) Nonmetallic Piping Lined With Nonmetals. Fluid service requirements for the base (outer) material in para. A323.4.2 govern, except as stated in (d) below.

(c) Nonmetallic Lining Materials. The lining may be any material that, in the judgment of the user, is suitable for the intended service and for the method of manufacture and assembly of the piping. Fluid service requirements in para. A323.4.2 do not apply to materials used as linings.

(d) Properties of both the base and lining materials, and of any bond between them, shall be considered in establishing temperature limitations. Table A323.4.3 gives recommended temperature limits for thermoplastic materials used as linings.

A323.5 Deterioration of Materials in Service

Paragraph 323.5 applies in its entirety.

A325 MATERIALS — MISCELLANEOUS

Paragraph 325 applies in its entirety.

PART 8 STANDARDS FOR PIPING COMPONENTS

A326 DIMENSIONS AND RATINGS OF COMPONENTS

A326.1 Requirements

Paragraph 326 applies in its entirety except that references to Table A326.1 and Appendix B replace references to Table 326.1 and Appendix A, respectively.

A326.4 Abbreviations in Table A326.1 and Appendix B

The abbreviations tabulated below are used in this Chapter to replace lengthy phrases in the text, in the titles of standards in Table A326.1, and in the Specification Index for Appendix B. Those marked with an asterisk (*)

Table A323.4.3 Recommended Temperature Limits for Thermoplastics Used as Linings

Materials [Note (1)]	Minimum		Maximum	
	°C	°F	°C	°F
PFA	−198	−325	260	500
PTFE	−198	−325	260	500
FEP	−198	−325	204	400
ECTFE	−198	−325	171	340
ETFE	−198	−325	149	300
PVDF	−18	0	135	275
PP	−18	0	107	225
PVDC	−18	0	79	175

GENERAL NOTE: These temperature limits are based on material tests and do not necessarily reflect evidence of successful use as piping component linings in specific fluid services at these temperatures. The designer should consult the manufacturer for specific applications, particularly as temperature limits are approached.

NOTE: (1) See para. A326.4 for definitions of materials.

are in accordance with ASTM D1600, Standard Terminology for Abbreviated Terms Relating to Plastics. Those items marked with a dagger (†) are in accordance with ASTM F412, Standard Terminology Relating to Plastic Piping Systems.

Abbreviation	Term
ABS*†	Acrylonitrile-butadiene-styrene plastics
BPS	Bonding Procedure Specification
CPVC*†	Chlorinated poly(vinyl chloride) plastics
DR†	Dimension ratio
DS	Design stress
E-CTFE*	Ethylene-chlorotrifluoroethylene
ETFE*	Ethylene-tetrafluoroethylene copolymer
FEP*	Perfluoro (ethylene-propylene) copolymer
HDBS	Hydrostatic Design Basis Stress
HDS†	Hydrostatic Design Stress
PB*†	Polybutylene-1
PE*†	Polyethylene
PEX	Cross-linked polyethylene
PFA*	Perfluoro (alkoxyalkane)
PP*†	Polypropylene
PQR	Procedure Qualification Record
PR†	Pressure rating
PTFE*	Polytetrafluoroethylene
PVC*†	Poly(vinyl chloride)
PVDC*	Poly(vinylidene chloride)
PVDF*	Poly(vinylidene fluoride)
RPM	Reinforced plastic mortar
RTP	Reinforced thermosetting plastic
RTR	Reinforced thermosetting resin
SDR†	Standard dimension ratios
SIDR†	Standard inside diameter dimension ratio
WPS	Welding Procedure Specification

PART 9
FABRICATION, ASSEMBLY, AND ERECTION

A327 GENERAL

Piping materials and components are prepared for assembly and erection by one or more of the fabrication processes in paras. A328, A329, A332, and A334. When any of these processes is used in assembly and erection, requirements are the same as for fabrication.

A328 BONDING OF PLASTICS

Paragraph A328 applies only to joints in thermoplastic, RTR, and RPM piping. Bonding shall conform to paras. A328.1 through A328.7 and the applicable requirements of para. A311.

A328.1 Bonding Responsibility

Each employer is responsible for the bonding done by personnel of his/her organization and, except as provided in paras. A328.2.2 and A328.2.3, shall conduct the required performance qualification tests to qualify bonding procedure specifications (BPS) and bonders or bonding operators.

A328.2 Bonding Qualifications

A328.2.1 Qualification Requirements (20)

(a) Qualification of the BPS to be used, and of the performance of bonders and bonding operators, is required. To qualify a BPS, all tests and examinations specified therein and in para. A328.2.5 shall be completed successfully.

(b) In addition to the procedure for making the bonds, the BPS shall specify at least the following:

(1) all materials and supplies (including storage requirements)

(2) tools and fixtures (including proper care and handling)

(3) environmental requirements (e.g., temperature, humidity, and methods of measurement)

(4) joint preparation

(5) dimensional requirements and tolerances

(6) cure time (see para. FA328.2.1)

(7) protection of work

(8) tests and examinations other than those required by para. A328.2.5

(9) acceptance criteria for the completed test assembly

A328.2.2 Procedure Qualification by Others. Subject to the specific approval of the Inspector, a BPS qualified by others may be used provided that

(a) the Inspector satisfies him/herself that the proposed qualified BPS has been prepared and executed by a responsible recognized organization with expertise in the field of bonding

(b) by signature, the employer accepts both the BPS and procedure qualification record (PQR) as his/her own

(c) the employer has at least one currently employed bonder who, while in his/her employ, has satisfactorily passed a performance qualification test using the proposed qualified BPS

A328.2.3 Performance Qualification by Others. Without the Inspector's specific approval, an employer shall not accept a performance qualification test made by a bonder or bonding operator for another employer. If approval is given, it is limited to work on piping using the same or equivalent BPS. An employer accepting such performance qualification tests shall obtain a copy of the performance qualification test record from the previous employer, showing the name of the employer by whom the bonder or bonding operator was qualified,

Table A326.1 Component Standards (20)

Standard or Specification	Designation
Nonmetallic Fittings, Valves, and Flanges	
Process Glass Pipe and Fittings	ASTM C599
Threaded PVC Plastic Pipe Fittings, Sch 80	ASTM D2464
PVC Plastic Pipe Fittings, Sch 40	ASTM D2466
PVC Plastic Pipe Fittings, Sch 80	ASTM D2467
Socket-Type ABS Plastic Pipe Fittings, Sch 40	ASTM D2468
Thermoplastic Gas Pressure Pipe, Tubing, and Fittings	ASTM D2513
Reinforced Epoxy Resin Gas Pressure Pipe and Fittings	ASTM D2517
Plastic Insert Fittings for PE Plastic Pipe	ASTM D2609
Socket-Type PE Fittings for Outside Diameter-Controlled PE Pipe and Tubing	ASTM D2683
CPVC Plastic Hot- and Cold-Water Distribution Systems	ASTM D2846/D2846M
Butt Heat Fusion PE Plastic Fittings for PE Plastic Pipe and Tubing	ASTM D3261
Fiberglass RTR Pipe Fittings for Nonpressure Applications [Note (1)]	ASTM D3840
Machine Made "Fiberglass" (Glass-Fiber-Reinforced Thermosetting Resin) Flanges	ASTM D4024
Contact Molded Fiberglass RTR Flanges [Note (1)]	ASTM D5421
Fiberglass Pressure Pipe Fittings	ASTM D5685
Threaded CPVC Plastic Pipe Fittings, Sch 80	ASTM F437
Socket-Type CPVC Plastic Pipe Fittings, Sch 40	ASTM F438
CPVC Plastic Pipe Fittings, Schedule 80	ASTM F439
Electrofusion Type PE Fittings for Outside Diameter Controlled PE Pipe and Tubing	ASTM F1055
Plastic-Lined Ferrous Metal Pipe, Fittings, and Flanges [Notes (2), (3), and (4)]	ASTM F1545
Pressure-Rated Polypropylene (PP) Piping Systems	ASTM F2389
Plastic Industrial Ball Valves [Notes (2) and (3)]	MSS SP-122
Nonmetallic Pipes and Tubes	
PE Line Pipe	API 15LE
Low Pressure Fiberglass Line Pipe	API 15LR
Reinforced Concrete Low-Head Pressure Pipe	ASTM C361
Process Glass Pipe and Fittings	ASTM C599
ABS Plastic Pipe, Sch 40 and 80	ASTM D1527
PVC Plastic Pipe, Sch 40, 80 and 120	ASTM D1785
PE Plastic Pipe (SIDR-PR) Based on Controlled Inside Diameter	ASTM D2239
PVC Plastic Pressure-Rated Pipe (SDR Series)	ASTM D2241
ABS Plastic Pipe (SDR-PR)	ASTM D2282
Thermoplastic Gas Pressure Pipe, Tubing, and Fittings	ASTM D2513
Reinforced Epoxy Resin Gas Pressure Pipe and Fittings	ASTM D2517
PB Plastic Pipe (SDR-PR)	ASTM D2662
PB Plastic Tubing	ASTM D2666
Joints for IPS PVC Pipe Using Solvent Cement	ASTM D2672
PE Plastic Tubing	ASTM D2737
CPVC Plastic Hot- and Cold-Water Distribution System	ASTM D2846/D2846M
Filament-Wound Fiberglass RTR Pipe [Note (1)]	ASTM D2996

Table A326.1 Component Standards (Cont'd)

Standard or Specification	Designation
Nonmetallic Pipes and Tubes (Cont'd)	
Centrifugally Cast Fiberglass RTR Pipe	ASTM D2997
PB Plastic Pipe (SDR-PR) Based on Outside Diameter	ASTM D3000
PE Plastic Pipe (DR-PR) Based on Controlled Outside Diameter	ASTM D3035
Fiberglass RTR Pressure Pipe [Note (1)]	ASTM D3517
Fiberglass RTR Sewer and Industrial Pressure Pipe [Note (1)]	ASTM D3754
CPVC Plastic Pipe, Sch 40 and 80	ASTM F441/F441M
CPVC Plastic Pipe (SDR-PR)	ASTM F442/F442M
Crosslinked Polyethylene/Aluminum/Crosslinked Polyethylene (PEX-AL-PEX) Pressure Pipe	ASTM F1281
Polyethylene/Aluminum/Polyethylene (PE-AL-PE) Composite Pressure Pipe	ASTM F1282
Polyolefin Pipe and Fittings for Corrosive Waste Drainage Systems [Notes (2) and (3)]	ASTM F1412
Plastic-Lined Ferrous Metal Pipe, Fittings, and Flanges [Notes (2), (3), and (4)]	ASTM F1545
PVDF Corrosive Waste Drainage Systems	ASTM F1673
Pressure-Rated Polypropylene (PP) Piping Systems	ASTM F2389
Metric and Inch-sized Crosslinked Polyethylene (PEX) Pipe	ASTM F2788/F2788M
Reinforced Concrete Pressure Pipe, Steel Cylinder Type, for Water and Other Liquids	AWWA C300
Prestressed Concrete Pressure Pipe, Steel Cylinder Type, for Water and Other Liquids	AWWA C301
Reinforced Concrete Pressure Pipe, Noncylinder Type	AWWA C302
Polyvinyl Chloride (PVC) Pressure Pipe and Fabricated Fittings, 4 In. Through 60 In. (100 mm Through 1,500 mm)	AWWA C900
Fiberglass Pressure Pipe	AWWA C950
Miscellaneous	
Contact-Molded RTP Laminates for Corrosion Resistant Equipment	ASTM C582
Threads for Fiberglass RTR Pipe (60 deg stub) [Note (1)]	ASTM D1694
Solvent Cements for ABS Plastic Pipe and Fittings	ASTM D2235
Solvent Cements for PVC Plastic Piping Systems	ASTM D2564
Joints for Plastic Pressure Pipes Using Flexible Elastomeric Seals	ASTM D3139
Fiberglass RTR Pipe Joints Using Flexible Elastomeric Seals [Note (1)]	ASTM D4161
Design and Construction of Nonmetallic Enveloped Gaskets for Corrosive Service	ASTM F336
Solvent Cements for CPVC Plastic Pipe and Fittings	ASTM F493
Taper Pipe Threads 60° for Thermoplastic Pipe and Fittings	ASTM F1498

GENERAL NOTE: It is not practical to refer to a specific edition of each standard throughout the Code text. Instead, the approved edition references, along with the names and addresses of the sponsoring organizations, are shown in Appendix E.

NOTES:
(1) The term "fiberglass RTR" takes the place of the ASTM designation "fiberglass (glass-fiber-reinforced thermosetting resin)."
(2) This Standard allows the use of unlisted materials; see para. 323.1.2.
(3) This Standard contains no pressure–temperature ratings.
(4) Cautionary Note: A metallic piping component lined with nonmetal requires proper interaction between liner and host metallic piping component. This is demonstrated by qualification testing required in ASTM F1545. The designer should review this documentation for compliance.

the date of such qualification, and the date the bonder or bonding operator last bonded pressure piping under such performance qualification.

A328.2.4 Qualification Records. The employer shall maintain a self-certified record, available to the owner or owner's agent and to the Inspector, of the BPS used and the bonders or bonding operators employed by him/her, and showing the dates and results of BPS qualifications and bonding performance qualifications.

(20) **A328.2.5 Qualification Tests.** Tests, as specified in para. A328.2.1(a), shall be performed to qualify each BPS and the performance of each bonder and bonding operator. Test assemblies shall conform to (a) below and the test method shall be in accordance with either (b) or (c).

(a) Test Assembly. The assembly shall be fabricated in one pipe size in accordance with the BPS and shall contain at least one of each different type of joint identified in the BPS. More than one test assembly may be prepared if necessary to accommodate all of the joint types or to assure that at least one of each joint type is loaded in both circumferential and longitudinal directions. The size of pipe and fittings in the assembly shall be as follows:

(1) When the largest size to be qualified is DN 100 (NPS 4) or smaller, the test assembly shall be the largest size qualified.

(2) When the largest size to be qualified is greater than DN 100 (NPS 4), the size of the test assembly shall be between 25% and 100% of the largest piping size qualified, but shall be a minimum of DN 100 (NPS 4).

(b) Burst Test Method. The test assembly shall be subjected to a burst test in accordance with the applicable sections of ASTM D1599.[5] The time to burst in this standard may be extended. The test is successful if failure initiates outside of any bonded joint.

(c) Hydrostatic Test Method. The test assembly shall be subjected to hydrostatic pressure of at least P_T for not less than 1 hr with no leakage or separation of joints.

(1) For thermoplastics, P_T shall be determined in accordance with eq. (27)

$$P_T = 0.80\overline{T}\left(\frac{S_S + S_H}{D - \overline{T}}\right) \tag{27}$$

where

D = outside diameter of pipe

S_H = mean long-term hydrostatic strength (LTHS) at the test temperature, in accordance with ASTM D2837 or from the applicable component standard or manufacturer's data

S_S = mean short-term burst stress at the test temperature, in accordance with ASTM D1599[5] or from the applicable component standard or manufacturer's data

$\overline{T}$ = nominal thickness of pipe

(2) For RTR (laminated and filament-wound) and RPM, P_T shall be 3 times the manufacturer's allowable pressure for the components being joined.

(3) The test shall be conducted so that the joint is loaded in both the circumferential and longitudinal directions.

A328.2.6 Performance Requalification. Renewal of a bonding performance qualification is required when

(a) a bonder or bonding operator has not used the specific bonding process for a period of 6 months or more, or

(b) there is specific reason to question the individual's ability to make bonds that meet the BPS

A328.3 Bonding Materials and Equipment

A328.3.1 Materials. Bonding materials that have deteriorated by exposure to air or prolonged storage, or will not spread smoothly, shall not be used in making joints.

A328.3.2 Equipment. Fixtures and tools used in making joints shall be in such condition as to perform their functions satisfactorily.

A328.4 Preparation for Bonding

Preparation shall be defined in the BPS and shall specify such requirements as

(a) cutting
(b) cleaning
(c) preheat
(d) end preparation
(e) fit-up

A328.5 Bonding Requirements

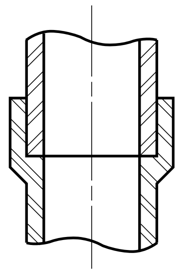
A328.5.1 General

(a) Production joints shall be made only in accordance with a written bonding procedure specification (BPS) that has been qualified in accordance with para. A328.2. Manufacturers of piping materials, bonding materials, and bonding equipment should be consulted in the preparation of the BPS.

(b) Production joints shall be made only by qualified bonders or bonding operators who have appropriate training or experience in the use of the applicable BPS and have satisfactorily passed a performance qualification test that was performed in accordance with a qualified BPS.

[5] Titles of referenced standards and specifications are listed in Table A326.1, except ASTM D1599, Test Method for Resistance to Short-Time Hydraulic Pressure of Plastic Pipe, Tubing, and Fittings; ASTM D2657, Practice for Heat Fusion Joining of Polyolefin Pipe and Fittings; ASTM D2855, Practice for Making Solvent-Cemented Joints with PVC Pipe and Fittings; and ASTM F1290, Practice for Electrofusion Joining Polyolefin Pipe and Fittings.

Figure A328.5.3 Thermoplastic Solvent Cemented Joint



Socket Joint

(c) Each qualified bonder and bonding operator shall be assigned an identification symbol. Unless otherwise specified in the engineering design, each pressure-containing bond or adjacent area shall be stenciled or otherwise suitably marked with the identification symbol of the bonder or bonding operator. Identification stamping shall not be used and any marking paint or ink shall not be detrimental to the piping material. In lieu of marking the bond, appropriate records may be filed.

(d) Qualification in one BPS does not qualify a bonder or bonding operator for any other bonding procedure.

(e) Longitudinal joints are not covered in para. A328.

A328.5.2 Hot Gas Welded Joints in Thermoplastic Piping[5]

(a) Preparation. Surfaces to be hot gas welded together shall be cleaned of any foreign material. For butt welds, the joining edges should be beveled at 20 deg to 40 deg with 1 mm ($^1/_{32}$ in.) root face and root gap.

(b) Procedure. Joints shall be made in accordance with the qualified BPS.

(c) Branch Connections. A fabricated branch connection shall be made by inserting the branch pipe in the hole in the run pipe. Dimensions of the joint shall conform to Figure 328.4.4, illustration (c). The hole in the run pipe shall be beveled at 45 deg. Alternatively, a fabricated branch connection shall be made using a manufactured full reinforcement saddle with integral socket.

A328.5.3 Solvent Cemented Joints in Thermoplastic Piping[5]

(a) Preparation. Thermoplastic pipe and fitting surfaces shall be prepared in accordance with ASTM D2855 for PVC, ASTM F493 for CPVC, and ASTM D2235 for ABS. A dry fit test of each joint is required before solvent cementing. The pipe shall enter the fitting socket between one-third and two-thirds of the full socket depth when assembled by hand.

(b) Procedure. Joints shall be made in accordance with the qualified BPS. ASTM D2855 provides a suitable basis for development of such a procedure. Solvent cements for PVC, CPVC, and ABS shall conform to ASTM D2564, D2846, and D2235, respectively. Application of cement to both surfaces to be joined and assembly of these surfaces shall produce a continuous bond between them with visual evidence of cement at least flush with the outer end of the fitting bore around the entire joint perimeter. See Figure A328.5.3.

(c) Branch Connections. A fabricated branch connection shall be made using a manufactured full reinforcement saddle with integral branch socket. The reinforcement saddle shall be solvent cemented to the run pipe over its entire contact surface.

A328.5.4 Heat Fusion Joints in Thermoplastic Piping[5]

(a) Preparation. Surfaces to be heat fused together shall be cleaned of all foreign material.

(b) Procedure. Joints shall be made in accordance with the qualified BPS. The general procedures in ASTM D2657, Techniques I — Socket Fusion, II — Butt Fusion, and III — Saddle Fusion, provide a suitable basis for development of such a procedure. Uniform heating of both surfaces to be joined and assembly of these surfaces shall produce a continuous homogeneous bond between them and shall produce a small fillet of fused material at the outer limits of the joint. See Figure A328.5.4 for typical heat fusion joints. Fixtures shall be used to align components when joints are made.

(c) Branch Connections. A fabricated branch connection is permitted only where molded fittings are unavailable.

A328.5.5 Electrofusion Joints in Thermoplastic Piping[5]

(a) Preparation. Surfaces to be heat fused together shall be cleaned of all foreign material.

(b) Procedure. Joints shall be made in accordance with the qualified BPS. The general procedures in ASTM F1290, Technique I — Coupling Procedure and Technique II — Saddle Procedure, provide a suitable basis for the development of such a procedure. See Figure A328.5.5.

A328.5.6 Adhesive Joints in RTR and RPM Piping

(a) Procedure. Joints shall be made in accordance with the qualified BPS. Application of adhesive to the surfaces to be joined and assembly of these surfaces shall produce a continuous bond between them and shall seal over all cuts to protect the reinforcement from the service fluid. See Figure A328.5.6.

(b) Branch Connections. A fabricated branch connection shall be made using a manufactured full reinforcement saddle having a socket or integral length of branch pipe suitable for a nozzle or coupling. The hole in the run pipe shall be made with a hole saw; the cut

Figure A328.5.4 Thermoplastic Heat Fusion Joints

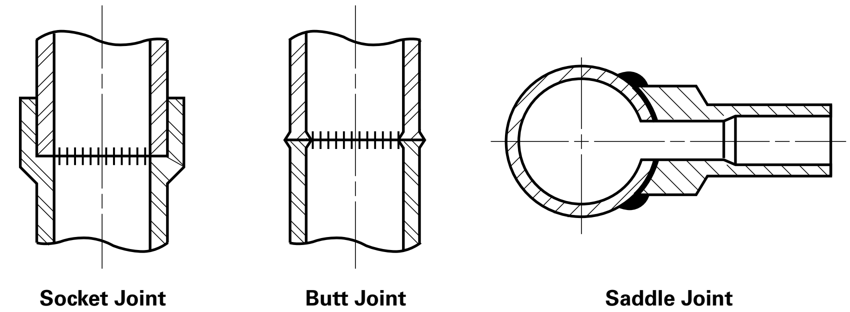


Figure A328.5.5 Thermoplastic Electrofusion Joints

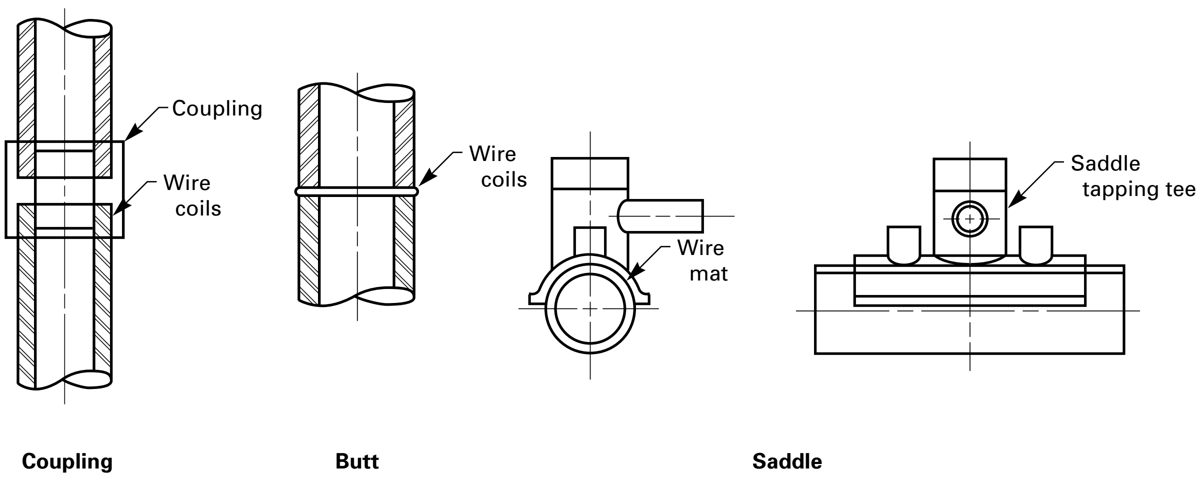
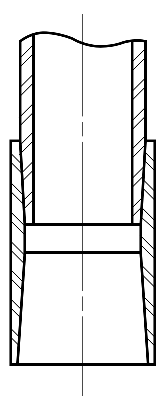


Figure A328.5.6 Fully Tapered Thermosetting Adhesive Joint



edges of the hole shall be sealed with adhesive at the time the saddle is bonded to the run pipe.

A328.5.7 Butt-and-Wrapped Joints in RTR and RPM Piping[5]

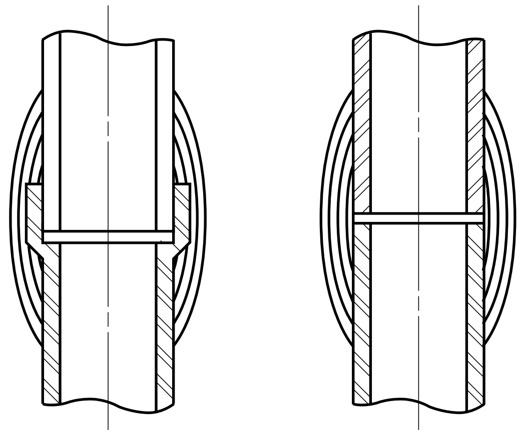
(a) Procedure. Joints shall be made in accordance with the qualified BPS. Application of plies of reinforcement saturated with catalyzed resin to the surfaces to be joined shall produce a continuous structure with them. Cuts shall be sealed to protect the reinforcement from the service fluid. See Figure A328.5.7.

(b) Branch Connections. For a fabricated branch connection made by inserting the branch pipe into a hole in the run pipe, the hole shall be made with a hole saw.

A328.6 Bonding Repair

Defective material, joints, and other workmanship that fails to meet the requirements of this Code and of the engineering design shall be repaired or replaced. See also para. 341.3.3.

Figure A328.5.7 Thermosetting Wrapped Joints



A328.7 Seal Bonds

If threaded joints are to be seal bonded in accordance with para. A311.2.2, the work shall be done by qualified bonders and all exposed threads shall be covered by the seal bond.

A329 FABRICATION OF PIPING LINED WITH NONMETALS

A329.1 Welding of Metallic Piping

A329.1.1 General

(a) Paragraph A329.1 applies only to welding subassemblies of metallic piping that have previously been lined with nonmetals.

(b) Welding that conforms to para. A329.1 may be used in accordance with para. A318.3.1.

A329.1.2 Specific Welding Requirements. Welding shall conform to the requirements of para. 328 and the following additional requirements:

(a) Modifications made in preparation for welding to suit manufacturer's recommendations shall be specified in the engineering design.

(b) Welding shall be performed so as to maintain the continuity of the lining and its serviceability.

(c) If a lining has been damaged, it shall be repaired or replaced.

(d) Qualification to one WPS for a specific lining material does not qualify a welder or welding operator for any other welding procedure involving different lining materials.

A329.2 Flaring of Nonmetallic Linings

A329.2.1 General

(a) Paragraph A329.2 applies only to the flaring of linings in pipe that has previously been lined with nonmetals.

(b) Flaring that conforms to para. A329.2 may be used in accordance with para. A318.3.2.

(c) Flaring shall be performed only in accordance with a written flaring procedure specification, and only by qualified operators who have appropriate training or experience in the use of the applicable flaring procedure specification.

A332 BENDING AND FORMING

A332.1 General

Paragraph 332.1 applies in its entirety.

A332.2 Bending

Paragraph 332.2 applies, except para. 332.2.2.

A332.3 Forming

Paragraph 332.3 applies, except for heat treatment.

A334 JOINING NONPLASTIC PIPING

A334.1 Borosilicate Glass Piping

Short unflanged pieces used to correct for differences between fabrication drawings and field dimensions may be cut to length and finished in the field.

A334.2 Repair of Defects

Defective material, joints, and other workmanship in nonplastic piping that fail to meet the requirements of para. A334 or of the engineering design shall be repaired or replaced.

Completed repairs and replacements shall be examined, subject to the same limitations on imperfections as the original work.

A335 ASSEMBLY AND ERECTION

A335.1 Alignment

Paragraph 335.1 applies in its entirety.

A335.2 Flanged and Mechanical Joints

Paragraph 335.2 applies in its entirety.

A335.2.5 Nonmetallic Bolted Joints

(a) Bolted joints in nonmetallic piping may be assembled with any combination of flange material and flange facings, except that the following apply when other than flat face flanges and full face gaskets are used:

(1) consideration shall be given to the strength of the flanges, and to sustained loads, displacement strains, and occasional loads described in paras. A302.3.3 and A302.3.4

(2) an appropriate bolt-up sequence shall be specified

(b) Appropriate limits shall be specified for bolt-up torque, and those limits shall not be exceeded.

(c) Flat washers shall be used under bolt heads and nuts.

A335.2.6 Metallic Piping Lined With Nonmetals. In assembling mechanical joints in metallic piping lined with nonmetals, consideration shall be given to means for maintaining electrical continuity between pipe sections, where static sparking could cause ignition of flammable vapors. See Appendix F, para. FA323.4(a).

A335.3 Threaded Joints

Paragraph 335.3 applies except for para. 335.3.2. See para. A335.3.2.

A335.3.2 Joints for Seal Bonding. A threaded joint to be seal bonded shall be made up without thread compound. A joint containing thread compound that leaks during leak testing may be seal bonded in accordance with para. A328.6, provided all compound is removed from exposed threads.

A335.3.4 Tools, Nonmetallic Piping. Either strap wrenches or other full circumference wrenches shall be used to tighten threaded pipe joints. Tools and other devices used to hold or apply forces to the pipe shall be such that the pipe surface is not scored or deeply scratched.

A335.3.5 RTR and RPM Piping. In assembling threaded joints in RTR and RPM piping, where threads may be exposed to fluids that can attack the reinforcing material, threads shall be coated with sufficient resin to cover the threads and completely fill the clearance between the pipe and the fitting.

A335.4 Tubing Joints

A335.4.1 Flared Joints in Thermoplastic Tubing. In addition to preparation in accordance with para. 335.4.1, the end of the tubing shall be cut perpendicular to the tube centerline, preferably with a tubing cutter specially made for thermoplastic tubing. No cuts, scratches, dirt, or surface damage to either inside or outside diameter are permitted on the pipe end to be flared.

A335.4.2 Flareless and Compression Tubing Joints. Paragraph 335.4.2 applies.

A335.5 Caulked Joints

Paragraph 335.5 applies.

A335.6 Special Joints

Paragraph 335.6 applies, except that expanded joints are not permitted.

A335.6.3 Flexible Elastomeric Sealed Joints. Assembly of flexible elastomeric sealed joints shall be in accordance with the manufacturer's recommendations and the following:

(a) Seal and bearing surfaces shall be free from injurious imperfections.

(b) Any lubricant used to facilitate joint assembly shall be compatible with the joint components and the intended service.

(c) Proper joint clearances and piping restraints (if not integral in the joint design) shall be provided to prevent joint separation when expansion can occur due to thermal and/or pressure effects.

A335.8 Assembly of Brittle Piping

A335.8.1 General. Care shall be used to avoid scratching of brittle nonmetallic piping in handling and supporting. Any scratched or chipped components shall be replaced. Care shall be used in handling glass-lined and cement-lined metal pipe because the lining can be injured or broken by blows that do not dent or break the pipe.

A335.8.2 Borosilicate Glass Piping. In addition to the precaution in para. A335.8.1, borosilicate glass piping components shall be protected from weld spatter. Any component so damaged shall be replaced. Flanges and cushion inserts shall be carefully fitted and aligned to pipe, fittings, and valve ends. Gaskets shall be of the construction recommended for the joint. Installation and torquing of bolts shall be in accordance with the manufacturer's recommendations.

A335.9 Cleaning of Piping

See Appendix F, para. F335.9.

PART 10
INSPECTION, EXAMINATION, AND TESTING

A340 INSPECTION

Paragraph 340 applies in its entirety.

A341 EXAMINATION

A341.1 General

Paragraph 341.1 applies.

A341.2 Responsibility for Examination

Paragraph 341.2 applies in its entirety.

Table A341.3.2 Acceptance Criteria for Bonds

Type of Imperfection	Thermoplastic Material: Hot Gas Welded Joint	Thermoplastic Material: Solvent Cemented Joint	Thermoplastic Material: Heat Fusion Joint	RTR and RPM Materials [Note (1)] — Adhesive Cemented Joint
Cracks	None permitted	Not applicable	None permitted	None permitted
Unfilled areas in joint	None permitted	None permitted	None permitted	None permitted
Unbonded areas in joint	None permitted	None permitted	None permitted	None permitted
Inclusions of charred material	None permitted	Not applicable	None permitted	None permitted
Unfused filler material inclusions	None permitted	Not applicable	Not applicable	None permitted
Protrusion of material into pipe bore, % of pipe wall thickness	Not applicable	Cement, 50%	Fused material, 25%	Adhesive, 25%

NOTE: (1) RTR = reinforced thermosetting resin; RPM = reinforced plastic mortar.

A341.3 Examination Requirements

A341.3.1 Responsibility for Examination. Paragraph 341.3.1 applies, except for paras. 341.3.1(a) and 341.3.1(b), which apply only for metals.

A341.3.2 Acceptance Criteria. Acceptance criteria shall be as stated in the engineering design, and shall at least meet the applicable requirements for bonds in Table A341.3.2 and requirements elsewhere in the Code.

A341.3.3 Defective Components and Workmanship. Paragraph 341.3.3 applies in its entirety.

A341.3.4 Progressive Sampling for Examination. Paragraph 341.3.4 applies in its entirety.

A341.4 Extent of Required Examination

A341.4.1 Examination Normally Required. Piping in Normal Fluid Service shall be examined to the extent specified herein or to any greater extent specified in the engineering design. Acceptance criteria are as stated in para. A341.3.2 unless otherwise specified.

(a) Visual Examination. At least the following shall be examined in accordance with para. 344.2:

(1) materials and components in accordance with para. 341.4.1(a)(1).

(2) at least 5% of fabrication. For bonds, each type of bond made by each bonder and bonding operator shall be represented.

(3) 100% of fabrication for bonds other than circumferential, except those in components made in accordance with a listed specification.

(4) assembly and erection of piping in accordance with paras. 341.4.1(a)(4), 341.4.1(a)(5), and 341.4.1(a)(6).

(b) Other Examination. Not less than 5% of all bonded joints shall be examined by in-process examination in accordance with para. 344.7, the joints to be examined being selected to ensure that the work of each bonder and bonding operator making the production joints is examined.

(c) Certifications and Records. Paragraph 341.4.1(c) applies.

A341.4.2 Examination — Category D Fluid Service. Piping and piping elements for Category D Fluid Service as designated in the engineering design shall be visually examined to the extent necessary to satisfy the examiner that components, materials, and workmanship conform to the requirements of this Code and the engineering design.

A341.5 Supplementary Examination

A341.5.1 General. Any applicable method of examination described in para. 344 may be specified by the engineering design to supplement the examination required by para. A341.4. The extent of supplementary examination to be performed and any acceptance criteria that differ from those in para. A341.3.2 shall be specified in the engineering design.

A341.5.2 Examinations to Resolve Uncertainty. Paragraph 341.5.3 applies.

A342 EXAMINATION PERSONNEL

Paragraph 342 applies in its entirety.

A343 EXAMINATION PROCEDURES

Paragraph 343 applies in its entirety.

A344 TYPES OF EXAMINATION

A344.1 General

Paragraph 344.1 applies in its entirety.

A344.2 Visual Examination

Paragraph 344.2 applies in its entirety.

A344.5 Radiographic Examination

Radiographic examination may be used in accordance with para. 344.1.2.

A344.6 Ultrasonic Examination

Ultrasonic examination may be used in accordance with para. 344.1.2.

A344.7 In-Process Examination

Paragraph 344.7 applies in its entirety.

A345 TESTING

A345.1 Required Leak Test

(a) Prior to initial operation, each piping system shall be tested to ensure tightness. The test shall be a hydrostatic leak test in accordance with para. A345.4, except as provided herein.

(b) Paragraphs 345.1(a) and 345.1(b) apply.

A345.2 General Requirements for Leak Test

Requirements in para. A345.2 apply to more than one type of leak test.

A345.2.1 Limitations on Pressure. Paragraphs 345.2.1(b) and 345.2.1(c) apply.

A345.2.2 Other Test Requirements

(a) Paragraph 345.2.2(a) applies.

(b) The possibility of brittle fracture shall be considered when conducting leak tests on brittle materials or at low temperature.

(c) Paragraphs 345.2.3 through 345.2.7 apply.

A345.3 Preparation for Leak Test

Paragraph 345.3 applies in its entirety, considering bonds in place of welds, and excluding expansion joints.

A345.4 Hydrostatic Leak Test

A345.4.1 Test Fluid. Paragraph 345.4.1 applies.

A345.4.2 Test Pressure

(a) Nonmetallic Piping. Except as provided in para. A345.4.3, the hydrostatic test pressure at any point in a nonmetallic piping system shall be not less than 1.5 times the design pressure, but shall not exceed 1.5 times the maximum rated pressure of the lowest-rated component in the system.

(b) Thermoplastic Piping. For piping systems in which the design temperature is above the test temperature, para. 345.4.2(b) applies, except that S and S_T shall be from Table B-1 instead of Table A-1 or Table A-1M.

(c) Metallic Piping With Nonmetallic Lining. Paragraph 345.4.2 applies.

A345.4.3 Hydrostatic Test of Piping With Vessels as a System. Paragraph 345.4.3 applies.

A345.5 Pneumatic Leak Test

A345.5.1 Precautions. In addition to the requirements of para. 345.5.1, a pneumatic test of nonmetallic piping is permitted only with the owner's approval, and precautions in Appendix F, para. FA323.4 should be considered.

A345.5.2 Other Requirements

(a) Paragraphs 345.5.2 through 345.5.5 apply.

(b) PVC and CPVC piping shall not be pneumatically tested.

A345.6 Hydrostatic–Pneumatic Leak Test

If a combined hydrostatic–pneumatic leak test is used, the requirements of para. A345.5 shall be met, and the pressure in the liquid-filled part of the piping shall not exceed the values calculated in accordance with para. A345.4.2 or 345.4.2, as applicable.

A345.7 Initial Service Leak Test

Paragraph 345.7 applies in its entirety for Category D Fluid Service only.

A345.8 Sensitive Leak Test

Paragraph 345.8 applies.

A346 RECORDS

Paragraph 346 applies in its entirety.

Chapter VIII
Piping for Category M Fluid Service

M300 GENERAL STATEMENTS

(a) Chapter VIII pertains to piping designated by the owner as being in Category M Fluid Service. See para. 300(b)(1) and Appendix M.

(b) The organization, content, and paragraph designations of this Chapter correspond to those of the base Code (Chapters I through VI) and Chapter VII. The prefix M is used.

(c) Provisions and requirements of the base Code and Chapter VII apply only as stated in this Chapter.

(d) Consideration shall be given to the possible need for engineered safeguards as described in Appendix G, para. G300.3, in addition to the inherent safeguards described in paras. G300.1 and G300.2.

(e) This Chapter makes no provision for piping to be used under severe cyclic conditions. If it is not feasible to eliminate the severe cyclic conditions, the engineering design shall specify any necessary provisions in accordance with para. 300(c)(5).

(f) Chapter I applies in its entirety.

PART 1
CONDITIONS AND CRITERIA

M301 DESIGN CONDITIONS

Paragraph 301 applies in its entirety, with the exceptions of paras. 301.3 and 301.5. See paras. M301.3 and M301.5.

M301.3 Design Temperature, Metallic Piping

Use of any temperature other than the fluid temperature as the design temperature shall be substantiated by heat transfer calculations confirmed by tests or by experimental measurements.

M301.5 Dynamic Effects

Paragraph 301.5 applies with the exception of paras. 301.5.1 and 301.5.4. See paras. M301.5.1 and M301.5.4.

M301.5.1 Impact. Design, layout, and operation of piping shall be conducted so as to minimize impact and shock loads. In the event that such loadings are unavoidable, para. 301.5.1 applies.

M301.5.4 Vibration. Suitable dynamic analysis, such as computer simulation, shall be made where necessary to avoid or minimize conditions that lead to detrimental vibration, pulsation, or resonance effects in the piping.

M302 DESIGN CRITERIA

M302.1 General

Paragraph M302 pertains to pressure–temperature ratings, stress criteria, design allowances, and minimum design values, together with permissible variations of these factors as applied to piping design. Paragraph 302 applies in its entirety, with the exception of para. 302.2.4. See para. M302.2.4.

M302.2.4 Allowance for Pressure and Temperature Variations, Metallic Piping. Use of allowances in para. 302.2.4 is not permitted.

PART 2
PRESSURE DESIGN OF METALLIC PIPING COMPONENTS

M303 GENERAL

Paragraph 303 applies in its entirety.

M304 PRESSURE DESIGN OF METALLIC COMPONENTS

Paragraph 304 applies in its entirety.

PART 3
FLUID SERVICE REQUIREMENTS FOR METALLIC PIPING COMPONENTS

M305 PIPE

M305.1 General

Listed pipe may be used in accordance with para. M305.2. Unlisted pipe may be used only as provided in para. 302.2.3.

M305.2 Specific Requirements for Metallic Pipe

Pipe listed in para. 305.2.2 shall not be used. The provision for severe cyclic conditions in para. 305.2.3 does not apply [see para. M300(e)].

M306 METALLIC FITTINGS, BENDS, MITERS, LAPS, AND BRANCH CONNECTIONS

General. Fittings, bends, miters, laps, and branch connections may be used in accordance with paras. M306.1 through M306.6. Pipe and other materials used in such components shall be suitable for the manufacturing process and the fluid service.

M306.1 Pipe Fittings

Paragraph 306.1 applies in its entirety, with the exception of paras. 306.1.3 and 306.1.4. See para. M306.1.3.

M306.1.3 Specific Fittings

(a) Proprietary welding branch outlet fittings that have been design proof tested successfully as prescribed in ASME B16.9, MSS SP-97, or ASME BPVC, Section VIII, Division 1, UG-101 may be used within their established ratings.

(b) Fittings conforming to MSS SP-43 and MSS SP-119 shall not be used.

(c) Proprietary "Type C" lap-joint stub-end buttwelding fittings shall not be used.

M306.2 Pipe Bends

Paragraph 306.2 applies, except that bends designed as creased or corrugated shall not be used.

M306.3 Miter Bends

A miter bend shall conform to para. 306.3.1 and shall not make a change in direction at a single joint (angle α in Figure 304.2.3) greater than 22.5 deg. Paragraph 306.3.3 does not apply [see para. M300(e)].

M306.4 Fabricated or Flared Laps

M306.4.1 General. The following requirements do not apply to fittings conforming to para. M306.1, nor to laps integrally forged on pipe ends. Paragraph 306.4.1 applies.

M306.4.2 Flared Laps. Flared laps shall not be used.

M306.5 Fabricated Branch Connections

The following requirements do not apply to fittings conforming to para. M306.1. Paragraph 306.5.1 applies, with the following exceptions:

(a) Of the methods listed in para. 304.3.1(a), the one in para. 304.3.1(a)(3) may be used only if those in paras. 304.3.1(a)(1) and 304.3.1(a)(2) are unavailable.

(b) Of the branch connections described in paras. 304.3.2(b) and 304.3.2(c), those having threaded outlets are permitted only in accordance with para. M314 and those having socket welding outlets are permitted only in accordance with para. M311.2.

M306.6 Closures

The following requirements do not apply to blind flanges or to fittings conforming to para. M306.1. Of the closures described in para. 304.4, flat closures in accordance with ASME BPVC, Section VIII, Division 1, UG-34 and UW-13, and conical closures without transition knuckles [UG-32(g) and UG-33(f)], may be used only if others are not available. The requirements in M306.5 apply to openings in closures [see also para. 304.4.2(b)].

M307 METALLIC VALVES AND SPECIALTY COMPONENTS

The following requirements for valves shall also be met as applicable by other pressure-containing piping components, e.g., traps, strainers, and separators. See also Appendix F, paras. F301.4 and F307.

M307.1 General

Paragraph 307.1 applies, subject to the requirements in para. M307.2.

M307.2 Specific Requirements

(a) Paragraph 307.2.2 applies.

(b) Valves having threaded bonnet joints (other than union joints) shall not be used.

(c) Only metallic valves conforming to the following requirements may be used:

(1) Special consideration shall be given to valve design to prevent stem leakage to the environment.

(2) Bonnet or cover plate closures and body joints shall be flanged, secured by at least four bolts with gasketing conforming to para. 308.4; or proprietary, attached by bolts, lugs, or other substantial means, and having a gasket design that increases gasket compression as fluid pressure increases; or secured with a full penetration weld made in accordance with para. M311; or secured by a straight thread sufficient for mechanical strength, a metal-to-metal seat, and a seal weld made in accordance with para. M311, all acting in series.

M308 FLANGES, BLANKS, FLANGE FACINGS, AND GASKETS

Paragraph 308.1 applies in its entirety.

M308.2 Specific Requirements for Metallic Flanges

Paragraph 308.2.4 does not apply [see para. M300(e)]. The following shall not be used:

(a) single-welded slip-on flanges
(b) expanded-joint flanges
(c) slip-on flanges used as lapped flanges unless the requirements in para. 308.2.1(c) are met
(d) threaded metallic flanges, except those employing lens rings or similar gaskets and those used in lined pipe where the liner extends over the gasket face

M308.3 Flange Facings

Paragraph 308.3 applies in its entirety.

M308.4 Gaskets

Paragraph 308.4 applies in its entirety.

M308.5 Blanks

All blanks shall be marked with material, rating, and size.

M309 BOLTING

Paragraph 309 applies, except for para. 309.2.4 [see para. M300(e)].

PART 4
FLUID SERVICE REQUIREMENTS FOR METALLIC PIPING JOINTS

M310 METALLIC PIPING, GENERAL

Paragraph 310 applies in its entirety.

M311 WELDED JOINTS IN METALLIC PIPING

Welded joints may be made in any metal for which it is possible to qualify welding procedures, welders, and welding operators in accordance with para. M328.

M311.1 General

Paragraph 311.1 applies with the following exceptions:
(a) Split backing rings shall not be used.
(b) Socket welded joints greater than DN 50 (NPS 2) are not permitted.
(c) Examination shall be in accordance with para. M341.4.

M311.2 Specific Requirements

Paragraphs 311.2.1(a); 311.2.2(a), 311.2.2(b), and 311.2.2(d); 311.2.3; and 311.2.4 apply.

M312 FLANGED JOINTS IN METALLIC PIPING

Paragraph 312 applies in its entirety.

M313 EXPANDED JOINTS IN METALLIC PIPING

Expanded joints shall not be used.

M314 THREADED JOINTS IN METALLIC PIPING

M314.1 General

Paragraphs 314.1(a), 314.1(b), and 314.1(c) apply.

M314.2 Specific Requirements

M314.2.1 Taper-Threaded Joints. Paragraph 314.2.1 applies except that only components suitable for Normal Fluid Service in sizes 8 ≤ DN ≤ 25 ($^1/_4$ ≤ NPS ≤ 1) are permitted (see Table 314.2.1). Sizes smaller than DN 20 (NPS $^3/_4$) shall be safeguarded (see Appendix G).

M314.2.2 Straight-Threaded Joints. Paragraph 314.2.2 applies. In addition, components shall have adequate mechanical strength and the joint shall have a confined seating surface not subject to relative rotation as or after the joint is tightened. [See Figure 335.3.3, illustrations (b) and (c) for acceptable construction.]

M315 TUBING JOINTS IN METALLIC PIPING

Paragraph 315 applies, except for para. 315.2(b).

M316 CAULKED JOINTS

Caulked joints shall not be used.

M317 SOLDERED AND BRAZED JOINTS

Soldered, brazed, and braze welded joints shall not be used.

M318 SPECIAL JOINTS IN METALLIC PIPING

Paragraph 318 applies, with the exception that adhesive joints and bell type joints shall not be used.

PART 5
FLEXIBILITY AND SUPPORT OF METALLIC PIPING

M319 FLEXIBILITY OF METALLIC PIPING

Paragraph 319 applies, with the exception that the simplified rules in para. 319.4.1(c) do not apply.

M320 ANALYSIS OF SUSTAINED LOADS

Paragraph 320 applies.

M321 PIPING SUPPORT

Paragraph 321 applies, except that supporting elements welded to the piping shall be of listed material.

PART 6
SYSTEMS

M322 SPECIFIC PIPING SYSTEMS

M322.3 Instrument Piping

Paragraph 322.3 applies, with the exception that for signal tubing in contact with process fluids and process temperature–pressure conditions

(a) tubing shall be not larger than 16 mm ($^5\!/_8$ in.) O.D. and shall be suitable for the service

(b) an accessible block valve shall be provided to isolate the tubing from the pipeline

(c) joining methods shall conform to the requirements of para. M315

M322.6 Pressure-Relieving Systems

Paragraph 322.6 applies, except for para. 322.6.3. See para. M322.6.3.

M322.6.3 Overpressure Protection

(a) Paragraph 322.6.3(a) applies.

(b) Relief set pressure shall be in accordance with ASME BPVC, Section VIII, Division 1.

(c) The maximum relieving pressure shall be in accordance with Section VIII, Division 1.

PART 7
METALLIC MATERIALS

M323 GENERAL REQUIREMENTS

M323.1 Materials and Specifications

Paragraph 323.1.1 applies. See paras. M323.1.2, M323.1.3, and M323.1.4.

M323.1.2 Unlisted Materials. Paragraph 323.1.2 applies, with the additional requirement that the designer shall fully document the determination of allowable stresses as part of the engineering design.

M323.1.3 Unknown Materials. Materials of unknown specification shall not be used.

M323.1.4 Reclaimed Metallic Materials. Reclaimed materials may be used when the material certification records are available for the specific materials employed, and the designer is assured that the material is sound and free from harmful defects.

M323.2 Temperature Limitations

Paragraph 323.2 applies with the exception that, in regard to lower temperature limits, the relaxation of minimum temperature limits stated in Notes (3) and (6) of Table 323.2.2 and in paras. 323.2.2(h) and 323.2.2(i) is not permitted.

M323.3 Impact Testing Methods and Acceptance Criteria

Paragraph 323.3 applies in its entirety.

M323.4 Fluid Service Requirements for Metallic Materials

Paragraph 323.4.1 applies.

M323.4.2 Specific Requirements. Paragraph 323.4.2 applies, except that cast irons other than ductile iron shall not be used for pressure-containing parts, and lead and tin shall be used only as linings.

M323.4.3 Metallic Cladding and Lining Materials. In addition to the requirements of para. 323.4.3, where materials covered in paras. 323.4.2(c)(2) and 323.4.3 are used as cladding or lining in which the cladding or lining also serves as a gasket or as part of the flange facing, consideration shall be given to the design of the flanged joint to prevent leakage to the environment.

M323.5 Deterioration of Materials in Service

Paragraph 323.5 applies in its entirety.

M325 MATERIALS — MISCELLANEOUS

M325.1 Joining and Auxiliary Materials

In applying para. 325, materials such as solvents, brazes, and solders shall not be used. Nonmetallic materials used as gaskets and packing materials shall be suitable for the fluid service.

PART 8
STANDARDS FOR PIPING COMPONENTS

M326 DIMENSIONS AND RATINGS OF COMPONENTS

Paragraph 326.1.3 applies.

M326.1 Dimensional Requirements

M326.1.1 Listed Piping Components. Except for prohibitions and restrictions stated elsewhere in Chapter VIII, components made in accordance with standards and specifications listed in Table 326.1 may be used in Category M service.

M326.1.2 Unlisted Piping Components. Paragraph 326.1.2 applies, except that dimensions of unlisted components shall be governed by requirements in paras. 303 and 304.

M326.2 Ratings of Components

Paragraph 326.2 applies in its entirety.

M326.3 Reference Documents

Paragraph 326.3 applies in its entirety.

PART 9
FABRICATION, ASSEMBLY, AND ERECTION OF METALLIC PIPING

M327 GENERAL

Metallic piping materials and components are prepared for assembly and erection by one or more of the fabrication processes in paras. M328, M330, M331, and M332. When any of these processes is used in assembly and erection, requirements are the same as for fabrication.

M328 WELDING OF METALS

Welding shall be in accordance with paras. M311.1 and 328, except see para. M328.3.

M328.3 Welding Materials

Paragraph 328.3 applies in its entirety, except that split backing rings shall not be used, and removable backing rings and consumable inserts may be used only where their suitability has been demonstrated by procedure qualification.

M330 PREHEATING OF METALS

Paragraph 330 applies in its entirety.

(20) M331 HEAT TREATMENT OF METALS

Paragraph 331 applies in its entirety, with the exception that no requirements less stringent than those of Table 331.1.2 or Table 331.1.3 for PWHT shall be specified.

M332 BENDING AND FORMING OF METALS

Paragraph 332 applies in its entirety, except that bending that conforms to para. 332.2.3 is not permitted.

M335 ASSEMBLY AND ERECTION OF METALLIC PIPING

M335.1 General

M335.1.1 Alignment. In addition to the requirements of para. 335.1, any bending or forming required for alignment and fit-up shall be heat treated if required by para. 332.4.

M335.2 Flanged Joints

Paragraph 335.2 applies in its entirety.

M335.3 Threaded Joints

Paragraphs 335.3.1 and 335.3.2 apply. See paras. M335.3.3 and M335.3.4.

M335.3.3 Straight-Threaded Joints. The requirements of para. 335.3.3 are subject to the limitations in para. M322.

M335.3.4 Condition of Threads. Taper-threaded components and threaded ends permitted under para. M314.2.1 shall be examined before assembly for cleanliness and continuity of threads and shall be rejected if not in conformance with ASME B1.20.1 or other applicable standards.

M335.4 Tubing Joints

M335.4.1 Flared Tubing Joints. The requirements of para. 335.4.1 apply; however, see para. M322 for limitations associated with specific piping systems.

M335.4.2 Flareless and Compression Tubing Joints. The requirements of para. 335.4.2 apply; however, see para. M322 for limitations associated with specific piping systems.

M335.6 Special Joints

Special joints shall be in accordance with paras. M318 and 335.6.1.

M335.9 Cleaning of Piping

See Appendix F, para. F335.9.

M335.10 Identification of Piping

See Appendix F, para. F335.10.

PART 10
INSPECTION, EXAMINATION, TESTING, AND RECORDS OF METALLIC PIPING

M340 INSPECTION

Paragraph 340 applies in its entirety.

M341 EXAMINATION

Paragraphs 341.1, 341.2, 341.3, and 341.5 apply in their entirety. See para. M341.4.

M341.4 Extent of Required Examination

Paragraph 341.4.1 applies with the following exceptions:

(a) *Visual Examination*

(1) All fabrication shall be examined.

(2) All threaded, bolted, and other mechanical joints shall be examined.

(b) Other Examination. The radiography/ultrasonic examination requirements of para. 341.4.1(b)(1) apply, except that 100% of circumferential butt and miter welds and of fabricated lap and branch connection welds comparable to those shown in Figure 328.5.4E; Figure 328.5.4F; and Figure 328.5.5, illustrations (d) and (e), shall be examined.

M342 EXAMINATION PERSONNEL

Paragraph 342 applies.

M343 EXAMINATION PROCEDURES

Paragraph 343 applies.

M344 TYPES OF EXAMINATION

Paragraph 344 applies in its entirety.

M345 TESTING

Paragraph 345 applies, except that

(a) a sensitive leak test in accordance with para. 345.8 shall be included in the required leak test (para. 345.1)

(b) the initial service leak test (para. 345.7) does not apply

M346 RECORDS

Paragraph 346 applies in its entirety.

PARTS 11 THROUGH 20, CORRESPONDING TO CHAPTER VII

See para. M300(b).

MA300 GENERAL STATEMENTS

Paragraphs MA300 through MA346 apply to nonmetallic piping and piping lined with nonmetals, based on Chapter VII. Paragraph A300(d) applies.

PART 11 CONDITIONS AND CRITERIA

MA301 DESIGN CONDITIONS

Paragraph A301 applies in its entirety.

MA302 DESIGN CRITERIA

Paragraphs A302.1 and A302.4 apply. See paras. MA302.2 and MA302.3.

MA302.2 Pressure–Temperature Design Criteria

Paragraph A302.2 applies, with the exception of para. A302.2.4. See para. MA302.2.4.

MA302.2.4 Allowances for Pressure and Temperature Variation. Paragraph A302.2.4(a) applies to both nonmetallic piping and to metallic piping with nonmetallic lining.

MA302.3 Allowable Stresses and Other Design Limits

Paragraph A302.3 applies.

MA302.4 Allowances

Paragraph 302.4 applies in its entirety.

PART 12 PRESSURE DESIGN OF NONMETALLIC PIPING COMPONENTS

MA303 GENERAL

Paragraph A303 applies in its entirety.

MA304 PRESSURE DESIGN OF NONMETALLIC COMPONENTS

Paragraph A304 applies in its entirety.

PART 13 FLUID SERVICE REQUIREMENTS FOR NONMETALLIC PIPING COMPONENTS

MA305 PIPE

Paragraph A305 applies in its entirety.

MA306 NONMETALLIC FITTINGS, BENDS, MITERS, LAPS, AND BRANCH CONNECTIONS

Paragraphs A306.1 and A306.2 apply. See para. MA306.3.

MA306.3 Miter Bends

Miter bends not designated as fittings conforming to para. A306.1 shall not be used.

MA306.4 Fabricated Laps

Fabricated laps shall not be used.

MA306.5 Fabricated Branch Connections

Nonmetallic fabricated branch connections shall not be used.

MA307 VALVES AND SPECIALTY COMPONENTS

Paragraph A307 applies, except that nonmetallic valves and specialty components shall not be used.

MA308 FLANGES, BLANKS, FLANGE FACINGS, AND GASKETS

Paragraphs A308.1, 308.3, and A308.4 apply in their entirety. See para. MA308.2.

MA308.2 Nonmetallic Flanges

Threaded nonmetallic flanges shall not be used.

MA309 BOLTING

Paragraph A309 applies in its entirety.

PART 14
FLUID SERVICE REQUIREMENTS FOR NONMETALLIC PIPING JOINTS

MA310 GENERAL

Paragraph 310 applies in its entirety.

MA311 BONDED JOINTS

MA311.1 General

Paragraph A311.1 applies in its entirety.

MA311.2 Specific Requirements

Hot gas welded, heat fusion, solvent cemented, and adhesive bonded joints are not permitted except in linings.

MA312 FLANGED JOINTS

Paragraph 312 applies in its entirety.

MA313 EXPANDED JOINTS

Expanded joints shall not be used.

MA314 THREADED JOINTS

MA314.1 General

Threaded joints shall not be used.

MA315 TUBING JOINTS IN NONMETALLIC PIPING

Paragraph A315 applies in its entirety.

MA316 CAULKED JOINTS

Caulked joints shall not be used.

MA318 SPECIAL JOINTS

Paragraph A318 applies in its entirety.

PART 15
FLEXIBILITY AND SUPPORT OF NONMETALLIC PIPING

MA319 PIPING FLEXIBILITY

Paragraph A319 applies in its entirety.

MA321 PIPING SUPPORT

Paragraph A321 applies in its entirety.

PART 16
NONMETALLIC AND NONMETALLIC-LINED SYSTEMS

MA322 SPECIFIC PIPING SYSTEMS

Paragraph A322 applies in its entirety.

PART 17
NONMETALLIC MATERIALS

MA323 GENERAL REQUIREMENTS

Paragraph A323.1 applies with the additional requirement described in para. MA323.1.2. Paragraph A323.2 applies in its entirety. See para. MA323.4.

MA323.1.2 Unlisted Materials. Paragraph 323.1.2 applies with the additional requirement that the designer shall fully document the determination of allowable stresses as part of the engineering design.

MA323.4 Fluid Service Requirements for Nonmetallic Materials

Paragraph A323.4.1 applies. See paras. MA323.4.2 and MA323.4.3.

MA323.4.2 Specific Requirements. Paragraph A323.4.2 applies, except that materials listed under paras. A323.4.2(a), A323.4.2(b), and A323.4.2(d) may be used only as linings. Thermoplastics may be used as gaskets in accordance with paras. M325.1 and MA323.4.3.

MA323.4.3 Nonmetallic Lining Materials. Paragraph A323.4.3 applies with the additional requirement that where a material in para. A323.4.2 is used as a lining that also serves as a gasket or as part of the flange facing, consideration shall be given to design of the flanged joint to prevent leakage to the environment.

PART 18
STANDARDS FOR NONMETALLIC AND NONMETALLIC-LINED PIPING COMPONENTS

MA326 DIMENSIONS AND RATINGS OF COMPONENTS

Paragraph A326 applies in its entirety. Table A326.1 applies, except for components and systems prohibited or restricted elsewhere in this Chapter.

PART 19
FABRICATION, ASSEMBLY, AND ERECTION OF NONMETALLIC AND NONMETALLIC-LINED PIPING

MA327 GENERAL

Paragraph A327 applies in its entirety.

MA328 BONDING OF PLASTICS

Paragraph A328 applies in its entirety.

MA329 FABRICATION OF PIPING LINED WITH NONMETALS

Paragraph A329 applies in its entirety.

MA332 BENDING AND FORMING

Paragraph A332 applies in its entirety.

MA334 JOINING NONPLASTIC PIPING

Paragraph A334 applies in its entirety.

MA335 ASSEMBLY AND ERECTION

Paragraph A335 applies in its entirety.

PART 20
INSPECTION, EXAMINATION, TESTING, AND RECORDS OF NONMETALLIC AND NONMETALLIC-LINED PIPING

MA340 INSPECTION

Paragraph 340 applies in its entirety.

MA341 EXAMINATION

Paragraph A341 applies in its entirety.

MA341.1 General

Paragraphs 341.1, 341.2, A341.3, and A341.5 apply in their entirety. See para. MA341.4.

MA341.4 Extent of Required Examination

Paragraph A341.4.1 applies, except as follows:

(a) *Visual Examination*

(1) All fabrication shall be visually examined.

(2) All bolted and other mechanical joints shall be examined.

MA342 EXAMINATION PERSONNEL

Paragraph 342 applies in its entirety.

MA343 EXAMINATION PROCEDURES

Paragraph 343 applies in its entirety.

MA344 TYPES OF EXAMINATION

Paragraph A344 applies in its entirety.

MA345 TESTING

Paragraph A345 applies except that

(a) a sensitive leak test in accordance with para. 345.8 shall be included in the required leak test (para. A345.1)

(b) the initial service leak test (para. A345.7) does not apply

MA346 RECORDS

Paragraph 346 applies in its entirety.

Chapter IX
High Pressure Piping

(20) K300 GENERAL STATEMENTS

(a) Chapter IX provides alternative rules for design and construction of piping designated by the owner as being in High Pressure Fluid Service. See para. 300(b)(1) and Appendix M.

(1) Use of this Chapter is permitted only when the owner designates the piping as being in High Pressure Fluid Service. When piping is so designated, the requirements of this Chapter apply in their entirety.

(2) There are no pressure limitations for the application of these rules. See Appendix F, para. FK300.

(b) *Responsibilities.* In addition to the responsibilities stated in para. 300(b)

(1) for piping designated as being in High Pressure Fluid Service, the owner shall provide all system operations information necessary for the designer to perform the analyses and testing required by this Chapter

(2) the designer shall make a written report to the owner summarizing the design calculations and certifying that the design has been performed in accordance with this Chapter

(c) The organization, content, and, wherever possible, paragraph designations of this Chapter correspond to those of the base Code (Chapters I through VI). The prefix K is used.

(d) Provisions and requirements of the base Code apply only as stated in this Chapter.

(e) Paragraphs 300(a) and 300(c) through 300(f) apply.

(20) K300.1 Scope

K300.1.1 Content and Coverage. Paragraph 300.1.1 applies with the exceptions stated in paras. K300.1.3 and K300.1.6.

K300.1.2 Packaged Equipment Piping. Interconnecting piping as described in para. 300.1.2 shall conform to the requirements of this Chapter.

K300.1.3 Exclusions. In addition to the exclusions stated in para. 300.1.3, this Chapter excludes nonmetallic piping and piping lined with nonmetals.

K300.1.4 Units of Measure. Paragraph 300.1.4 applies.

K300.1.5 Rounding. Paragraph 300.1.5 applies.

K300.1.6 Category M Fluid Service. This Chapter makes no provision for piping in Category M Fluid Service. If such piping is required by the owner, the engineering design shall be developed as provided in para. 300(c)(5).

K300.2 Definitions

Paragraph 300.2 applies except for terms relating only to nonmetals and severe cyclic conditions.

The term "allowable stress" is used in lieu of basic allowable stress.

The term "safeguarding" and other terms characterizing hazardous fluid services are not used in this Chapter but should be taken into account in design.

K300.3 Nomenclature

Paragraph 300.3 applies.

K300.4 Status of Appendices

Paragraph 300.4 and Table 300.4 apply, except for Appendices A, B, H, L, R, S, V, and X.

PART 1
CONDITIONS AND CRITERIA

K301 DESIGN CONDITIONS

Paragraph 301 applies with the exceptions of paras. 301.2, 301.3, 301.4.2, 301.5, and 301.7.3.

K301.2 Design Pressure

K301.2.1 General. Paragraph 301.2.1 applies, except that references to para. 302.2.4 are not applicable and refer to para. K304 instead of para. 304.

K301.2.2 Required Pressure Containment or Relief. Paragraphs 301.2.2(a) and 301.2.2(b) apply, but refer to para. K322.6.3 instead of para. 322.6.3. Paragraph 301.2.2(c) is not applicable.

K301.3 Design Temperature

Paragraph 301.3 applies with the exceptions of paras. 301.3.1 and 301.3.2 and the following exceptions in the text:

(a) Refer to para. K301.2 instead of para. 301.2.

(b) Refer to para. K301.3.2 instead of para. 301.3.2.

K301.3.1 Design Minimum Temperature. Paragraph 301.3.1 applies, but refer to para. K323.2.2 instead of para. 323.2.2.

K301.3.2 Uninsulated Components. The fluid temperature shall be used as the component temperature.

K301.4 Ambient Effects

K301.4.2 Fluid Expansion Effects. Paragraph 301.4.2 applies, except that reference to para. 322.6.3(b)(2) is not applicable.

K301.5 Dynamic Effects

Paragraph 301.5 applies with the exception of para. 301.5.4.

K301.5.4 Vibration. Suitable dynamic analysis shall be made where necessary, to avoid or minimize conditions that lead to detrimental vibration, pulsation, or resonance effects in the piping.

K301.7 Thermal Expansion and Contraction Effects

K301.7.3 Loads Due to Differences in Expansion Characteristics. Paragraph 301.7.3 applies, except that reference to metallic–nonmetallic piping is not applicable.

K302 DESIGN CRITERIA

K302.1 General

In para. K302, pressure–temperature ratings, stress criteria, design allowances, and minimum design values are stated, and permissible variations of these factors as applied to design of high pressure piping systems are formulated.

The designer shall be satisfied as to the adequacy of the design, and of materials and their manufacture, considering at least the following:

(a) tensile, compressive, flexural, and shear strength at design temperature

(b) fatigue strength

(c) design stress and its basis

(d) ductility and toughness

(e) possible deterioration of mechanical properties in service

(f) thermal properties

(g) temperature limits

(h) resistance to corrosion and erosion

(i) fabrication methods

(j) examination and testing methods

(k) hydrostatic test conditions

(l) bore imperfections

K302.2 Pressure–Temperature Design Criteria

K302.2.1 Listed Components Having Established Ratings. Pressure–temperature ratings for certain piping components have been established and are contained in some of the standards in Table K326.1. Unless limited elsewhere in this Chapter, those ratings are acceptable for design pressures and temperatures under this Chapter. With the owner's approval, the rules and limits of this Chapter may be used to extend the pressure–temperature ratings of a component beyond the ratings of the listed standard, but not beyond the limits stated in para. K323.2.

K302.2.2 Listed Components Not Having Specific Ratings

(a) Piping components for which design stresses have been developed in accordance with para. K302.3, but that do not have specific pressure–temperature ratings, shall be rated by rules for pressure design in para. K304, within the range of temperatures for which stresses are shown in Table K-1, modified as applicable by other rules of this Chapter.

(b) Piping components that do not have allowable stresses or pressure–temperature ratings shall be qualified for pressure design as required by para. K304.7.2.

K302.2.3 Unlisted Components. Piping components not listed in Table K326.1 may be used subject to all of the following requirements:

(a) The material shall comply with para. K323.

(b) The designer shall be satisfied that the design is suitable for the intended service.

(c) Pressure–temperature ratings shall be established in accordance with the rules in para. K304.

(d) Fatigue analysis shall be performed as required by para. K304.8.

K302.2.4 Allowance for Pressure and Temperature Variations. Variations in pressure, temperature, or both above the design conditions, except during pressure-relieving events (see para. K322.6.3), are not permitted for any piping system. The design pressure and design temperature resulting in the most severe coincident pressure and temperature shall determine the design conditions. See paras. K301.2 and K301.3.

K302.2.5 Ratings at Junction of Different Services. Paragraph 302.2.5 applies.

K302.3 Allowable Stresses and Other Design Limits

K302.3.1 General. The allowable stresses defined below shall be used in design calculations unless modified by other provisions of this Chapter. (20)

(a) Tension. Allowable stresses in tension for use in design in accordance with this Chapter are listed in Table K-1, except that maximum allowable stress values and design stress intensity values for bolting, respectively, are listed in ASME BPVC, Section II, Part D, Tables 3 and 4.

The tabulated stress values in Table K-1 are grouped by materials and product form and are for stated temperatures up to the limit provided for the materials in para. K323.2.1. Straight line interpolation between temperatures to determine the allowable stress for a specific design temperature is permissible. Extrapolation is not permitted.

(b) Shear and Bearing. Allowable stress in shear shall be 0.57 times S_{yt}. Allowable stress in bearing shall be 1.0 times S_{yt}. See para. K302.3.2(b) for definition of S_{yt}.

(c) Compression. Allowable stress in compression shall be no greater than the allowable stress in tension tabulated in Table K-1. Consideration shall be given to structural stability.

(d) Fatigue. Allowable values of stress amplitude, which are provided as a function of design life in ASME BPVC, Section VIII, Division 3, Article KD-3, may be used in fatigue analysis in accordance with para. K304.8.

(20) **K302.3.2 Bases for Allowable Stresses.** The bases for establishing allowable stress values for materials in this Chapter are as follows:

(a) Bolting Materials. The criteria of ASME BPVC, Section II, Part D, Appendix 2, 2-120 or 2-130, or Section VIII, Division 3, Article KD-6, KD-620, as applicable, apply.

(b) Other Materials. Allowable stress values at temperature for materials other than bolting materials shall not exceed the lower of the values calculated from eqs. (31a) and (31b). S_{ut} and S_{yt} shall be determined in accordance with eqs. (31d) and (31c), except that S_{ut} and S_{yt} shall not exceed S_T and S_Y, respectively.

$$S = \frac{1}{1.25} S_{yt} \tag{31a}$$

$$S = \frac{1}{3}\left(S_{ut} + S_{yt}\right) \tag{31b}$$

$$S_{yt} = S_Y R_Y \tag{31c}$$

$$S_{ut} = 1.1 S_T R_T \tag{31d}$$

where

R_T = ratio of the average temperature dependent trend curve value of tensile strength to the room temperature tensile strength
R_Y = ratio of the average temperature dependent trend curve value of yield strength to the room temperature yield strength
S = allowable stress
S_T = specified minimum tensile strength at room temperature
S_{ut} = tensile strength at temperature
S_Y = specified minimum yield strength at room temperature
S_{yt} = yield strength at temperature

(c) Unlisted Materials. For a material that conforms to para. K323.1.2, allowable stress values at temperature shall be calculated in accordance with (b).

(1) Except as provided in (2), S_{ut} and S_{yt} shall be determined in accordance with eqs. (31d) and (31c), respectively.

(2) If the tensile and yield strengths at temperature for an unlisted material are contained in ASME BPVC, Section II, Part D, Tables U-1 and Y-1, respectively, those tensile and yield strengths at temperature values may be used directly in the determination of allowable stress.

(d) Cyclic Stresses. Allowable values of alternating stress shall be in accordance with ASME BPVC, Section VIII, Division 3, Article KD-3.

K302.3.3 Castings.[1] Cast piping components shall conform to all of the following requirements:

(a) All surfaces shall have a roughness average, R_a, not greater than 6.3 μm R_a (250 μin. R_a); see ASME B46.1 for a definition of R_a.

(b) All nonferromagnetic surfaces shall be examined using the liquid penetrant method in accordance with ASTM E165, with acceptability judged in accordance with MSS SP-93, Table 1. All ferromagnetic surfaces shall be examined using either the liquid penetrant method or the magnetic particle method, in accordance with ASTM E165 or ASTM E709, respectively. Acceptability of imperfections, including those in weld repairs, shall be judged in accordance with MSS SP-93, Table 1 or MSS SP-53, Table 1, respectively.

(c) Each casting shall be fully examined either ultrasonically in accordance with ASTM E114 or radiographically in accordance with ASTM E94. Cracks and hot tears (Category D and E discontinuities in accordance with the standards listed in Table K302.3.3D) and imperfections whose depths exceed 3% of nominal wall thickness are not permitted. Acceptable severity levels for radiographic examination of castings shall be in accordance with Table K302.3.3D.

[1] See Notes to Tables 302.3.3C and 302.3.3D for titles of standards referenced herein.

Table K302.3.3D Acceptable Severity Levels for Steel Castings

Thickness Examined, mm (in.)	Applicable Standards	Acceptable Severity Level	Acceptable Discontinuity Categories
$\overline{T} \leq 51$ (2)	ASTM E446	1	A, B, C
$51 < \overline{T} \leq 114$ (4.5)	ASTM E186	1	A, B, C
$114 < \overline{T} \leq 305$ (12)	ASTM E280	1	A, B, C

K302.3.4 Weld Joint Quality Factor. Piping components containing welds shall have a weld joint quality factor $E_j = 1.00$ (see Table 302.3.4), except that the acceptance criteria for these welds shall be in accordance with para. K341.3.2. Spiral (helical seam) welds are not permitted.

K302.3.5 Limits of Calculated Stresses Due to Sustained Loads and Displacement Strains

(a) Internal Pressure Stresses. Stresses due to internal pressure shall be considered safe when the wall thickness of the piping component, and its means of stiffening, meet the requirements of para. K304.

(b) External Pressure Stresses. Stresses due to external pressure shall be considered safe when the wall thickness of the piping component, and its means of stiffening, meet the requirements of para. K304.

(c) Stresses Due to Sustained Loads, S_L. The stresses due to sustained loads, S_L, in any component in a piping system (see para. K320) shall not exceed S_h, where S_h is the allowable stress provided in Table K-1 at the metal temperature for the operating condition being considered. The thickness of pipe used in calculating S_L shall be the nominal thickness minus the mechanical, corrosion, and erosion allowance, c.

(d) Allowable Displacement Stress Range, S_A. The computed displacement stress range, S_E, in a piping system (see para. 319.4.4) shall not exceed the allowable displacement stress range, S_A (see para. 319.2.3), calculated by

$$S_A = 1.25S_c + 0.25S_h \tag{32}$$

where

S_c = allowable stress from Table K-1 at minimum metal temperature expected during the displacement cycle under analysis

S_h = allowable stress from Table K-1 at maximum metal temperature expected during the displacement cycle under analysis

K302.3.6 Limits of Calculated Stresses Due to Occasional Loads (20)

(a) Operation. Stresses due to occasional loads may be calculated using the equations for stress due to sustained loads in para. K320.2. The sum of the stresses due to sustained loads, such as pressure and weight, S_L, and of the stresses produced by occasional loads, such as wind and earthquake, shall not exceed 1.2 times the allowable stress provided in Table K-1. Wind and earthquake forces need not be considered as acting concurrently.

(b) Test. Stresses due to test conditions are not subject to the limitations in para. K302.3. It is not necessary to consider other occasional loads, such as wind and earthquake, as occurring concurrently with test loads.

K302.4 Allowances

In determining the minimum required thickness of a piping component, allowances shall be included for corrosion, erosion, and thread or groove depth. See the definition of c in para. K304.1.1(b).

K302.5 Mechanical Strength

Paragraph 302.5 applies.

PART 2
PRESSURE DESIGN OF PIPING COMPONENTS

K303 GENERAL

Components manufactured in accordance with standards listed in Table K326.1 shall be considered suitable for use at pressure–temperature ratings in accordance with para. K302.2.

K304 PRESSURE DESIGN OF HIGH PRESSURE COMPONENTS

K304.1 Straight Pipe

K304.1.1 General

(a) The required wall thickness of straight sections of pipe shall be determined in accordance with eq. (33).

$$t_m = t + c \tag{33}$$

The minimum wall thickness, T, for the pipe selected, considering manufacturer's minus tolerance, shall be not less than t_m.

(b) The following nomenclature is used in the equation for pressure design of straight pipe:

$c = c_i + c_o$
= the sum of mechanical allowances[2] (thread or groove depth) plus corrosion and erosion allowances (where c_i = the sum of *internal* allowances and c_o = the sum of *external* allowances). For threaded components, the nominal thread depth (dimension h of ASME B1.20.1 or equivalent) shall apply, except that for straight threaded connections, the external thread groove depth need not be considered provided

(1) it does not exceed 20% of the wall thickness

(2) the ratio of outside to inside diameter, D/d, is greater than 1.1

(3) the internally threaded attachment provides adequate reinforcement

(4) the thread plus the undercut area, if any, does not extend beyond the reinforcement for a distance more than the nominal wall thickness of the pipe

t = pressure design wall thickness, as calculated in para. K304.1.2 for internal pressure, or in accordance with the procedure listed in para. K304.1.3 for external pressure

t_m = minimum required wall thickness, including mechanical, corrosion, and erosion allowances

Adequate reinforcement by the attachment is defined as that necessary to ensure that the static burst pressure of the connection will equal or exceed that of the unthreaded portion of the pipe. The adequacy of the reinforcement shall be substantiated as required by para. K304.7.2.

(20) **K304.1.2 Straight Pipe Under Internal Pressure.** The internal pressure design wall thickness, t, shall be not less than that calculated in accordance with eq. (34a) for pipe with a specified outside diameter and minimum wall thickness, or eq. (34b) for pipe with a specified inside diameter and minimum wall thickness[3]

$$t = \frac{D - 2c_o}{2}\left[1 - e^{(-P/S)}\right] \tag{34a}$$

or

$$t = \frac{d + 2c_i}{2}\left[e^{(-P/S)} - 1\right] \tag{34b}$$

Alternatively, the internal design gage pressure, P, may be calculated by eq. (35a) or (35b)[3]

$$P = S \times \ln\left[\frac{D - 2c_o}{D - 2(T - c_i)}\right] \tag{35a}$$

or

$$P = S \times \ln\left[\frac{d + 2(T - c_o)}{d + 2c_i}\right] \tag{35b}$$

where

D = outside diameter of pipe. For design calculations in accordance with this Chapter, the outside diameter of the pipe is the maximum value allowable under the specifications.

d = inside diameter of pipe. For design calculations in accordance with this Chapter, the inside diameter of the pipe is the maximum value allowable under the specifications.

P = internal design gage pressure

S = allowable stress from Table K-1

T = pipe wall thickness (measured or minimum in accordance with the purchase specification)

K304.1.3 Straight Pipe Under External Pressure. The (20) pressure design thickness for straight pipe under external pressure shall be determined in accordance with para. K304.1.2. Straight pipe under external pressure shall also meet the criteria against buckling given in ASME BPVC, Section VIII, Division 3, Article KD-2, KD-222.

K304.2 Curved and Mitered Segments of Pipe

K304.2.1 Pipe Bends. The minimum required wall thickness, t_m, of a bend, after bending, may be determined as for straight pipe in accordance with para. K304.1, provided that the bend radius of the pipe centerline is equal to or greater than ten times the nominal pipe outside diameter and the tolerances and strain limits of para. K332 are met. Otherwise the design shall be qualified as required by para. K304.7.2.

K304.2.2 Elbows. Manufactured elbows not in accordance with para. K303 and pipe bends not in accordance with para. K304.2.1 shall be qualified as required by para. K304.7.2.

K304.2.3 Miter Bends. Miter bends are not permitted.

K304.2.4 Curved Segments of Pipe Under External Pressure. (20) The wall thickness of curved segments of pipe subjected to external pressure may be determined as specified for straight pipe in para. K304.1.3.

K304.3 Branch Connections

K304.3.1 General. Acceptable branch connections include a fitting in accordance with para. K303, an extruded outlet in accordance with para. 304.3.4, or a

[2] For machined surfaces or grooves where the tolerance is not specified, the tolerance shall be assumed to be 0.5 mm (0.02 in.) in addition to the specified depth of the cut.

[3] Any mechanical, corrosion, or erosion allowance, c, not specified as internal, c_i, or external, c_o, shall be assumed to be internal, i.e., $c = c_i$ and $c_o = 0$.

branch connection fitting (see para. 300.2) similar to that shown in Figure K328.5.4.

K304.3.2 Strength of Branch Connections

(a) The opening made for a branch connection reduces both static and fatigue strength of the run pipe. There shall be sufficient material in the branch connection to contain pressure and meet reinforcement requirements.

(b) Static pressure design of a branch connection not in accordance with para. K303 shall conform to para. 304.3.4 for an extruded outlet or shall be qualified as required by para. K304.7.2.

K304.3.3 Reinforcement of Welded Branch Connections. Branch connections made as provided in para. 304.3.3 are not permitted.

K304.4 Closures

(a) Closures not in accordance with para. K303 or (b) below shall be qualified as required by para. K304.7.2.

(b) Closures may be designed in accordance with the methods, allowable stresses, and temperature limits of ASME BPVC, Section VIII, Division 2 or Division 3, and ASME BPVC, Section II, Part D.

K304.5 Pressure Design of Flanges and Blanks

K304.5.1 Flanges — General

(a) Flanges not in accordance with para. K303 or (b) below shall be qualified as required by para. K304.7.2.

(b) A flange may be designed in accordance with the methods, allowable stresses, and temperature limits of ASME BPVC, Section VIII, Division 2, Part 4, para. 4.16, or Part 5, or Division 3, Article KD-6, and ASME BPVC, Section II, Part D.

K304.5.2 Blind Flanges

(a) Blind flanges not in accordance with para. K303 or (b) or (c) below shall be qualified as required by para. K304.7.2.

(b) A blind flange may be designed in accordance with eq. (36). The thickness of the flange selected shall be not less than t_m (see para. K304.1.1 for nomenclature), considering manufacturing tolerance

$$t_m = t + c \tag{36}$$

The methods, allowable stresses, and temperature limits of ASME BPVC, Section VIII, Division 2, Part 4, para. 4.6 may be used, with the following changes in nomenclature, to calculate t_m:

c = sum of mechanical allowances, defined in para. K304.1.1

t = pressure design thickness as calculated for the given style of blind flange using the appropriate equation of ASME BPVC, Section VIII, Division 2, Part 4, para. 4.6

(c) A blind flange may be designed in accordance with the rules, allowable stresses, and temperature limits of ASME BPVC, Section VIII, Division 3, Article KD-6 and ASME BPVC, Section II, Part D.

K304.5.3 Blanks. Design of blanks shall be in accordance with para. 304.5.3(b), except that E shall be 1.00 and the definitions of S and c shall be in accordance with para. K304.1.1.

K304.6 Reducers

Reducers not in accordance with para. K303 shall be qualified as required by para. K304.7.2.

K304.7 Pressure Design of Other Components

K304.7.1 Listed Components. Other pressure-containing components manufactured in accordance with standards in Table K326.1 may be utilized in accordance with para. K303.

K304.7.2 Unlisted Components. Pressure design of unlisted components to which the rules elsewhere in para. K304 do not apply shall be based on the pressure design criteria of this Chapter. The designer shall ensure that the pressure design has been substantiated through one or more of the means stated in (a), (b), and (c) below. Note that designs are also required to be checked for adequacy of mechanical strength as described in para. K302.5. (20)

(a) extensive, successful service experience under comparable design conditions with similarly proportioned components made of the same or like material.

(b) performance testing sufficient to substantiate both the static pressure design and fatigue life at the intended operating conditions. Static pressure design may be substantiated by demonstrating that failure or excessive plastic deformation does not occur at a pressure equivalent to two times the internal design pressure, P. The test pressure shall be two times the design pressure multiplied by the ratio of allowable stress at test temperature to the allowable stress at design temperature, and by the ratio of actual yield strength to the specified minimum yield strength at room temperature from Table K-1.

(c) detailed stress analysis (e.g., finite element method) with results evaluated as described in ASME BPVC, Section VIII, Division 3, Article KD-2, except that for linear elastic analysis, the Division 3 stress intensity limits due to combined sustained and occasional loads may be increased by the same factor applied in para. K302.3.6(a).

(d) for (a), (b), and (c) above, interpolations supported by analysis are permitted between sizes, wall thicknesses, and pressure classes, as well as analogies among related materials with supporting material property data. Extrapolation is not permitted.

(20) **K304.7.3 Components With Nonmetallic Parts.** Gaskets, packing, seals, and valve seats that meet the applicable requirements of para. A302.1 may be used. Other nonmetallic parts are not permitted.

K304.7.4 Expansion Joints. Expansion joints are not permitted.

K304.8 Fatigue Analysis

(20) **K304.8.1 General.** A fatigue analysis shall be performed on each piping system, including all components[4] and joints therein, and considering the stresses resulting from attachments, to determine its suitability for the cyclic operating conditions[5] specified in the engineering design. Except as permitted in (a) and (b) below, or in paras. K304.8.4 and K304.8.5, this analysis shall be in accordance with ASME BPVC, Section VIII, Division 3.[6] The cyclic conditions shall include pressure variations as well as thermal variations or displacement stresses. The requirements of para. K304.8 are in addition to the requirements for a flexibility analysis stated in para. K319. No formal fatigue analysis is required in systems that

(a) are duplicates of successfully operating installations or replacements without significant change of systems with a satisfactory service record or

(b) can readily be judged adequate by comparison with previously analyzed systems

(20) **K304.8.2 Amplitude of Alternating Stress**

(a) The values of the alternating stress intensity, the associated mean stress, and the equivalent alternating stress intensity shall be determined in accordance with ASME BPVC, Section VIII, Division 3, Articles KD-2 and KD-3. The allowable amplitude of the equivalent alternating stress shall be determined from the applicable design fatigue curve in Article KD-3.

(b) If it can be shown that the piping component will fail in a leak-before-burst mode, the number of design cycles (design fatigue life) may be calculated in accordance with either ASME BPVC, Section VIII, Division 3, Article KD-3 or Article KD-4. If a leak-before-burst mode of failure cannot be shown, the fracture mechanics evaluation outlined in Article KD-4 shall be used to determine the number of design cycles of the component.

(c) Additional Considerations. The designer is cautioned that the considerations listed in para. K302.1 may reduce the fatigue life of the component below the value predicted by para. (a) or (b) above.

K304.8.3 Pressure Stress Evaluation for Fatigue Analysis (20)

(a) For fatigue analysis of straight pipe, eq. (37) may be used to calculate the stress intensity[7] at the inside surface due only to internal pressure

$$S = \frac{PD^2}{2(T-c)[D-(T-c)]} \tag{37}$$

(b) For fatigue analysis of curved pipe, eq. (37) may be used, with the dimensions of the straight pipe from which it was formed, to calculate the maximum stress intensity at the inside surface due only to internal pressure, provided that the centerline bend radius is not less than ten times the nominal outside diameter of the pipe, and that the tolerance and strain limits of para. K332 are met. Bends of smaller radius shall be qualified as required by para. K304.7.2.

(c) If the value of S calculated by eq. (37) exceeds two times S_{yt} at the average temperature during the loading cycle, an inelastic analysis shall be performed. See para. K302.3.2(b) for the definition of S_{yt}.

K304.8.4 Fatigue Evaluation by Test. With the owner's approval, the design fatigue life of a component may be established by destructive testing in accordance with para. K304.7.2 in lieu of the above analysis requirements.

K304.8.5 Extended Fatigue Life. The design fatigue life of piping components may be extended beyond that determined by ASME BPVC, Section VIII, Division 3, Article KD-3 by the use of one of the following methods, provided that the component is qualified in accordance with para. K304.7.2: (20)

(a) surface treatments, such as improved surface finish

(b) prestressing methods, such as autofrettage, shot peening, or shrink fit

The designer is cautioned that the benefits of prestress may be reduced due to thermal, strain softening, or other effects.

PART 3
FLUID SERVICE REQUIREMENTS FOR PIPING COMPONENTS

K305 PIPE

Pipe includes components designated as tube or tubing in the material specification, when intended for pressure service.

[4] Bore imperfections may reduce fatigue life.

[5] If the range of temperature change varies, equivalent full temperature cycles N may be computed using eq. (1d) in para. 302.3.5.

[6] Fatigue analysis in accordance with ASME BPVC, Section VIII, Division 3 requires that stress concentration factors be used in computing the cyclic stresses.

[7] The term "stress intensity" is defined in ASME BPVC, Section VIII, Division 3.

Table K305.1.2 Required Ultrasonic or Eddy Current Examination of Pipe and Tubing for Longitudinal Defects

Diameter, mm (in.)	Examination Required	Paragraph Reference
d < 3.2 ($\frac{1}{8}$) or D < 6.4 ($\frac{1}{4}$)	None	...
3.2 ($\frac{1}{8}$) ≤ d ≤ 17.5 ($\frac{11}{16}$) and 6.4 ($\frac{1}{4}$) ≤ D ≤ 25.4 (1)	Eddy current (ET) [Note (1)] or ultrasonic (UT)	K344.8 or K344.6
d > 17.5 ($\frac{11}{16}$) or D > 25.4 (1)	Ultrasonic (UT)	K344.6

NOTE: (1) This examination is limited to cold drawn austenitic stainless steel pipe and tubing.

K305.1 Requirements

K305.1.1 General. Pipe and tubing shall be either seamless or longitudinally welded with straight seam and a joint quality factor E_j = 1.00, examined in accordance with Note (2) of Table K341.3.2. Spiral (helical seam) welds are not permitted.

K305.1.2 Additional Examination. Pipe and tubing shall have passed a 100% examination for longitudinal defects in accordance with Table K305.1.2. This examination is in addition to acceptance tests required by the material specification.

K305.1.3 Heat Treatment. Heat treatment, if required, shall be in accordance with para. K331.

K305.1.4 Unlisted Pipe and Tubing. Unlisted pipe and tubing may be used only in accordance with para. K302.2.3.

K306 FITTINGS, BENDS, AND BRANCH CONNECTIONS

Pipe and other materials used in fittings, bends, and branch connections shall be suitable for the manufacturing or fabrication process and otherwise suitable for the service.

K306.1 Pipe Fittings

K306.1.1 General. All castings shall have examination and acceptance criteria in accordance with para. K302.3.3. All welds shall have a weld quality factor E_j = 1.00, with examination and acceptance criteria in accordance with paras. K341 through K344. Spiral (helical seam) welds are not permitted. Listed fittings may be used in accordance with para. K303. Unlisted fittings may be used only in accordance with para. K302.2.3.

K306.1.2 Specific Fittings

(a) Socket welding fittings are not permitted.

(b) Threaded fittings are permitted only in accordance with para. K314.

(c) Branch connection fittings (see para. 300.2) whose design has been performance tested successfully as required by para. K304.7.2(b) may be used within their established ratings.

K306.2 Pipe Bends

K306.2.1 General. A bend made in accordance with para. K332.2 and verified for pressure design in accordance with para. K304.2.1 shall be suitable for the same service as the pipe from which it is made.

K306.2.2 Corrugated and Other Bends. Bends of other design (such as creased or corrugated) are not permitted.

K306.3 Miter Bends

Miter bends are not permitted.

K306.4 Fabricated or Flared Laps

Only forged laps are permitted.

K306.5 Fabricated Branch Connections

Fabricated branch connections constructed by welding shall be fabricated in accordance with para. K328.5.4 and examined in accordance with para. K341.4.

K307 VALVES AND SPECIALTY COMPONENTS (20)

The following requirements for valves shall also be met, as applicable, by other pressure-containing piping components, e.g., traps, strainers, and separators. See also Appendix F, paras. F301.4 and F307.

K307.1 General

K307.1.1 Listed Valves. A listed valve is suitable for use in High Pressure Fluid Service, except as stated in para. K307.2.

K307.1.2 Unlisted Valves. Unlisted valves may be used only in accordance with para. K302.2.3.

K307.2 Specific Requirements

K307.2.1 Bonnet Bolting. The bonnets of bolted bonnet valves shall be secured to their bodies by at least four bolts.

K307.2.2 Stem Retention. Paragraph 307.2.2 applies.

K308 FLANGES, BLANKS, FLANGE FACINGS, AND GASKETS

K308.1 General

Pressure design of unlisted flanges shall be verified in accordance with para. K304.5.1 or qualified as required by para. K304.7.2.

K308.2 Specific Flanges

K308.2.1 Threaded Flanges. Threaded flanges may be used only within the limitations on threaded joints in para. K314.

K308.2.2 Other Flange Types. Slip-on, socket welding, and expanded joint flanges, and flanges for flared laps, are not permitted.

K308.3 Flange Facings

The flange facing shall be suitable for the service and for the gasket and bolting employed.

K308.4 Gaskets

Gaskets shall be selected so that the required seating load is compatible with the flange rating and facing, the strength of the flange, and its bolting. Materials shall be suitable for the service conditions. Mode of gasket failure shall be considered in gasket selection and joint design.

K308.5 Blanks

Blanks shall have a marking, identifying material, pressure–temperature rating, and size, that is visible after installation.

K309 BOLTING

Bolting, including bolts, bolt studs, studs, cap screws, nuts, and washers, shall meet the requirements of ASME BPVC, Section VIII, Division 2, Part 3, para. 3.7; Part 4, para. 4.16; and Part 5, para. 5.7. See also Appendix F, para. F309, of this Code.

PART 4
FLUID SERVICE REQUIREMENTS FOR PIPING JOINTS

K310 GENERAL

Joints shall be suitable for the fluid handled, and for the pressure–temperature and other mechanical loadings expected in service.

Factors such as assembly and disassembly (if applicable), cyclic loading, vibration, shock, bending, and thermal expansion and contraction of joints shall be considered in the engineering design.

K311 WELDED JOINTS

K311.1 General

Welds shall conform to the following:

(a) Welding shall be in accordance with para. K328.

(b) Preheating and heat treatment shall be in accordance with paras. K330 and K331, respectively.

(c) Examination shall be in accordance with para. K341.4, with acceptance criteria as shown in Table K341.3.2.

K311.2 Specific Requirements

K311.2.1 Backing Rings and Consumable Inserts. Backing rings shall not be used. Consumable inserts shall not be used in butt welded joints except when specified by the engineering design.

K311.2.2 Fillet Welds. Fillet welds may be used only for structural attachments in accordance with the requirements of paras. K321 and K328.5.2.

K311.2.3 Other Weld Types. Socket welds and seal welds are not permitted.

K312 FLANGED JOINTS

Flanged joints shall be selected for leak tightness, considering the requirements of para. K308, flange facing finish, and method of attachment. See also para. F312.

K312.1 Joints Using Flanges of Different Ratings

Paragraph 312.1 applies.

K313 EXPANDED JOINTS

Expanded joints are not permitted.

K314 THREADED PIPE JOINTS

For the purposes of this paragraph, "pipe" does not include tube or tubing.

K314.1 General

Except as provided in paras. K314.2 and K314.3, threaded pipe joints are not permitted.

(a) Layout of piping shall be such as to minimize strain on threaded joints that could adversely affect sealing.

(b) Supports shall be designed to control or minimize strain and vibration on threaded joints and seals.

K314.2 Taper-Threaded Pipe Joints (20)

(a) Taper-threaded pipe joints shall be used only for instrumentation, vents, drains, and similar purposes, and shall be not larger than DN 15 (NPS $\frac{1}{2}$).

(b) The nominal wall thickness of piping components with external taper threads shall be at least as thick as that specified for Schedule 160 in ASME B36.10M.

K314.3 Straight-Threaded Pipe Joints

K314.3.1 Joints With Seal Formed by Projecting Pipe. Threaded joints where the threads are used to attach flanges or fittings, and in which the pipe end projects through the flange or fitting and is machined to form the sealing surface with a lens ring, cone ring, the mating pipe end, or other similar sealing device, may be used. Such joints shall be qualified in accordance with para. K304.7.2.

K314.3.2 Other Straight-Threaded Joints

(a) Other Joints Using Components Conforming to Listed Standards. Pipe joints may incorporate straight-threaded fittings conforming to listed standards in Table K326.1, provided the fittings

(1) are compatible with the pipe with which they are used, considering tolerances and other characteristics

(2) comply with para. K302.2.1 or K302.2.2

(b) Other Joints Using Components Not Conforming to Listed Standards. Other straight-threaded pipe joints (e.g., a union comprising external and internal ends joined with a threaded union nut, or other constructions shown typically in Figure 335.3.3) may be used. Such joints shall be qualified by performance testing in accordance with para. K304.7.2(b). Testing shall be conducted for each material type/grade and heat treatment condition, component configuration (e.g., elbow), size (e.g., NPS), and pressure rating. Performance testing of joints in which the process of making up the joint involves significant uncontrolled loads (e.g., hammer unions) shall include testing designed to simulate actual loads.

K315 TUBING JOINTS

K315.1 Flared End Tubing Joints

Flared end tubing joints, whether the flare provides the seal, carries the load, or both, may be used, provided the type of fitting selected is adequate for the design pressure, other loadings, and the design temperature. The design shall also be qualified in accordance with para. K304.7.2.

K315.2 Flareless Tubing Joints Using Components Conforming to Listed Standards

Tubing joints may incorporate flareless type fittings conforming to listed standards in Table K326.1, provided the fittings

(a) are compatible with the tubing with which they are used, considering tolerances and other characteristics

(b) comply with para. K302.2.1 or K302.2.2

K315.3 Flareless Tubing Joints Using Components Not Conforming to Listed Standards

Tubing joints may incorporate flareless type fittings not conforming to listed standards in Table K326.1, provided the type of fitting selected is adequate for the design pressure, other loadings, and the design temperature, and meets the requirements of para. K302.2.3.

K316 CAULKED JOINTS

Caulked joints are not permitted.

K317 SOLDERED AND BRAZED JOINTS

K317.1 Soldered Joints

Soldered joints are not permitted.

K317.2 Brazed and Braze Welded Joints (20)

(a) Braze welded joints and fillet joints made with brazing filler metal are not permitted.

(b) Brazed joints shall be made in accordance with para. K333 and shall be qualified as required by para. K304.7.2. Such application is the owner's responsibility. The melting point of brazing alloys shall be considered when exposure to fire is possible.

K318 SPECIAL JOINTS

Special joints are those not covered elsewhere in this Part.

K318.1 General

Joints may be used in accordance with para. 318.2 and the requirements for materials and components in this Chapter.

K318.2 Specific Requirements

K318.2.1 Prototype Tests. A prototype joint shall have been subjected to performance tests in accordance with para. K304.7.2(b) to determine the safety of the joint under test conditions simulating all expected service conditions. Testing shall include cyclic simulation.

K318.2.2 Prohibited Joints. Bell type and adhesive joints are not permitted.

PART 5
FLEXIBILITY AND SUPPORT

K319 FLEXIBILITY

Flexibility analysis shall be performed for each piping system. Paragraphs 319.1 through 319.6 apply, except for para. 319.4.1(c). The computed displacement stress range shall be within the allowable displacement stress range in para. K302.3.5 and shall also be included in the fatigue analysis in accordance with para. K304.8.

K320 ANALYSIS OF SUSTAINED LOADS

K320.1 Basic Assumptions and Requirements

Paragraph 320.1 applies, but refer to para. K302.3.5(c) instead of para. 302.3.5(c).

K320.2 Stress Due to Sustained Loads

Paragraph 320.2 applies, except that references to expansion joints are not applicable.

K321 PIPING SUPPORT

Piping supports and methods of attachment shall be in accordance with para. 321 except as modified below, and shall be detailed in the engineering design.

K321.1 General

K321.1.1 Objectives. Paragraph 321.1.1 applies, but substitute "Chapter" for "Code" in 321.1.1(a).

K321.1.4 Materials. Paragraph 321.1.4 applies, but replace 321.1.4(e) with the following:

(e) Attachments welded to the piping shall be of a material compatible with the piping and the service. Other requirements are specified in paras. K321.3.2 and K323.4.2(b).

K321.3 Structural Attachments

K321.3.2 Integral Attachments. Paragraph 321.3.2 applies, but substitute "K321.1.4(e)" for "321.1.4(e)" and "Chapter IX" for "Chapter V."

PART 6
SYSTEMS

K322 SPECIFIC PIPING SYSTEMS

K322.3 Instrument Piping

K322.3.1 Definition. Instrument piping within the scope of this Chapter includes all piping and piping components used to connect instruments to high pressure piping or equipment. Instruments, permanently sealed fluid-filled tubing systems furnished with instruments as temperature- or pressure-responsive devices, and control piping for air or hydraulically operated control apparatus (not connected directly to the high pressure piping or equipment) are not within the scope of this Chapter.

K322.3.2 Requirements. Instrument piping within the scope of this Chapter shall be in accordance with para. 322.3.2 except that the design pressure and temperature shall be determined in accordance with para. K301, and the requirements of para. K310 shall apply. Instruments, and control piping not within the scope of this Chapter, shall be designed in accordance with para. 322.3.

K322.6 Pressure-Relieving Systems

Paragraph 322.6 applies, except for para. 322.6.3.

(20) **K322.6.3 Overpressure Protection.** Overpressure protection for high pressure piping systems shall conform to the following:

(a) The cumulative capacity of pressure relief devices shall be sufficient to prevent the pressure from rising more than 10% above the design pressure at the operating temperature during the relieving condition.

(b) System protection shall include one pressure relief device with a set pressure at or below the design pressure at the operating temperature for the relieving condition. The set pressure of additional pressure relief devices shall not exceed 105% of the design pressure.

PART 7
MATERIALS

K323 GENERAL REQUIREMENTS

(a) Paragraph K323 states limitations and required qualifications for materials based on their inherent properties. Their use is also subject to requirements elsewhere in Chapter IX and in Table K-1.

(b) Specific attention should be given to the manufacturing process to ensure uniformity of properties throughout each piping component.

(c) See para. K321.1.4 for support materials.

K323.1 Materials and Specifications

K323.1.1 Listed Materials

(a) Any material used in a pressure-containing piping component shall conform to a listed specification, except as provided in (b) below or in para. K323.1.2.

(b) Materials manufactured to specification editions different from those listed in Appendix E may be used, provided

(1) the requirements for chemical composition and heat-treatment condition in the edition of the specification to which the material was manufactured meet the requirements of the listed edition

(2) the specified minimum tensile and yield strengths, and, if applicable, the specified maximum tensile and yield strengths, required by the two editions of the specification are the same, and

(3) the material has been tested and examined in accordance with the requirements of the listed edition of the specification

A material that does not meet the requirements of (b)(1), (b)(2), and (b)(3) may be evaluated as an unlisted material in accordance with para. K323.1.2.

K323.1.2 Unlisted Materials. An unlisted material may be used, provided it conforms to a published specification covering chemistry, physical and mechanical properties, method and process of manufacture, heat treatment, and quality control, and otherwise meets the requirements of this Chapter. Allowable stresses shall be determined in accordance with the applicable allowable stress basis of this Chapter or a more conservative basis.

K323.1.3 Unknown Materials. Materials of unknown specification, type, or grade are not permitted.

K323.1.4 Reclaimed Materials. Reclaimed pipe and other piping components may be used provided they are properly identified as conforming to a listed specification, have documented service history for the material and fatigue life evaluation, and otherwise meet the requirements of this Chapter. Sufficient cleaning and inspection shall be made to determine minimum wall thickness and freedom from defects that would be unacceptable in the intended service.

K323.1.5 Product Analysis. Conformance of materials to the product analysis chemical requirements of the applicable specification shall be verified, and certification shall be supplied. Requirements for product analysis are defined in the applicable materials specification.

K323.1.6 Repair of Materials by Welding. A material defect may be repaired by welding, provided that all of the following criteria are met:

(a) The material specification provides for weld repair.

(b) The welding procedure and welders or welding operators are qualified as required by para. K328.2.

(c) The repair and its examination are performed in accordance with the material specification and with the owner's approval.

K323.2 Temperature Limitations

The designer shall verify that materials that meet other requirements of this Chapter are suitable for service throughout the operating temperature range.

K323.2.1 Upper Temperature Limits, Listed Materials. A listed material shall not be used at a temperature above the maximum for which a stress value is shown in Appendix K, Table K-1.

(20) **K323.2.2 Lower Temperature Limits, Listed Materials**

(a) The design minimum temperature for listed materials and their welds shall not be colder than the impact test temperature determined in accordance with para. K323.3.4(a), except as provided in (b) or (c) below.

(b) For listed materials and their welds subjected to neither longitudinal nor circumferential stress greater than 41 MPa (6 ksi), the design minimum temperature shall not be colder than the lower of −46°C (−50°F) and the impact test temperature determined in accordance with para. K323.3.4(a).

(c) For listed materials and their welds exempted from Charpy impact testing by Table K323.3.1, Note (2), the design minimum temperature shall not be colder than −46°C (−50°F).

K323.2.3 Temperature Limits, Unlisted Materials. An unlisted material acceptable under para. K323.1.2 shall be qualified for service at all temperatures within a stated range from design minimum temperature to design (maximum) temperature, in accordance with para. K323.2.4. However, the upper temperature limit shall be less than the temperature for which an allowable stress, determined in accordance with para. 302.3.2, is governed by the creep or stress rupture provisions of that paragraph.

K323.2.4 Verification of Serviceability

(a) When an unlisted material is used, the designer is responsible for demonstrating the validity of the allowable stresses and other design limits, and of the approach taken in using the material, including the derivation of stress data and the establishment of temperature limits.

(b) Paragraph 323.2.4(b) applies except that allowable stress values shall be determined in accordance with para. K302.3.

K323.3 Impact Testing Methods and Acceptance Criteria

K323.3.1 General. Except as provided in Table K323.3.1, Note (2), piping components and welds used in High Pressure Fluid Service shall be subjected to Charpy V-notch impact testing. The testing shall be performed in accordance with Table K323.3.1 on representative samples using the testing methods described in paras. K323.3.2, K323.3.3, and K323.3.4. Acceptance criteria are described in para. K323.3.5. (20)

K323.3.2 Procedure. Paragraph 323.3.2 applies.

K323.3.3 Test Specimens

(a) Each set of impact test specimens shall consist of three specimen bars. Impact tests shall be made using standard 10 mm (0.394 in.) square cross section Charpy V-notch specimen bars oriented in the transverse direction.

(b) Where component size and/or shape does not permit specimens as specified in (a) above, standard 10 mm square cross-section longitudinal Charpy specimens may be prepared.

(c) Where component size and/or shape does not permit specimens as specified in (a) or (b) above, subsize longitudinal Charpy specimens may be prepared. Test temperature shall be reduced in accordance with Table 323.3.4. See also Table K323.3.1, Note (2).

(d) If necessary in (a), (b), or (c) above, corners of specimens parallel to and on the side opposite the notch may be as shown in Figure K323.3.3.

K323.3.4 Test Temperatures. For all Charpy impact tests, the test temperature criteria in (a) or (c) below shall be observed. (20)

(a) Charpy impact tests shall be conducted at a temperature no warmer than the coldest of the following:

(1) 20°C (70°F)

Table K323.3.1 Impact Testing Requirements

Test Characteristics		Column A Pipe, Tubes, and Components Made From Pipe or Tubes	Column B Other Components, Fittings, Etc.	Column C Bolts
Tests on Materials	Number of tests	As required by the material specification, or one test set per lot [see Note (1)], whichever is greater, except as permitted by Note (2).		
	Location and orientation of specimens [see Note (3)]	(a) Transverse to the longitudinal axis, with notch parallel to axis. [See Note (4).] (b) Where component size and/or shape does not permit specimens as specified in (a) above, paras. K323.3.3(b), (c), and (d) apply as needed.	(a) Transverse to the direction of maximum elongation during rolling or to direction of major working during forging. Notch shall be oriented parallel to direction of maximum elongation or major working. (b) If there is no single identifiable axis, e.g., for castings or triaxial forgings, specimens shall either meet the longitudinal values of Table K323.3.5, or three sets of orthogonal specimens shall be prepared, and the lowest impact values obtained from any set shall meet the transverse values of Table K323.3.5. (c) Where component size and/or shape does not permit specimens as specified in (a) or (b) above, paras. K323.3.3(c) and (d) apply as needed.	(a) Bolts ≤52 mm (2 in.) nominal size made in accordance with ASTM A320 shall meet the impact requirements of that specification. (b) For all other bolts, longitudinal specimens shall be taken. The impact values obtained shall meet the transverse values of Table K323.3.5.
Tests on Welds in Fabrication or Assembly	Test pieces [see Note (5)]	Test pieces for preparation of impact specimens shall be made for each welding procedure, type of electrode, or filler metal (i.e., AWS E-XXXX classification) and each flux to be used. All test pieces shall be subject to heat treatment, including cooling rates and aggregate time at temperature or temperatures, essentially the same as the heat treatment which the finished component will have received.		
	Number of test pieces [see Note (6)]	(1) One test piece with a thickness T for each range of material thicknesses which can vary from $\frac{1}{2}T$ to T + 6 mm ($\frac{1}{4}$ in.). (2) Unless otherwise specified in this Chapter [see Note (4)] or the engineering design, test pieces need not be made from individual material lots, or from material for each job, provided welds in other certified material of the same thickness ranges and to the same specification (type and grade, not heat or lot) have been tested as required and the records of those tests are made available.		
	Location and orientation of specimens	(1) Weld metal impact specimens shall be taken across the weld with the notch in the weld metal. Each specimen shall be oriented so that the notch axis is normal to the surface of the material and one face of the specimen shall be within 1.5 mm ($\frac{1}{16}$ in.) of the surface of the material. (2) Heat-affected zone impact specimens shall be taken across the weld and have sufficient length to locate the notch in the heat-affected zone, after etching. The notch shall be cut approximately normal to the material surface in such a manner as to include as much heat-affected zone material as possible in the resulting fracture. (3) The impact values obtained from both the weld metal and heat-affected zone specimens shall be compared to the transverse values in Table K323.3.5 for the determination of acceptance criteria.		

NOTES:

(1) A lot shall consist of pipe or components of the same nominal size, made from the same heat of material, and heat treated together. If a continuous type furnace is used, pipe or components may be considered to have been heat treated together if they are processed during a single continuous time period at the same furnace conditions.

(2) Impact tests are not required when the maximum obtainable longitudinal Charpy specimen has a width along the notch less than 2.5 mm (0.098 in.). See para. K323.2.2(c).

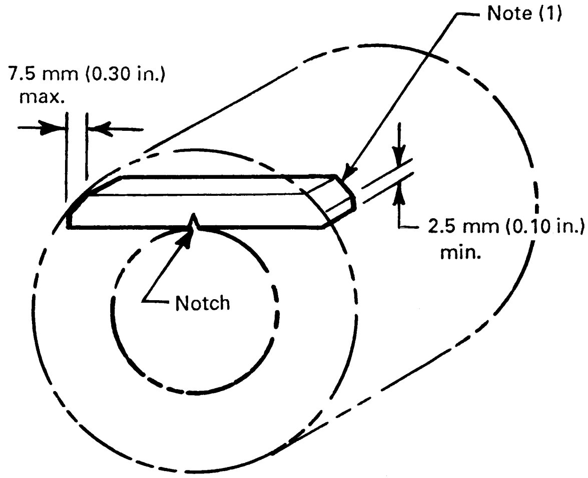
(3) Impact tests shall be performed on a representative sample of material after completion of all heat treatment and forming operations involving plastic deformation, except that cold bends made in accordance with para. K304.2.1 need not be tested after bending.

(4) For longitudinally welded pipe, specimens shall be taken from the base metal, weld metal, and the heat-affected zone.

(5) For welds in the fabrication or assembly of piping or components, including repair welds.

(6) The test piece shall be large enough to permit preparing the number of specimens required by para. K323.3. If this is not possible, additional test pieces shall be prepared.

Figure K323.3.3 Example of an Acceptable Impact Test Specimen



GENERAL NOTE: This Figure illustrates how an acceptable transverse Charpy specimen can be obtained from a tubing or component shape too small for a full length standard specimen in accordance with ASTM A370. The corners of a longitudinal specimen parallel to and on the side opposite the notch may be as shown.

NOTE: (1) Corners of the Charpy specimen [see para. K323.3.3(d)] may follow the contour of the component within the dimension limits shown.

(2) when the design minimum temperature is warmer than or equal to −46°C (−50°F), the lowest component temperature expected in service at which a material or weld will be subjected to a longitudinal or circumferential stress greater than 41 MPa (6 ksi)

(3) when the design minimum temperature is colder than −46°C (−50°F), the design minimum temperature

(b) In specifying the temperatures in (a)(2) and (a)(3), the following shall be considered:

(1) range of operating conditions
(2) upset conditions
(3) ambient temperature extremes
(4) required leak test temperature

(c) Where the largest possible test specimen has a width along the notch less than the lesser of 80% of the material thickness or 8 mm (0.315 in.), the test shall be conducted at a reduced temperature in accordance with Table 323.3.4, considering the temperature as reduced below the test temperature required by (a).

K323.3.5 Acceptance Criteria

(a) Minimum Energy Requirements for Materials Other Than Bolting. The applicable minimum impact energy requirements for materials shall be those shown in Table K323.3.5. Lateral expansion shall be measured in accordance with ASTM A370 (for title see para.

Table K323.3.5 Minimum Required Charpy V-Notch Impact Values

Specimen Orientation	Pipe Wall or Component Thickness, mm (in.)	Number of Specimens [Note (1)]	Energy, J (ft-lbf) [Note (2)] for Specified Minimum Yield Strength, MPa (ksi)	
			≤932 (≤135)	>932 (>135)
Transverse	≤25 (≤1)	Average for 3	27 (20)	34 (25)
		Minimum for 1	20 (15)	27 (20)
	>25 and ≤51 (>1 and ≤2)	Average for 3	34 (25)	41 (30)
		Minimum for 1	27 (20)	33 (24)
	>51 (>2)	Average for 3	41 (30)	47 (35)
		Minimum for 1	33 (24)	38 (28)
Longitudinal	≤25 (≤1)	Average for 3	54 (40)	68 (50)
		Minimum for 1	41 (30)	54 (40)
	>25 and ≤51 (>1 and ≤2)	Average for 3	68 (50)	81 (60)
		Minimum for 1	54 (40)	65 (48)
	>51 (>2)	Average for 3	81 (60)	95 (70)
		Minimum for 1	65 (48)	76 (56)

NOTES:
(1) See para. K323.3.5(c) for permissible retests.
(2) Energy values in this Table are for standard size specimens. For subsize specimens, these values shall be multiplied by the ratio of the actual specimen width to that of a full-size specimen, 10 mm (0.394 in.).

323.3.2). The results shall be included in the impact test report.

(b) Minimum Energy Requirements for Bolting Materials. The applicable minimum energy requirements shall be those shown in Table K323.3.5 except as provided in Table K323.3.1.

(c) Weld Impact Test Requirements. Where two base metals having different required impact energy values are joined by welding, the impact test energy requirements shall equal or exceed the requirements of the base material having the lower required impact energy.

(d) Retests

(1) Retest for Absorbed Energy Criteria. When the average value of the three specimens equals or exceeds the minimum value permitted for a single specimen, and the value for more than one specimen is below the required average value, or when the value for one specimen is below the minimum value permitted for a single specimen, a retest of three additional specimens shall be made. The value for each of these retest specimens shall equal or exceed the required average value.

(2) Retest for Erratic Test Results. When an erratic result is caused by a defective specimen or uncertainty in the test, a retest will be allowed. The report giving test results shall specifically state why the original specimen was considered defective or which step of the test procedure was carried out incorrectly.

K323.4 Requirements for Materials

K323.4.1 General. Requirements in para. K323.4 apply to pressure-containing parts, not to materials used as supports, gaskets, packing, or bolting. See also Appendix F, para. F323.4.

K323.4.2 Specific Requirements

(a) Ductile iron and other cast irons are not permitted.

(b) Zinc-coated materials are not permitted for pressure containing components and may not be attached to pressure-containing components by welding.

K323.4.3 Metallic Clad and Lined Materials. Materials with metallic cladding or lining may be used in accordance with the following provisions:

(a) For metallic clad or lined piping components, the base metal shall be an acceptable material as defined in para. K323, and the thickness used in pressure design in accordance with para. K304 shall not include the thickness of the cladding or lining. The allowable stress used shall be that for the base metal at the design temperature. For such components, the cladding or lining may be any material that, in the judgment of the user, is suitable for the intended service and for the method of manufacture and assembly of the piping component.

(b) Fabrication by welding of clad or lined piping components and the inspection and testing of such components shall be done in accordance with applicable provisions of ASME BPVC, Section VIII, Division 1, UCL-30 through UCL-52, and the provisions of this Chapter.

(c) If a metallic liner also serves as a gasket or as part of the flange facing, the requirements and limitations in para. K308.4 apply.

K323.5 Deterioration of Materials in Service

Paragraph 323.5 applies.

K325 MISCELLANEOUS MATERIALS

Paragraph 325 applies.

PART 8
STANDARDS FOR PIPING COMPONENTS

K326 REQUIREMENTS FOR COMPONENTS

K326.1 Dimensional Requirements

K326.1.1 Listed Piping Components. Dimensional standards for piping components are listed in Table K326.1. Dimensional requirements contained in specifications listed in Appendix K shall also be considered requirements of this Code.

K326.1.2 Unlisted Piping Components. Piping components not listed in Table K326.1 or Appendix K shall meet the pressure design requirements described in para. K302.2.3 and the mechanical strength requirements described in para. K302.5.

K326.1.3 Threads. The dimensions of piping connection threads not otherwise covered by a governing component standard or specification shall conform to the requirements of applicable standards listed in Table K326.1 or Appendix K.

K326.2 Ratings of Components

K326.2.1 Listed Components. The pressure–temperature ratings of components listed in Table K326.1 are accepted for pressure design in accordance with para. K303.

K326.2.2 Unlisted Components. The pressure–temperature ratings of unlisted piping components shall conform to the applicable provisions of para. K304.

K326.3 Reference Documents

The documents listed in Table K326.1 contain references to codes, standards, and specifications not listed in Table K326.1. Such unlisted codes, standards, and specifications shall be used only in the context of the listed documents in which they appear.

Table K326.1 Component Standards (20)

Standard or Specification	Designation
Bolting	
Square, Hex, Heavy Hex, and Askew Head Bolts and Hex, Heavy Hex, Hex Flange, Lobed Head, and Lag Screws (Inch Series)	ASME B18.2.1
Nuts for General Applications: Machine Screw Nuts, Hex, Square, Hex Flange, and Coupling Nuts (Inch Series)	ASME B18.2.2
Metallic Fittings, Valves, and Flanges	
Pipe Flanges and Flanged Fittings: NPS $^1/_2$ Through NPS 24 Metric/Inch Standard [Note (1)]	ASME B16.5
Factory-Made Wrought Buttwelding Fittings [Note (1)]	ASME B16.9
Forged Fittings, Socket-Welding and Threaded [Note (1)]	ASME B16.11
Valves — Flanged, Threaded, and Welding End [Note (1)]	ASME B16.34
Line Blanks [Note (1)]	ASME B16.48
Standard Marking System for Valves, Fittings, Flanges, and Unions	MSS SP-25
High Pressure Chemical Industry Flanges and Threaded Stubs for Use with Lens Gaskets [Note (1)]	MSS SP-65
Metallic Pipe and Tubes	
Welded and Seamless Wrought Steel Pipe [Note (1)]	ASME B36.10M
Stainless Steel Pipe [Note (1)]	ASME B36.19M
Miscellaneous	
Threading, Gauging, and Thread Inspection of Casing, Tubing, and Line Pipe Threads	API 5B
Unified Inch Screw Threads (UN and UNR Thread Form)	ASME B1.1
Pipe Threads, General Purpose (Inch)	ASME B1.20.1
Metallic Gaskets for Pipe Flanges	ASME B16.20
Buttwelding Ends	ASME B16.25
Surface Texture (Surface Roughness, Waviness, and Lay)	ASME B46.1

GENERAL NOTE: The approved edition dates of these standards and specifications, along with the names and addresses of the sponsoring organizations, are shown in Appendix E.

NOTE: (1) The use of components made in accordance with these standards is permissible, provided they are

(a) examined and leak tested in accordance with the requirements of paras. K341 and K345, respectively.

(b) impact tested in accordance with the methods described in paras. K323.3.1 through K323.3.4, and meet the acceptance criteria specified in para. K323.3.5. Note that such impact testing may require the destruction of one component from the same lot as the component to be used in service [see Table K323.3.1, Note (1)].

(c) in accordance with the fluid service requirements in Parts 3 and 4 of this Chapter.

The design, materials, fabrication, assembly, examination, inspection, and testing requirements of this Chapter are not applicable to components manufactured in accordance with the documents listed in Table K326.1, unless specifically stated in this Chapter or in the listed document.

K326.4 Repair of Piping Components by Welding

A defect in a piping component may be repaired by welding subject to all of the following requirements:

(a) The piping component specification provides for weld repair or, if not covered by a specification, the manufacturer allows for weld repair.

(b) The welding procedure and welders or welding operators are qualified as required by para. K328.2.

(c) The repair and its examination are performed in accordance with the piping component specification or, if not covered by a specification, the manufacturer's requirements.

(d) The owner approves the weld repair.

PART 9
FABRICATION, ASSEMBLY, AND ERECTION

K327 GENERAL

Piping materials and components are prepared for assembly and erection by one or more of the fabrication processes covered in paras. K328, K330, K331, K332, and K333. When any of these processes is used in assembly or erection, requirements are the same as for fabrication.

(20) K328 WELDING

Welding shall conform to the requirements of this Part and the applicable requirements of para. K311.

(20) K328.1 Welding Responsibility

Each employer is responsible for

(a) the welding performed by personnel of its organization

(b) conducting the qualification tests required to qualify the welding procedure specifications used by personnel in its organization

(c) conducting the qualification tests required to qualify its welders and welding operators

K328.2 Welding Qualifications

(20) **K328.2.1 Qualification Requirements.** Qualification of the welding procedures to be used and of the performance of welders and welding operators shall comply with the requirements of ASME BPVC, Section IX, except as modified herein.

(a) Impact tests shall be performed for all procedure qualifications in accordance with para. K323.3.

(b) Except as provided in (f), test weldments shall be made using the same specification and type or grade of base metal(s), and the same specification and classification of filler metal(s) as will be used in production welding.

(c) Test weldments shall be subjected to essentially the same heat treatment, including cooling rate and cumulative time at temperature, as the production welds.

(d) When tensile specimens are required by ASME BPVC, Section IX, the yield strength shall also be determined, using the method required for the base metal. The yield strength of each test specimen shall be not less than the specified minimum yield strength at room temperature (S_Y) for the base metals joined. Where two base metals having different S_Y values are joined by welding, the yield strength of each test specimen shall be not less than the lower of the two S_Y values.

(e) Mechanical testing is required for all performance qualification tests.

(f) If the same specification and classification of filler metal(s) as will be used in production welding are employed, qualification on pipe or tubing shall also qualify for plate of the same type or grade, but qualification on plate does not qualify for pipe or tubing.

(g) For thickness greater than 51 mm (2 in.), the procedure test coupon shall be at least 75% as thick as the thickest joint to be welded in production.

K328.2.2 Procedure Qualification by Others. Qualification of welding procedures by others is not permitted.

K328.2.3 Performance Qualification by Others. Welding performance qualification by others is not permitted.

K328.2.4 Qualification Records. Paragraph 328.2.4 applies.

K328.3 Materials

K328.3.1 Electrodes and Filler Metal. Paragraph 328.3.1 applies, together with the following additional requirements: (20)

(a) Welding electrodes and filler metals shall be specified in the engineering design.

(b) With the owner's approval, a welding electrode or filler metal not conforming to a specification listed in ASME BPVC, Section II, Part C may be used if a procedure qualification test, including an all-weld-metal test in accordance with AWS B4.0M or AWS B4.0[8], is first successfully made.

K328.3.2 Weld Backing Material. Backing rings shall not be used.

K328.3.3 Consumable Inserts. Paragraph 328.3.3 applies, except that procedures shall be qualified as required by para. K328.2.

K328.4 Preparation for Welding

K328.4.1 Cleaning. Paragraph 328.4.1 applies.

K328.4.2 End Preparation

(a) General

(1) Butt weld end preparation is acceptable only if the surface is machined or ground to bright metal.

(2) Butt welding end preparation contained in ASME B16.25 or any other end preparation that meets the procedure qualification is acceptable. [For convenience, the basic bevel angles taken from ASME B16.25, with some additional J-bevel angles, are shown in Figure 328.4.2, illustrations (a) and (b).]

(b) Circumferential Welds

(1) If components' ends are trimmed as shown in Figure 328.4.2, illustration (a) or (b) to accommodate consumable inserts, or as shown in Figure K328.4.3 to correct internal misalignment, such trimming shall not result in a finished wall thickness before welding less than the required minimum wall thickness, t_m.

(2) It is permissible to size pipe ends of the same nominal size to improve alignment, if wall thickness requirements are maintained.

(3) Where necessary, weld metal may be deposited on the inside or outside of the component to permit alignment or provide for machining to ensure satisfactory seating of inserts.

(4) When a butt weld joins sections of unequal wall thickness and the thicker wall is more than $1\frac{1}{2}$ times the thickness of the other, end preparation and geometry shall

[8] Titles of referenced AWS standards are as follows: AWS B4.0M, Standard Methods for Mechanical Testing of Welds, and AWS B4.0, Standard Methods for Mechanical Testing of Welds.

be in accordance with acceptable designs for unequal wall thickness in ASME B16.5.

K328.4.3 Alignment

(a) Girth Butt Welds

(1) Inside diameters of components at the ends to be joined shall be aligned within the dimensional limits in the welding procedure and the engineering design, except that no more than 1.5 mm ($^1/_{16}$ in.) misalignment is permitted as shown in Figure K328.4.3.

(2) If the external surfaces of the two components are not aligned, the weld shall be tapered between the two surfaces with a slope not steeper than 1:4.

(b) Longitudinal Butt Joints. Preparation for longitudinal butt welds (not made in accordance with a standard listed in Table K-1 or Table K326.1) shall conform to the requirements of (a).

(c) Branch Connection Welds

(1) The dimension m in Figure K328.5.4 shall not exceed ±1.5 mm ($^1/_{16}$ in.).

(2) The dimension g in Figure K328.5.4 shall be specified in the engineering design and the welding procedure.

K328.5 Welding Requirements

K328.5.1 General. The requirements of paras. 328.5.1(b), 328.5.1(d), 328.5.1(e), and 328.5.1(f) apply in addition to the requirements specified below.

(a) All welds, including tack welds, repair welds, and the addition of weld metal for alignment [paras. K328.4.2(b)(3) and K328.4.3(c)(1)], shall be made by qualified welders or welding operators, in accordance with a qualified procedure.

(b) Tack welds at the root of the joint shall be made with filler metal equivalent to that used for the root pass. Tack welds shall be fused with the root pass weld, except that those that have cracked shall be removed. Bridge tacks (above the root) shall be removed.

K328.5.2 Fillet Welds. Fillet welds, where permitted (see para. K311.2.2), shall be fused with and shall merge smoothly into the component surfaces.

K328.5.3 Seal Welds. Seal welds are not permitted.

K328.5.4 Welded Branch Connections. Branch connection fittings (see para. 300.2), attached by smoothly contoured full penetration groove welds of a design that permits 100% interpretable radiographic examination, are the only types acceptable.

Figure K328.5.4 shows acceptable details of welded branch connections. The illustrations are typical and are not intended to exclude acceptable types of construction not shown.

K328.5.5 Fabricated Laps. Fabricated laps are not permitted.

K328.6 Weld Repair

Paragraph 328.6 applies, except that procedures and performance shall be qualified as required by para. K328.2.1. See also para. K341.3.3.

K330 PREHEATING

K330.1 General (20)

The preheat requirements herein apply to all types of welding, including tack welds and repair welds.

K330.1.1 Requirements. Paragraph 330.1.1 applies.

K330.1.2 Unlisted Materials. Paragraph 330.1.2 applies.

K330.1.3 Temperature Verification. Paragraph 330.1.3(a) applies. Temperature-indicating materials and techniques shall not be detrimental to the base metals.

K330.1.4 Preheat Zone. Paragraph 330.1.4 applies.

K330.2 Specific Requirements

Paragraph 330.2 applies in its entirety.

K331 HEAT TREATMENT (20)

K331.1 General

K331.1.1 Postweld Heat Treatment Requirements. The provisions of para. 331.1.1 and Tables 331.1.1, 331.1.2, and 331.1.3 apply, except as specified below.

(a) The exemptions to mandatory postweld heat treatment in Table 331.1.3 for P-No. 1, all Group Nos., are not permitted when the control thickness exceeds 19 mm ($^3/_4$ in.).

(b) The exemptions to mandatory postweld heat treatment in Table 331.1.3 for P-No. 4, Group No. 1 and P-No. 5A, Group No. 1 materials are not permitted

(c) For quenched and tempered materials, any heat treatment of other than longitudinal welds shall be performed at a temperature no warmer than 28°C

Figure K328.4.3 Pipe Bored for Alignment: Trimming and Permitted Misalignment

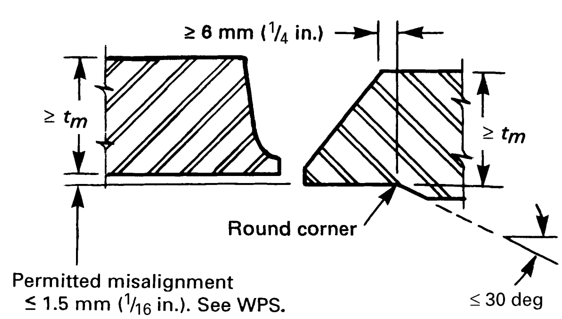
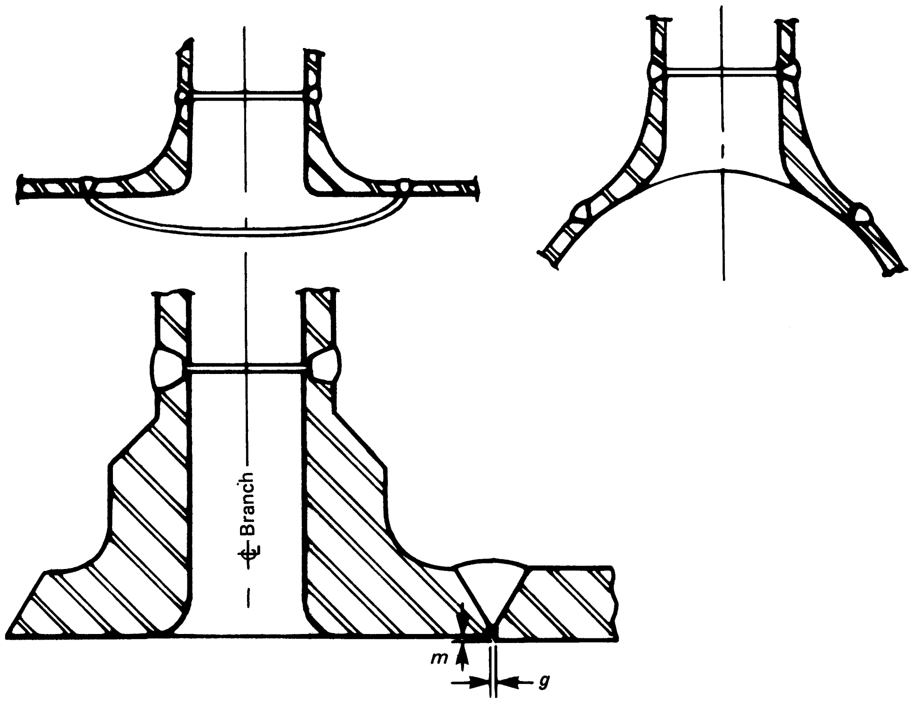


Figure K328.5.4 Some Acceptable Welded Branch Connections Suitable for 100% Radiography



(50°F) below the tempering temperature of the material. When this heat treatment temperature is lower than the range specified in Table 331.1.1, the decrease in heat treatment temperature shall be accompanied by an increase in holding time in accordance with Table 331.1.2.

(d) Longitudinal welds in quenched and tempered material shall be heat treated in accordance with the applicable material specification.

(e) Refer to para. K331.1.3 instead of para. 331.1.3.

(f) Refer to Appendix K instead of Appendix A.

(g) ASME B31P and para. 328.7 do not apply.

K331.1.2 Other Heat Treatments. Heat treatment for bending and forming shall be in accordance with para. K332.4.

K331.1.3 Definition of Thicknesses Governing Postweld Heat Treatment. The provisions of para. 331.1.3 apply, except for 331.1.3(b)(5).

K331.1.4 Heating and Cooling. Paragraph 331.1.4 applies.

K331.1.6 Temperature Verification. Heat treatment temperature shall be checked by thermocouple pyrometers or other suitable methods to ensure that the WPS requirements are met. Temperature-indicating materials and techniques shall not be detrimental to the base metals.

K331.2 Specific Requirements

Paragraph 331.2 applies, but refer to para. K331.1 instead of para 331.1.

K332 BENDING AND FORMING

K332.1 General

Pipe shall be hot or cold bent in accordance with a written procedure to any radius that will result in surfaces free of cracks and free of buckles. The procedure shall address at least the following, as applicable:

(a) material specification and range of size and thickness

(b) range of bend radii and fiber elongation

(c) minimum and maximum metal temperature during bending

(d) method of heating and maximum hold time

(e) description of bending apparatus and procedure to be used

(f) mandrels or material and procedure used to fill the bore

(g) method for protection of thread and machined surfaces

(h) examination to be performed

(i) required heat treatment

(j) postheat treatment dimensional adjustment technique

K332.2 Bending

K332.2.1 Bend Flattening. The difference between the maximum and the minimum diameters at any cross section of a bend shall not exceed 8% of nominal outside diameter for internal pressure and 3% for external pressure.

K332.2.2 Bending Temperature. Paragraph 332.2.2 applies, except that in cold bending of quenched and tempered ferritic materials, the temperature shall be at least 28°C (50°F) below the tempering temperature.

K332.3 Forming

Piping components shall be formed in accordance with a written procedure. The temperature range shall be consistent with material characteristics, end use, and specified heat treatment. The thickness after forming shall be not less than required by design. The procedure shall address at least the following, as applicable:

(a) material specification and range of size and thickness

(b) maximum fiber elongation expected during forming

(c) minimum and maximum metal temperature during bending

(d) method of heating and maximum hold time

(e) description of forming apparatus and procedure to be used

(f) materials and procedures used to provide internal support during forming

(g) examination to be performed

(h) required heat treatment

K332.4 Required Heat Treatment

(20) **K332.4.1 Hot Bending and Forming.** After hot bending and forming, heat treatment is required for all thicknesses of P-Nos. 3, 4, 5A, 5B, 6, 10A, 10B, and 15E materials that are not quenched and tempered. Times and temperatures shall be in accordance with para. 331. Quenched and tempered materials shall be reheat treated to the original material specification.

(20) **K332.4.2 Cold Bending and Forming**

(a) After cold bending and forming, heat treatment in accordance with (b) below is required, regardless of thickness, when specified in the engineering design or when the maximum calculated fiber elongation exceeds 5% strain or 50% of the basic minimum specified longitudinal elongation for the applicable specification, grade, and thickness for P-Nos. 1, 3, 4, 5A, 5B, 6, 10A, 10B, and 15E materials (unless it has been demonstrated that the selection of the pipe and the procedure for making the components provide assurance that the most severely formed portion of the material has retained an elongation of not less than 10%).

(b) Heat treatment is required regardless of thickness and shall conform to the temperatures and durations given in Table 331.1.1, except that for quenched and tempered materials, the stress relieving temperature shall not exceed a temperature 28°C (50°F) below the tempering temperature of the material.

K333 BRAZING AND SOLDERING (20)

Brazing shall conform to the requirements of this Part and the applicable requirements of para. K317.2. Braze welding and soldering are not permitted.

K333.1 Brazing Responsibility

Each employer is responsible for

(a) the brazing performed by personnel of its organization

(b) conducting the qualification tests required to qualify the brazing procedure specifications used by personnel in its organization

(c) conducting the qualification tests required to qualify its brazers and brazing operators

K333.2 Brazing Qualifications

K333.2.1 Qualification Requirements. The qualification of brazing procedures, brazers, and brazing operators shall be in accordance with the requirements of ASME BPVC, Section IX.

K333.2.2 Procedure Qualification by Others. Brazing procedure specifications qualified by a technically competent group or agency may be used, provided the following requirements are met:

(a) The owner shall approve the use of brazing procedure specifications qualified by others.

(b) The brazing procedure specifications shall meet the requirements of para. K333.2.1.

(c) The employer's business name shall be shown on each brazing procedure specification and on each brazing procedure qualification record.

(d) The employer shall accept responsibility for each brazing procedure qualification performed by others by signing and dating each brazing procedure qualification record.

(e) The employer shall conduct the qualification tests required to qualify its brazers and brazing operators.

K333.2.3 Performance Qualification by Others. An employer may accept the performance qualification of a brazer or brazing operator made by a technically competent group or agency, provided the following requirements are met:

(a) The owner shall approve the use of brazing performance qualifications qualified by others.

(b) The brazer or brazing operator performance qualifications were made on pipe test coupons.

(c) The employer shall have a brazing procedure specification such that the performance qualification is within the limits of the essential variables set forth in ASME BPVC, Section IX.

(d) The employer shall have a copy of the performance qualification test record. The record shall show the name of the technically competent group or agency by whom the brazer or brazing operator was qualified and the date of that qualification. Evidence shall also be provided that the brazer or brazing operator has maintained qualification in accordance with ASME BPVC, Section IX, QB-322.

(e) The employer's business name shall be shown on the brazing performance qualification record.

(f) The employer shall accept responsibility for the brazing performance qualifications performed by others by signing and dating the qualification.

K333.2.4 Qualification Records. The employer shall maintain copies of the brazing procedure specification and performance qualification records specified by ASME BPVC, Section IX. These records shall be made available to the Inspector upon request.

K333.3 Materials

Brazing filler metals and flux shall be in accordance with para. 333.2.1.

K333.4 Preparation and Cleaning

Paragraph 333.3 applies, except that soldering is not permitted.

K335 ASSEMBLY AND ERECTION

K335.1 General

Paragraph 335.1 applies.

K335.2 Flanged Joints

Paragraph 335.2 applies, except that bolts shall extend completely through their nuts.

K335.3 Threaded Joints

Paragraph 335.3 applies, except that threaded joints shall not be seal welded.

K335.4 Special Joints

Special joints (as defined in para. K318) shall be installed and assembled in accordance with the manufacturer's instructions, as modified by the engineering design. Care shall be taken to ensure full engagement of joint members.

K335.5 Cleaning of Piping

See Appendix F, para. F335.9.

PART 10
INSPECTION, EXAMINATION, AND TESTING

K340 INSPECTION

Paragraphs 340.1 through 340.4 apply.

K341 EXAMINATION

Paragraphs 341.1 and 341.2 apply.

K341.3 Examination Requirements

K341.3.1 General. Prior to initial operation, each piping installation, including components and workmanship, shall be examined in accordance with para. K341.4 and the engineering design. If heat treatment is performed, examination shall be conducted after its completion.

K341.3.2 Acceptance Criteria. Acceptance criteria shall be as stated in the engineering design and shall at least meet the applicable requirements stated in (a) and (b) below, and elsewhere in this Chapter.

(a) Table K341.3.2 states acceptance criteria (limits on imperfections) for welds. See Figure 341.3.2 for typical weld imperfections.

(b) Acceptance criteria for castings are specified in para. K302.3.3.

K341.3.3 Defective Components and Workmanship. (20)
Defects (imperfections of a type or magnitude not acceptable by the criteria specified in para. K341.3.2) shall be repaired, or the defective item or work shall be replaced.

Examination shall be as follows:

(a) When the defective item or work is repaired, the repaired portion of the item or work shall be examined after the completion of any required heat treatment. The examination shall use the same methods and acceptance criteria employed for the original examination.

(b) When the defective item or work is replaced, the new item or work used to replace the defective item or work shall be examined after the completion of any required heat treatment. The examination shall use any method and applicable acceptance criteria that meet the requirements for the original examination.

K341.4 Extent of Required Examination

Piping shall be examined to the extent specified herein or to any greater extent specified in the engineering design.

K341.4.1 Visual Examination (20)

(a) The requirements of para. 341.4.1(a) apply with the following exceptions in regard to extent of examination:

(1) *Materials and Components.* 100%.

(2) *Fabrication.* 100%.

(3) *Threaded, Bolted, and Other Joints.* 100%.

Table K341.3.2 Acceptance Criteria for Welds

Type of Imperfection	Criteria (A–F) for Types of Welds, and for Required Examination Methods [Note (1)]					
	Methods		Type of Weld			
	Visual	Ultrasonics or Radiography	Girth Groove	Longitudinal Groove [Note (2)]	Fillet [Note (3)]	Branch Connection [Note (4)]
Crack	✓	✓	A	A	A	A
Lack of fusion	✓	✓	A	A	A	A
Incomplete penetration	✓	✓	A	A	A	A
Internal porosity	...	✓	B	B	N/A	B
Linear indication	...	✓	C	C	N/A	C
Undercutting	✓	✓	A	A	A	A
Surface porosity or exposed slag inclusion	✓	...	A	A	A	A
Concave root surface (suck-up)	✓	✓	D	D	N/A	D
Surface finish	✓	...	E	E	E	E
Reinforcement or internal protrusion	✓	...	F	F	F	F

GENERAL NOTES:
(a) Weld imperfections are evaluated by one or more of the types of examination methods given, as specified in paras. K341.4.1 and K341.4.2.
(b) "N/A" indicates this Chapter does not establish acceptance criteria or does not require evaluation of this kind of imperfection for this type of weld.
(c) Check (✓) indicates examination method generally used for evaluating this kind of weld imperfection.
(d) Ellipsis (...) indicates examination method not generally used for evaluating this kind of weld imperfection.
(e) Symbols A through F are explained in the table on the next page.

NOTES:
(1) Criteria given are for required examination. More-stringent criteria may be specified in the engineering design.
(2) Longitudinal welds include only those permitted in paras. K302.3.4 and K305. The criteria shall be met by all welds, including those made in accordance with a standard listed in Table K326.1 or in Appendix K.
(3) Fillet welds include only those permitted in para. K311.2.2.
(4) Branch connection welds include only those permitted in para. K328.5.4.

Criterion Value Notes for Table K341.3.2

Criterion		Acceptable Value Limits [Note (1)]	
Symbol	Measure		
A	Extent of imperfection	Zero (no evident imperfection)	
B	Size and distribution of internal porosity	See ASME BPVC, Section VIII, Division 1, Appendix 4	
C	Internal slag inclusion, tungsten inclusion, or linear indication. Indications are unacceptable if the amplitude exceeds the reference level, or indications have lengths that exceed		
	Individual length [Note (2)]	6 mm ($\frac{1}{4}$ in.) for $\overline{T}_w \leq 19$ mm ($\frac{3}{4}$ in.)	
		$\overline{T}_w/3$ for 19 mm ($\frac{3}{4}$ in.) $< \overline{T}_w \leq 57$ mm ($2\frac{1}{4}$ in.)	
		19 mm ($\frac{3}{4}$ in.) for $\overline{T}_w > 57$ mm ($2\frac{1}{4}$ in.)	
	Cumulative length	$\leq \overline{T}_w$ in any $12\,\overline{T}_w$ weld length	
D	Depth of root surface concavity	Wall Thickness, $\overline{T}_w$, mm (in.)	Depth of Surface Concavity, mm (in.)
		≤13 ($\frac{1}{2}$)	≤1.5 ($\frac{1}{16}$)
		>13 ($\frac{1}{2}$) and ≤51 (2)	≤3 ($\frac{1}{8}$)
		>51 (2)	≤4 ($\frac{5}{32}$)
		and total joint thickness including weld reinforcement $\geq \overline{T}_w$	
E	Surface roughness	≤12.5 μm (500 μin.) R_a (see ASME B46.1 for definition of roughness average, R_a)	
F	Height of reinforcement or internal protrusion [Note (3)] in any plane through the weld shall be within the limits of the applicable height value in the tabulation at the right. Weld metal shall be fused with and merge smoothly into the component surfaces.	Wall Thickness, $\overline{T}_w$, mm (in.)	External Weld Reinforcement or Internal Weld Protrusion, mm (in.)
		≤13 ($\frac{1}{2}$)	≤1.5 ($\frac{1}{16}$)
		>13 ($\frac{1}{2}$) and ≤51 (2)	≤3 ($\frac{1}{8}$)
		>51 (2)	≤4 ($\frac{5}{32}$)

NOTES:

(1) Where two limiting values are given, the lesser measured value governs acceptance. $\overline{T}_w$ is the nominal wall thickness of the thinner of two components joined by a butt weld.

(2) For ultrasonic examination, refer to para. K344.6.3 for acceptable value limits.

(3) For groove welds, height is the lesser of the measurements made from the surfaces of the adjacent components. For fillet welds, height is measured from the theoretical throat; internal protrusion does not apply. Required thickness t_m shall not include reinforcement or internal protrusion.

(4) Piping Erection. All piping erection shall be examined to verify dimensions and alignment. Supports, guides, and points of cold spring shall be checked to ensure that movement of the piping under all conditions of startup, operation, and shutdown will be accommodated without undue binding or unanticipated constraint.

(b) Pressure-Containing Threads. 100% examination for finish and fit is required. Items with visible imperfections in thread finish or any of the following defects shall be rejected:

(1) Tapered Threads. Failure to meet gaging requirements in API Spec 5B or ASME B1.20.1, as applicable.

(2) Straight Threads. Excessively loose or tight fit when gaged for light interference fit.

(c) Brazed Joints. 100% of all brazed joints shall be examined by in-process examination in accordance with para. K344.7.

K341.4.2 Radiographic and Ultrasonic Examination

(a) All girth, longitudinal, and branch connection welds shall be 100% radiographically examined, except as permitted in (b) below.

(b) When specified in the engineering design and with the owner's approval, ultrasonic examination of welds may be substituted for radiographic examination where $\overline{T}_w \geq 13\text{ mm}$ ($\frac{1}{2}$ in.).

(c) In-process examination (see para. 344.7) shall not be substituted for radiographic or ultrasonic examination of welds.

K341.4.3 Certifications and Records. Paragraph 341.4.1(c) applies.

K341.5 Supplementary Examination

Any of the examination methods described in para. K344 may be specified by the engineering design to supplement the examination required by para. K341.4. The extent of supplementary examination to be performed and any acceptance criteria that differ from those specified in para. K341.3.2 shall be specified in the engineering design.

K341.5.1 Hardness Tests. Paragraph 341.5.2 applies.

K341.5.2 Examinations to Resolve Uncertainty. Paragraph 341.5.3 applies.

K342 EXAMINATION PERSONNEL

Paragraph 342 applies in its entirety.

K343 EXAMINATION PROCEDURES

Paragraph 343 applies, except that the examination methods shall comply with para. K344.

K344 TYPES OF EXAMINATION

K344.1 General

Paragraphs 344.1.1 and 344.1.2 apply. In para. 344.1.3, terms other than "100% examination" apply only to supplementary examinations.

K344.2 Visual Examination

Paragraph 344.2 applies in its entirety.

K344.3 Magnetic Particle Examination

The method for magnetic particle examination shall be as specified in

(a) paragraph K302.3.3(b) for castings

(b) ASME BPVC, Section V, Article 7 for welds and other components

K344.4 Liquid Penetrant Examination

The method for liquid penetrant examination shall be as specified in

(a) paragraph K302.3.3(b) for castings

(b) ASME BPVC, Section V, Article 6 for welds and other components

K344.5 Radiographic Examination

The method for radiographic examination shall be as specified in

(a) paragraph K302.3.3(c) for castings

(b) ASME BPVC, Section V, Article 2 for welds and other components

K344.6 Ultrasonic Examination

K344.6.1 Castings. The method for ultrasonic examination of castings shall be as specified in para. K302.3.3(c).

K344.6.2 Pipe and Tubing

(a) Method. Pipe and tubing, required or selected in accordance with Table K305.1.2 to undergo ultrasonic examination, shall pass a 100% examination for longitudinal defects in accordance with ASTM E213, Ultrasonic Testing of Metal Pipe and Tubing. Longitudinal (axial) reference notches shall be introduced on the outer and inner surfaces of the calibration (reference) standard in accordance with Figure 3(c) of ASTM E213 to a depth not greater than the larger of 0.1 mm (0.004 in.) or 4% of specimen thickness and a length not more than 10 times the notch depth.

(b) Acceptance Criteria. Any indication greater than that produced by the calibration notch represents a defect; defective pipe and tubing shall be rejected.

(c) Records. For pipe and tubing that passes this examination, a report shall be prepared that contains at least the information specified in 15.2.1 through 15.2.6 of ASTM E213.

K344.6.3 Welds

(a) Method. The method for ultrasonic examination of welds shall be as specified in ASME BPVC, Section V, Article 4 for nominal thickness, $\overline{T}_w$, greater than or equal to 13 mm (½ in.) but less than 25 mm (1 in.), and ASME BPVC, Section VIII, Division 3, KE-301 and KE-302 for nominal wall thickness, $\overline{T}_w$, greater than or equal to 25 mm (1 in.).

(b) Acceptance Criteria. Cracks, lack of fusion, incomplete penetration, or undercutting are unacceptable regardless of size or length (see Table K341.3.2). In addition, for an internal slag inclusion, tungsten inclusion, or linear indication

(1) for nominal wall thickness, $\overline{T}_w$, greater than or equal to 13 mm (½ in.) but less than 25 mm (1 in.), the acceptance criterion for the thickness to be examined specified in para. 344.6.2 applies.

(2) for nominal wall thickness, $\overline{T}_w$, greater than or equal to 25 mm (1 in.), the acceptance criteria specified in ASME BPVC, Section VIII, Division 3, KE-333 for the thickness to be examined apply.

K344.7 In-Process Examination

Paragraph 344.7 applies in its entirety.

K344.8 Eddy Current Examination

K344.8.1 Method. The method for eddy current examination of pipe and tubing shall follow the general guidelines of ASME BPVC, Section V, Article 8, subject to the following specific requirements:

(a) Cold drawn austenitic stainless steel pipe and tubing, selected in accordance with Table K305.1.2 for eddy current examination, shall pass a 100% examination for longitudinal defects.

(b) A calibration (reference) standard shall be prepared from a representative sample. A longitudinal (axial) reference notch shall be introduced on the inner surface of the standard to a depth not greater than the larger of 0.1 mm (0.004 in.) or 5% of specimen thickness and a length not more than 6.4 mm (0.25 in.).

K344.8.2 Acceptance Criteria. Any indication greater than that produced by the calibration notch represents a defect; defective pipe or tubing shall be rejected.

K344.8.3 Records. For pipe and tubing that passes this examination, a report shall be prepared that includes at least the following information:

(a) material identification by type, size, lot, heat, etc.

(b) listing of examination equipment and accessories

(c) details of examination technique (including examination speed and frequency) and end effects, if any

(d) description of the calibration standard, including dimensions of the notch, as measured

(e) examination results

K345 LEAK TESTING

K345.1 Required Leak Test (20)

Prior to initial operation, each piping system shall be leak tested.

(a) Each weld and each piping component, except bolting and individual gaskets to be used during final system assembly and pressure relief devices to be used during operation, shall be hydrostatically or pneumatically leak tested in accordance with para. K345.4 or K345.5, respectively. The organization conducting the test shall ensure that during the required leak testing of components and welds, adequate protection is provided to prevent injury to people and damage to property from missile fragments, shock waves, or other consequences of any failure that might occur in the pressurized system.

(b) In addition to the requirements of (a) above, a leak test of the installed piping system, excluding pressure relief devices to be used during operation, shall be conducted at a pressure not less than 110% of the design pressure to ensure tightness, except as provided in (c) or (d) below.

(c) If the leak test required in (a) above is conducted on the installed piping system, the additional test in (b) above is not required.

(d) With the owner's approval, pressure relief devices to be used during operation may be included in the leak test required in (b) above. The leak test pressure may be reduced to prevent the operation of, or damage to, the pressure relief devices, but shall not be less than 90% of the lowest set pressure of the pressure relief devices in the system.

(e) For closure welds, examination in accordance with para. K345.2.3(c) may be substituted for the leak test required in (a) above.

(f) None of the following leak tests may be used in lieu of the leak tests required in para. K345.1:

(1) initial service leak test (para. 345.7)

(2) sensitive leak test (para. 345.8)

(3) alternative leak test (para. 345.9)

K345.2 General Requirements for Leak Tests

Paragraphs 345.2.4 through 345.2.7 apply. See below for paras. K345.2.1, K345.2.2, and K345.2.3.

K345.2.1 Limitations on Pressure (20)

(a) Through-Thickness Yielding. If the test pressure would produce stress (exclusive of stress intensification) in excess of S_{yt} at the outside surface of a component at test temperature, as determined by calculation or by testing in accordance with para. K304.7.2(b), the test pressure may be reduced to the maximum pressure that will result in a stress (exclusive of stress intensification) at the outside surface that will not exceed S_{yt}.

(b) The provisions of paras. 345.2.1(b) and 345.2.1(c) apply.

K345.2.2 Other Test Requirements. Paragraph 345.2.2 applies. In addition, the minimum metal temperature during testing shall be not less than the impact test temperature (see para. K323.3.4).

K345.2.3 Special Provisions for Leak Testing. Paragraphs (a), (b), and (c) below apply only to the leak test specified in para. K345.1(a). They are not applicable to the installed piping system leak test specified in para. K345.1(b).

(a) Piping Components and Subassemblies. Piping components and subassemblies may be leak tested either separately or as assembled piping.

(b) Flanged Joints. Flanged joints used to connect piping components that have previously been leak tested, and flanged joints at which a blank or blind flange is used to isolate equipment or other piping during the leak test, need not be leak tested.

(c) Closure Welds. Leak testing of the final weld connecting piping systems or components that have been successfully leak tested is not required, provided the weld is examined in-process in accordance with para. 344.7 and passes the required 100% radiographic examination in accordance with para. K341.4.2.

K345.3 Preparation for Leak Test

Paragraph 345.3 applies in its entirety.

K345.4 Hydrostatic Leak Test

Paragraph 345.4.1 applies. See paras. K345.4.2 and K345.4.3 below.

K345.4.2 Test Pressure for Components and Welds. Except as provided in para. K345.4.3, the hydrostatic test pressure at every point in a metallic piping system shall be as follows:

(a) not less than 1.25 times the design pressure.

(b) when the design temperature is greater than the test temperature, the minimum test pressure, at the point under consideration, shall be calculated by eq. (38)

$$P_T = 1.25PS_T/S \tag{38}$$

where

P = internal design gage pressure

P_T = minimum test gage pressure

S = allowable stress at component design temperature for the prevalent pipe material; see Appendix K, Table K-1

S_T = allowable stress at test temperature for the prevalent pipe material; see Table K-1

(c) in those cases where the piping system may not include pipe itself, any other component in the piping system, other than pipe-supporting elements and bolting, may be used to determine the S_T/S ratio based on the applicable allowable stresses obtained from Table K-1. In those cases where the piping system may be made up of equivalent lengths of more than one material, the S_T/S ratio shall be based on the minimum calculated ratio of the included materials.

K345.4.3 Hydrostatic Test of Piping With Vessels as a System. Paragraph 345.4.3(a) applies.

K345.5 Pneumatic Leak Test

Paragraph 345.5 applies, except for para. 345.5.4. See para. K345.5.4 below.

K345.5.4 Test Pressure. The pneumatic test pressure for components and welds shall be identical to that required for the hydrostatic test in accordance with para. K345.4.2.

K345.6 Hydrostatic–Pneumatic Leak Test for Components and Welds

If a combination hydrostatic–pneumatic leak test is used, the requirements of para. K345.5 shall be met, and the pressure in the liquid-filled part of the piping shall not exceed the limits stated in para. K345.4.2.

K346 RECORDS

K346.1 Responsibility (20)

It is the responsibility of the designer, the manufacturer, the fabricator, and the erector, as applicable, to prepare the records required by this Chapter and by the engineering design.

K346.2 Required Records (20)

At least the following records, as applicable, shall be provided to the owner or the Inspector by the person responsible for their preparation:

(a) the engineering design

(b) the written report required in para. K300(b)(2)

(c) material certifications

(d) procedures used for fabrication, welding, brazing, heat treatment, examination, and testing

(e) repair records of materials and piping components, including the welding procedure used for each, and location of repairs

(f) performance qualifications for welders, brazers, and welding and brazing operators

(g) qualifications of examination personnel

(h) records of examination of pipe and tubing for longitudinal defects as specified in paras. K344.6.2(c) and K344.8.3, as applicable

K346.3 Retention of Records

The owner shall retain one set of the required records for at least 5 yr after they are received.

Chapter X
High Purity Piping

U300 GENERAL STATEMENTS

(a) Chapter X pertains to piping designated by the owner as being in High Purity Fluid Service. See also Appendix M.

(b) The organization, content, and paragraph designations of this Chapter correspond to those of the base Code (Chapters I through VI), Chapter VII, and Chapter VIII. The prefix U is used to designate Chapter X requirements.

(c) Provisions and requirements of the base Code, Chapter VII, and Chapter VIII apply only as stated in this Chapter.

(d) For piping not in High Purity Fluid Service, Code requirements are found in Chapters I through IX.

(e) *High Purity Piping.* Chapter X provides alternative rules for design and construction of piping designated by the owner as being High Purity Fluid Service.

(1) These rules apply only when specified by the owner, and only as a whole, not in part.

(2) Chapter X rules do not provide for High Pressure Fluid Service.

(3) Chapter VII applies to nonmetallic piping and piping lined with nonmetals in High Purity Fluid Service.

(f) Chapter I applies.

PART 1
CONDITIONS AND CRITERIA

Chapter II, Part 1 applies. See para. U301.3.2(b)(5).

U301 DESIGN CONDITIONS

U301.3 Design Temperature

U301.3.2 Uninsulated Components

(b)

(5) compression, face seal, and hygienic clamped fittings and joints — 100% of the fluid temperature

PART 2
PRESSURE DESIGN OF PIPING COMPONENTS

Chapter II, Part 2 applies. See Figure U304.5.3 for representative configuration for metal face seal blanks.

PART 3
FLUID SERVICE REQUIREMENTS FOR PIPING COMPONENTS

Chapter II, Part 3 applies. See paras. U306.6, U307.3, and U308.

U306 FITTINGS, BENDS, MITERS, LAPS, AND BRANCH CONNECTIONS

U306.6 Tube Fittings

(a) Tube fittings not listed in Table 326.1 or Appendix A shall meet the pressure design requirements described in para. 302.2.3 and the mechanical strength requirements described in para. 303.

(b) Compression-type tube fittings may be used in accordance with para. U315.2 provided that the type of fitting selected complies with the following:

(1) The gripping action of the fitting shall provide vibration resistance as demonstrated by exhibiting a stress intensity factor equal to or less than 1.5.

(2) Intermixing of components from different manufacturers is permitted only when specified in the engineering design.

(c) Face seal or hygienic clamp-type fittings in which the tightness of the joint is provided by a seating surface other than the threads (e.g., a metal face-seal fitting comprising internal and external threaded components, glands, and gasket or other constructions shown typically in Figure U335.7.1) may be used.

U307 VALVES AND SPECIALTY COMPONENTS

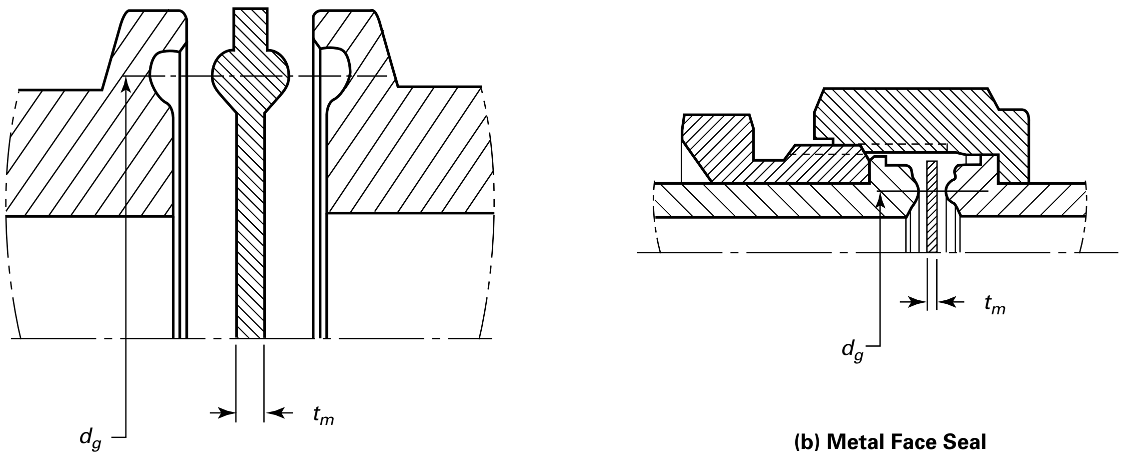
U307.3 High Purity Fluid Service Valves

Valves such as ball, bellows, and diaphragm valves designed for High Purity Fluid Service that are not listed in Table 326.1 shall meet the pressure design requirements described in para. 302.2.2 and the mechanical strength requirements described in para. 303.

U308 FLANGES, BLANKS, FLANGE FACINGS, AND GASKETS

Flanges should be avoided whenever possible. When flanges are utilized, para. 308 applies, except expanded joint flanges described in para. 308.2.2 are not permitted.

Figure U304.5.3 Blanks



(a) Hygienic Clamp-Type Fitting

(b) Metal Face Seal

PART 4
FLUID SERVICE REQUIREMENTS FOR PIPING JOINTS

Chapter II, Part 4 applies, except expanded joints, flared tube fittings, and caulked joints, described in paras. 313, 315, and 316, respectively, are not permitted. See paras. U311, U311.1(c), U314, and U315.

U311 WELDED JOINTS

Paragraph 311 applies, except for para. 311.1(c). See para. U311.1(c).

U311.1 General

(c) Examination shall be in accordance with para. U341.4.1.

U314 THREADED JOINTS

Threaded joints should be avoided whenever possible. When threaded joints are utilized, para. 314 applies.

U315 TUBING JOINTS

Paragraph 315 applies. See paras. U315.1, U315.2(c), and U315.3.

U315.1 General

In selecting and applying compression, face seal, and hygienic clamp-type tube fittings, the designer shall consider the possible adverse effects on the joints of such factors as assembly and disassembly, cyclic loading, vibration, shock, and thermal expansion and contraction. See para. FU315.

U315.2 Joints Conforming to Listed Standards

(c) Joints using compression, face seal, hygienic clamp, and automatic welding tube fittings covered by listed standards may be used.

U315.3 Joints Not Conforming to Listed Standards

(a) Compression-type tube fitting joints shall be fully gageable on initial installation to ensure sufficient tightening.

(b) Safeguarding is required for face seal or hygienic clamp-type joints used under severe cyclic conditions.

PART 5
FLEXIBILITY AND SUPPORT

Chapter II, Part 5 applies. See para. U319.3.6.

U319 PIPING FLEXIBILITY

U319.3 Properties for Flexibility Analysis

U319.3.6 Flexibility and Stress Intensification Factors. Paragraph 319.3.6 applies; however, piping components used in high-purity applications, e.g., multiport block valves, hygienic unions, crosses, and point-of-use and adaptor fittings, often do not have geometries similar to those in ASME B31J.

PART 6
SYSTEMS

Chapter II, Part 6 applies.

PART 7
METALLIC MATERIALS

The provisions and requirements in Chapter III for materials apply. Materials commonly used in high purity process piping systems include austenitic, ferritic, and duplex stainless steels, and nickel and nickel alloys.

PART 8
STANDARDS FOR PIPING COMPONENTS

Chapter IV applies.

PART 9
FABRICATION, ASSEMBLY, AND ERECTION

U327 GENERAL

Metallic piping materials and components are prepared for assembly and erection by one or more of the fabrication processes covered in paras. U328, U330, U331, and U332. When any of these processes is used in assembly or erection, requirements are the same as for fabrication.

(20) U328 WELDING

Paragraph 328 applies, except for paras. 328.3.2, 328.5.4, and 328.5.5. See paras. U328.2(a), U328.2(b), U328.2(c), U328.4, U328.4.2, U328.4.4, and U328.5.1(g) for additional requirements.

(20) U328.2 Welding and Brazing Qualification

The welding process shall be orbital GTAW, except for the following:

(a) Tack welds made prior to orbital welding may be manual GTAW.

(b) Manual GTAW may be used, with the owner's approval, on those welds where the orbital welding equipment cannot be used.

(c) A change in the type or nominal composition of the backing (purge) gas shall require requalification.

U328.4 Preparation for Welding

Paragraph 328.4.1 applies. Additionally, when weld coupon examination is specified in the engineering design or in the referencing code or standard (e.g., ASME BPE or SEMI), primary weld coupons shall be made in accordance with para. U328.4.4(b)(1) and examined in accordance with para. U344.8 prior to the start of production welding. This will demonstrate that the orbital welding equipment is set up properly and the weld program is sufficient to make repeatable production welds in accordance with the qualified welding procedure specification (WPS).

U328.4.2 End Preparations (20)

(a) Paragraph 328.4.2(a)(1) applies, with the exception that discoloration requirements shall be based on the referencing code or standard (e.g., ASME BPE or SEMI).

(b) End preparations for GTAW are as follows:

(1) Components having nominal wall thickness of 3 mm ($^1/_8$ in.) and less shall have ends prepared in accordance with the referencing code or standard (e.g., ASME BPE or SEMI).

(2) Pipe from 5 mm to 22 mm ($^3/_{16}$ in. to $^7/_8$ in.) nominal wall thickness shall be in accordance with ASME B16.25. "J" or bevel groove angles suitable for orbital welding are shown in Figure U328.4.2.

(3) For pipe with nominal wall thickness 5 mm to 22 mm ($^3/_{16}$ in. to $^7/_8$ in.), a modified "J" end preparation with an extended land as shown in Figure U328.4.2, illustration (a) may be used.

(4) A pipe with a modified "J" end preparation may be welded to a pipe fitting with a $37^1/_2$-deg bevel end as shown in Figure U328.4.2, illustration (b).

U328.4.4 Preparation of Weld Coupons

(a) Weld coupons shall be made by qualified welding operators using the same qualified WPS and the same variables used for production welds.

(b) *Methods*

(1) Primary weld coupons shall be made from two short sections of tubing selected from the same diameter, wall thickness, and alloy as the material used for production. Sections shall be of sufficient length for fit up in the weld head allowing for attachment of inside diameter purge apparatus outside of the weld head. The sections shall be welded together in a square groove weld on a butt joint.

(2) Production weld coupons may be made in accordance with (1) or, at the owner's discretion, may be cut from actual production welds. The weld coupons shall be selected to ensure that the work product of each welding operator doing the production welding is represented.

U328.5 Welding Requirements

U328.5.1 General

(g) Tack welds shall be fully consumed after completion of the weld. Tack welds shall be made by a qualified welder or welding operator.

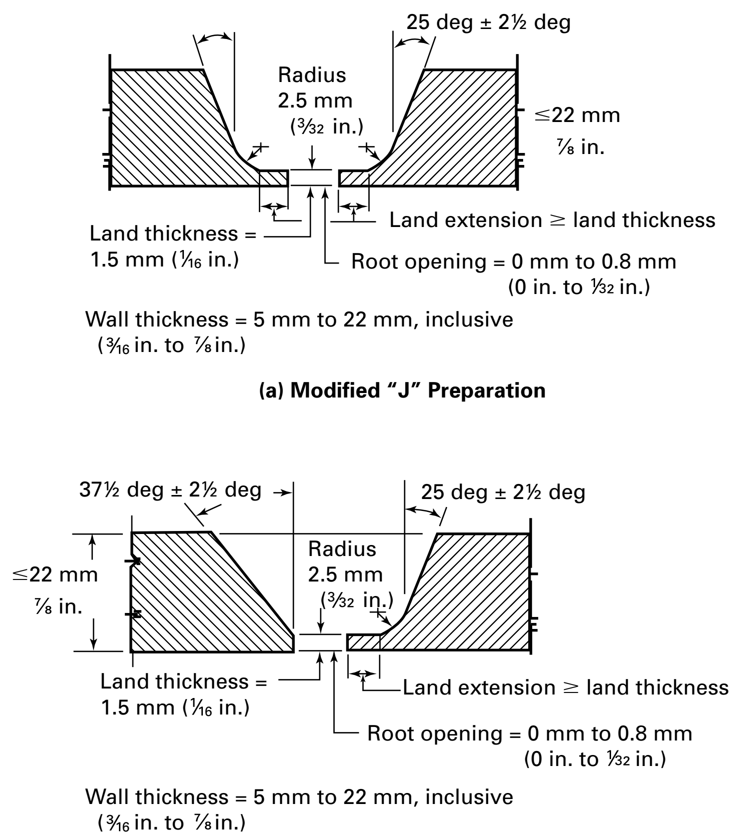
U330 PREHEATING

Paragraph 330 applies.

U331 HEAT TREATMENT

Paragraph 331 applies.

Figure U328.4.2 Modified Pipe End Preparations



(a) Modified "J" Preparation

(b) Modified Butt Weld Preparation

U332 BENDING AND FORMING

Paragraph 332 applies in its entirety.

U333 BRAZING AND SOLDERING

Brazing and soldering are not permitted.

U335 ASSEMBLY AND ERECTION

Paragraph 335 applies, except for paras. 335.4.1, 335.5, and 335.6. See paras. U335.7 and U335.8.

U335.7 Face Seal Joints

U335.7.1 Metal Face Seal. Metal face seal joints shall be installed and assembled in accordance with manufacturer's instructions. See Figure U335.7.1, illustration (a).

U335.7.2 Nonmetallic Face Seal. Nonmetallic face seal joints shall be installed and assembled in accordance with manufacturer's instructions. Care shall be taken to avoid distorting the seal when incorporating such joints into piping assemblies by welding. See Figure U335.7.1, illustration (b).

U335.8 Hygienic Clamp Joint Assembly

Hygienic clamp joint assembly components, e.g., those shown in Figures U335.8A, U335.8B, and U335.8C, shall be installed and assembled in accordance with the manufacturer's instructions. Care shall be taken to avoid distorting the seal when incorporating such joints into piping assemblies by welding.

PART 10
INSPECTION, EXAMINATION, AND TESTING

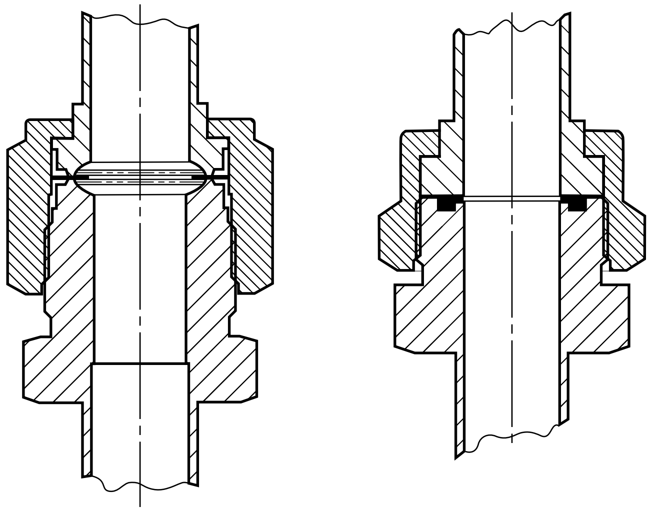
U340 INSPECTION

Paragraph 340 applies in its entirety.

U341 EXAMINATION

Paragraph 341 applies. See paras. U341.3.2 and U341.4.1.

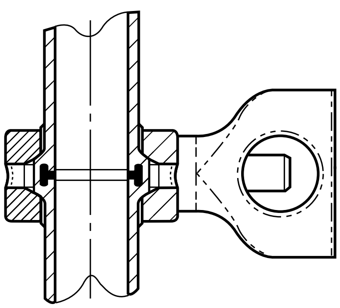
Figure U335.7.1 Face Seal Joints



(a) Metal Face Seal

(b) Nonmetallic Face Seal

Figure U335.8A Hygienic Clamp Joint Assembly



U341.3 Examination Requirements

U341.3.2 Acceptance Criteria. Acceptance criteria for all coupon and production welds shall be as stated in the engineering design or in the referencing code or standard (e.g., ASME BPE or SEMI) and shall at least meet the applicable requirements in para. 341.3.2.

U341.4 Extent of Required Examination

(20) **U341.4.1 Examination.** Production weld coupon examination in accordance with para. U344.8 may be used in lieu of the 5% random radiography/ultrasonic examination required in para. 341.4.1(b)(1) when any of the following are employed in fabrication:

(a) autogenous automatic or machine orbital welding

(b) automatic or machine orbital welding with the use of consumable inserts

(c) automatic or machine orbital welding with the use of filler wire

U341.4.5 Weld Coupon Examination. Weld coupons shall be made and examined in accordance with para. U344.8 when any of the following conditions exist:

(a) beginning of shift

(b) change of purge source

(c) change of power supply

(d) change of equipment, e.g., weld head, weld-head extensions, tungsten

(e) any time there is a weld defect

U342 EXAMINATION PERSONNEL

Paragraph 342 applies in its entirety. See para. U342.2(a).

U342.2 Specific Requirement

(a) For weld coupon examination

(1) the examinations shall be performed by personnel other than those performing the production work or

(2) with the owner's approval, the personnel performing the production work shall be permitted to perform the examination, provided the personnel meet the personnel qualification and certification requirements in para. 342.1

U343 EXAMINATION PROCEDURES

Paragraph 343 applies.

Figure U335.8B Hygienic Clamp Types

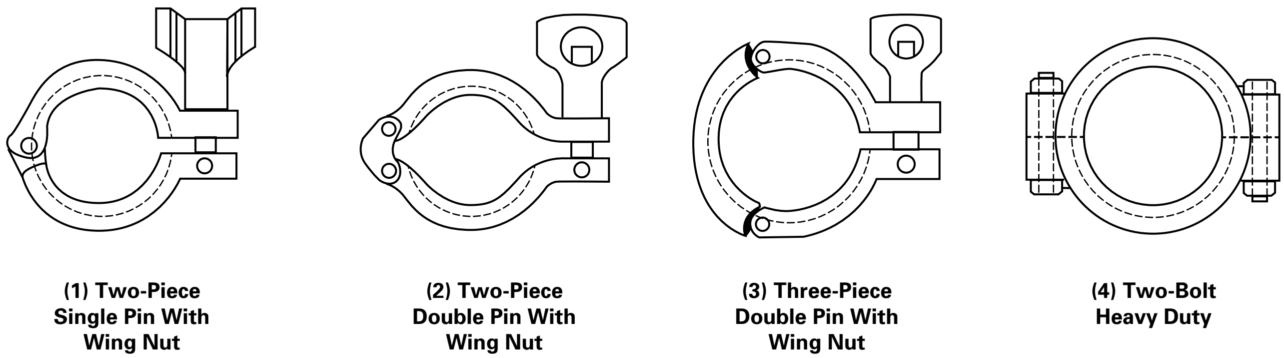
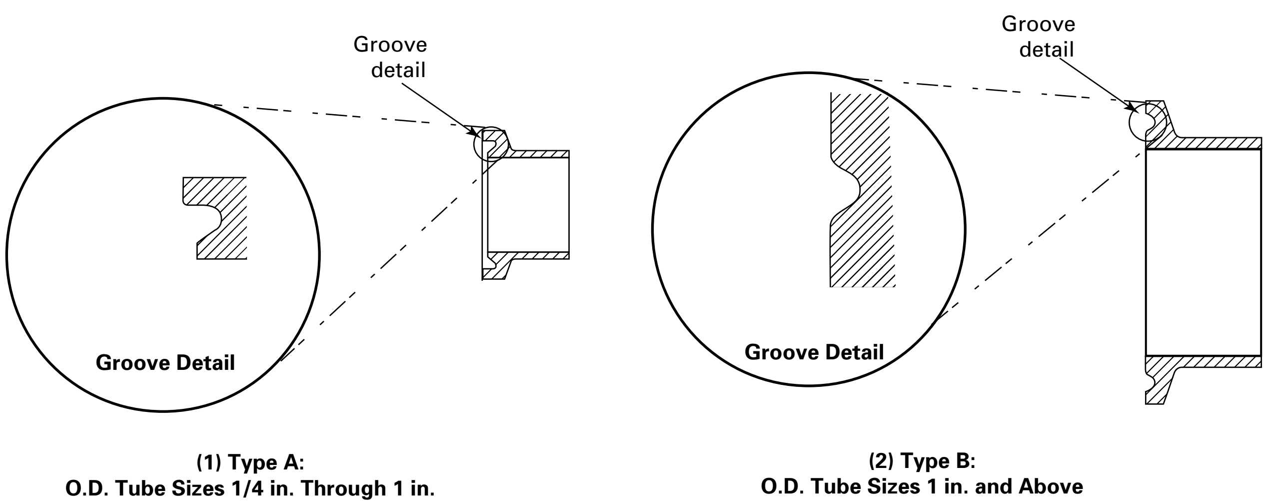


Figure U335.8C Hygienic Ferrules



U344 TYPES OF EXAMINATION

Paragraph 344 applies. See paras. U344.2 and U344.8.

U344.2 Visual Examination

Paragraph 344.2 applies, except that in addition to the method described in para. 344.2.2, borescopic examination shall be acceptable.

U344.8 Weld Coupon Examination

U344.8.1 Requirements. Weld coupon examination comprises examination of weld coupons for the following, as applicable:

(a) prior to welding of coupons made in accordance with para. U328.4.4(b)(1)

(1) joint preparation and cleanliness

(2) fit-up, collet or clamp grip, and alignment in the weld head

(3) variables in the orbital welding machine specified in the WPS

(b) after welding of coupons made in accordance with para. U328.4.4(b)(1), and for weld coupons made in accordance with para. U328.4.4(b)(2), for compliance with para. U341.3.2

(1) alignment

(2) weld penetration

(3) weld bead width variation

(4) weld bead meander

(5) discoloration

(6) weld defects, e.g., cracks, porosity, or sulfur stringers

To allow direct visual examination of the inside surfaces, the weld coupon may be cut or a suitable indirect visual examination method (e.g., borescopic examination) may be used.

U344.8.2 Method. A weld coupon shall be made to allow visual examination in accordance with para. U344.2, unless otherwise specified in the engineering design.

U345 TESTING

Paragraph 345 applies except for paras. 345.1, 345.8, and 345.9. See paras. U345.1, U345.8, and U345.9.

U345.1 Required Leak Test

Paragraph 345.1 applies, except that, at the owner's option, a helium mass spectrometer test in accordance with para. U345.8.1 may be substituted for the hydrostatic leak test.

U345.8 Sensitive Leak Test

Paragraph 345.8 applies, except that the helium mass spectrometer test described in para. U345.8.1 is also an acceptable method.

U345.8.1 Helium Mass Spectrometer Test. The test shall be one of the following methods and performed in accordance with the following:

(a) For pressurized systems, the test shall be in accordance with ASME BPVC, Section V, Article 10, Appendix IV (Helium Mass Spectrometer — Detector Probe Technique).

(1) The test pressure shall be the lesser of 105 kPa (15 psig) gage or 25% of the design pressure.

(2) Prior to testing, the test pressure shall be held a minimum of 30 min.

(3) Unless otherwise specified in the engineering design, the system tested is acceptable when no leakage is detected that exceeds the allowable leakage rate of 1×10^{-4} std cc/s.

(b) For evacuated systems, the test shall be in accordance with ASME BPVC, Section V, Article 10, Appendix V (Helium Mass Spectrometer Test — Tracer Probe Technique).

(1) The piping system shall be evacuated to an absolute pressure sufficient for connection of the helium mass spectrometer to the system.

(2) Unless otherwise specified in the engineering design, the system tested is acceptable when no leakage is detected that exceeds the allowable leakage rate of 1×10^{-5} std cc/s.

U345.9 Alternative Leak Test

Paragraph 345.9 applies, except that welds may be examined by weld coupon examination method in accordance with para. U341.4.5 and the test method may be helium mass spectrometer test in accordance with para. U345.8.1.

U346 RECORDS

U346.2 Responsibility

It is the responsibility of the piping designer, the manufacturer, the fabricator, and the erector, as applicable, to prepare the records required by this Code, ASME BPE, SEMI, or other industry standard as specified in the engineering design.

U346.3 Retention of Records

Paragraph 346.3 applies.

PART 11
HIGH PURITY PIPING IN CATEGORY M FLUID SERVICE

UM300 GENERAL STATEMENTS

(a) Chapter X, Part 11 pertains to piping designated by the owner as being high purity piping in Category M Fluid Service. See also Appendix M.

(b) The organization, content, and paragraph designations of these Parts correspond to those of Chapter VIII. The prefix UM is used.

(c) Paragraphs M300(d), M300(e), and M300(f) apply.

(d) Provisions and requirements of Chapter VIII apply with the additional requirements in paras. UM307, UM307.2, UM322, UM322.3, UM328, UM335, UM335.3.3, UM341, UM341.4(b)(1) and UM341.4(b)(2), and UM345(b).

UM307 METALLIC VALVES AND SPECIALTY COMPONENTS

Paragraph M307 applies in its entirety. See also para. UM307.2(a).

UM307.2 Specific Requirements

(a) For bellows or diaphragm sealed type valves, the bonnet or cover plate closure shall be secured by a straight thread sufficient for mechanical strength, have a metal-to-metal seat, and include a secondary stem seal.

UM322 SPECIFIC PIPING SYSTEMS

Paragraph M322 applies, except for para. M322.3(c). See para. UM322.3(c).

UM322.3 Instrument Piping

(c) joining methods shall conform to the requirements of para. U315

UM328 WELDING OF MATERIALS

Welding shall be in accordance with paras. M311.1 and U328, except examination shall be in accordance with para. UM341.

UM335 ASSEMBLY AND ERECTION OF METALLIC PIPING

Paragraph M335 applies, except for para. M335.3.3. See para. UM335.3.3.

UM335.3.3 Straight-Threaded Joints. The requirements of para. M335.3.3 are subject to the limitations in para. UM322.

UM341 EXAMINATION

Paragraph M341 applies. See UM341.4(b)(1) and UM341.4(b)(2).

UM341.4 Extent of Required Examination

(b) Other Examination

(1) The 100% radiography/ultrasonic examination required in para. M341.4(b) applies.

(2) The in-process examination alternative permitted in para. 341.4.1(b)(1) applies, except a weld coupon examination in accordance with para. U344.8 is also an acceptable substitute when specified in the engineering design or by the Inspector.

UM345 TESTING

Paragraph M345(a) applies. See (b).

(b) A sensitive leak test in accordance with para. U345.8 shall be included in the required leak test (para. U345.1).

APPENDIX A
ALLOWABLE STRESSES AND QUALITY FACTORS FOR METALLIC PIPING AND BOLTING MATERIALS

Begins on the next page.

Specification Index for Appendix A (20)

Spec. No.	Title
ASTM	
A36	Carbon Structural Steel
A47	Ferritic Malleable Iron Castings
A48	Gray Iron Castings
A53	Pipe, Steel, Black and Hot-Dipped, Zinc-Coated, Welded and Seamless
A105	Carbon Steel Forgings for Piping Applications
A106	Seamless Carbon Steel Pipe for High-Temperature Service
A126	Gray Iron Castings for Valves, Flanges, and Pipe Fittings
A134	Pipe, Steel, Electric-Fusion (Arc)-Welded (Sizes NPS 16 and Over)
A135	Electric-Resistance-Welded Steel Pipe
A139	Electric-Fusion (Arc)-Welded Steel Pipe (NPS 4 and Over)
A179	Seamless Cold-Drawn Low-Carbon Steel Heat-Exchanger and Condenser Tubes
A181	Carbon Steel Forgings, for General-Purpose Piping
A182	Forged or Rolled Alloy and Stainless Steel Pipe Flanges, Forged Fittings, and Valves and Parts for High-Temperature Service
A193	Alloy-Steel and Stainless Steel Bolting for High Temperature or High Pressure Service and Other Special Purpose Applications
A194	Carbon Steel, Alloy Steel, and Stainless Steel Nuts for Bolts for High Pressure or High Temperature Service, or Both
A197	Cupola Malleable Iron
A203	Pressure Vessel Plates, Alloy Steel, Nickel
A204	Pressure Vessel Plates, Alloy Steel, Molybdenum
A213	Seamless Ferritic and Austenitic Alloy-Steel Boiler, Superheater, and Heat-Exchanger Tubes
A216	Steel Castings, Carbon, Suitable for Fusion Welding, for High-Temperature Service
A217	Steel Castings, Martensitic Stainless and Alloy, for Pressure-Containing Parts, Suitable for High-Temperature Service
A234	Piping Fittings of Wrought Carbon Steel and Alloy Steel for Moderate and High Temperature Service
A240	Chromium and Chromium-Nickel Stainless Steel Plate, Sheet, and Strip for Pressure Vessels and for General Applications
A268	Seamless and Welded Ferritic and Martensitic Stainless Steel Tubing for General Service
A269	Seamless and Welded Austenitic Stainless Steel Tubing for General Service
A270	Seamless and Welded Austenitic and Ferritic/Austenitic Stainless Steel Sanitary Tubing
A276	Stainless Steel Bars and Shapes
A278	Gray Iron Castings for Pressure-Containing Parts for Temperatures Up to 650°F (350°C)
A283	Low and Intermediate Tensile Strength Carbon Steel Plates
ASTM (Cont'd)	
A285	Pressure Vessel Plates, Carbon Steel, Low- and Intermediate-Tensile Strength
A299	Pressure Vessel Plates, Carbon Steel, Manganese-Silicon
A302	Pressure Vessel Plates, Alloy Steel, Manganese-Molybdenum and Manganese-Molybdenum-Nickel
A307	Carbon Steel Bolts and Studs, 60 000 PSI Tensile Strength
A312	Seamless, Welded, and Heavily Cold Worked Austenitic Stainless Steel Pipes
A320	Alloy-Steel and Stainless Steel Bolting for Low-Temperature Service
A333	Seamless and Welded Steel Pipe for Low-Temperature Service and Other Applications with Required Notch Toughness
A334	Seamless and Welded Carbon and Alloy-Steel Tubes for Low-Temperature Service
A335	Seamless Ferritic Alloy-Steel Pipe for High-Temperature Service
A350	Carbon and Low-Alloy Steel Forgings, Requiring Notch Toughness Testing for Piping Components
A351	Castings, Austenitic, for Pressure-Containing Parts
A352	Steel Castings, Ferritic and Martensitic, for Pressure-Containing Parts, Suitable for Low-Temperature Service
A353	Pressure Vessel Plates, Alloy Steel, Double-Normalized and Tempered 9% Nickel
A354	Quenched and Tempered Alloy Steel Bolts, Studs, and Other Externally Threaded Fasteners
A358	Electric-Fusion-Welded Austenitic Chromium-Nickel Stainless Steel Pipe for High-Temperature Service and General Applications
A369	Carbon and Ferritic Alloy Steel Forged and Bored Pipe for High-Temperature Service
A376	Seamless Austenitic Steel Pipe for High-Temperature Service
A381	Metal-Arc-Welded Carbon or High-Strength Low-Alloy Steel Pipe for Use With High-Pressure Transmission Systems
A387	Pressure Vessel Plates, Alloy Steel, Chromium-Molybdenum
A395	Ferritic Ductile Iron Pressure-Retaining Castings for Use at Elevated Temperatures
A403	Wrought Austenitic Stainless Steel Piping Fittings
A409	Welded Large Diameter Austenitic Steel Pipe for Corrosive or High-Temperature Service
A420	Piping Fittings of Wrought Carbon Steel and Alloy Steel for Low-Temperature Service
A426	Centrifugally Cast Ferritic Alloy Steel Pipe for High-Temperature Service
A437	Stainless and Alloy-Steel Turbine-Type Bolting Material Specially Heat Treated for High-Temperature Service

Specification Index for Appendix A (Cont'd)

Spec. No.	Title
ASTM (Cont'd)	
A451	Centrifugally Cast Austenitic Steel Pipe for High-Temperature Service
A453	High-Temperature Bolting, with Expansion Coefficients Comparable to Austenitic Stainless Steels
A479	Stainless Steel Bars and Shapes for Use in Boilers and Other Pressure Vessels
A487	Steel Castings Suitable for Pressure Service
A494	Castings, Nickel and Nickel Alloy
A515	Pressure Vessel Plates, Carbon Steel, for Intermediate- and Higher-Temperature Service
A516	Pressure Vessel Plates, Carbon Steel, for Moderate- and Lower-Temperature Service
A524	Seamless Carbon Steel Pipe for Atmospheric and Lower Temperatures
A536	Ductile Iron Castings
A537	Pressure Vessel Plates, Heat-Treated, Carbon-Manganese-Silicon Steel
A553	Pressure Vessel Plates, Alloy Steel, Quenched and Tempered 7, 8, and 9 % Nickel
A563	Carbon and Alloy Steel Nuts
A571	Austenitic Ductile Iron Castings for Pressure-Containing Parts Suitable for Low-Temperature Service
A587	Electric-Resistance-Welded Low-Carbon Steel Pipe for the Chemical Industry
A645	Pressure Vessel Plates, 5 % and 5 $^1/_2$ % Nickel Alloy Steels, Specially Heat Treated
A671	Electric-Fusion-Welded Steel Pipe for Atmospheric and Lower Temperatures
A672	Electric-Fusion-Welded Steel Pipe for High-Pressure Service at Moderate Temperatures
A675	Steel Bars, Carbon, Hot-Wrought, Special Quality, Mechanical Properties
A691	Carbon and Alloy Steel Pipe, Electric-Fusion-Welded for High-Pressure Service at High Temperatures
A694	Carbon and Alloy Steel Forgings for Pipe Flanges, Fittings, Valves, and Parts for High-Pressure Transmission Service
A696	Steel Bars, Carbon, Hot-Wrought or Cold-Finished, Special Quality, for Pressure Piping Components
A707	Forged Carbon and Alloy Steel Flanges for Low-Temperature Service
A789	Seamless and Welded Ferritic/Austenitic Stainless Steel Tubing for General Service
A790	Seamless and Welded Ferritic/Austenitic Stainless Steel Pipe
A813	Single- or Double-Welded Austenitic Stainless Steel Pipe
A814	Cold-Worked Welded Austenitic Stainless Steel Pipe
A815	Wrought Ferritic, Ferritic/Austenitic, and Martensitic Stainless Steel Piping Fittings
A860	Wrought High-Strength Ferritic Steel Butt-Welding Fittings
A928	Ferritic/Austenitic (Duplex) Stainless Steel Pipe Electric Fusion Welded with Addition of Filler Metal
A992	Structural Steel Shapes
A995	Castings, Austenitic-Ferritic (Duplex) Stainless Steel, for Pressure-Containing Parts
A1010	Higher-Strength Martensitic Stainless Steel Plate, Sheet, and Strip
A1011	Steel, Sheet and Strip, Hot-Rolled, Carbon, Structural, High-Strength Low-Alloy, High-Strength Low-Alloy with Improved Formability, and Ultra-High Strength
A1053	Welded Ferritic-Martensitic Stainless Steel Pipe
B21	Naval Brass Rod, Bar, and Shapes
B26	Aluminum-Alloy Sand Castings
B42	Seamless Copper Pipe, Standard Sizes
B43	Seamless Red Brass Pipe, Standard Sizes
B61	Steam or Valve Bronze Castings
B62	Composition Bronze or Ounce Metal Castings
B68	Seamless Copper Tube, Bright Annealed
B75	Seamless Copper Tube
B88	Seamless Copper Water Tube
B96	Copper-Silicon Alloy Plate, Sheet, Strip, and Rolled Bar for General Purposes and Pressure Vessels
B98	Copper-Silicon Alloy Rod, Bar and Shapes
B127	Nickel-Copper Alloy (UNS N04400) Plate, Sheet, and Strip
B148	Aluminum-Bronze Sand Castings
B150	Aluminum Bronze Rod, Bar and Shapes
B152	Copper Sheet, Strip, Plate and Rolled Bar
B160	Nickel Rod and Bar
B161	Nickel Seamless Pipe and Tube
B162	Nickel Plate, Sheet and Strip
B163	Seamless Nickel and Nickel Alloy Condenser and Heat Exchanger Tubes
B164	Nickel-Copper Alloy Rod, Bar, and Wire
B165	Nickel-Copper Alloy (UNS N04400) Seamless Pipe and Tube
B166	Nickel-Chromium-Aluminum Alloy, Nickel-Chromium-Iron Alloys, Nickel-Chromium-Cobalt-Molybdenum Alloy, Nickel-Iron-Chromium-Tungsten Alloy, and Nickel-Chromium-Molybdenum-Copper Alloy Rod, Bar, and Wire

Specification Index for Appendix A (Cont'd)

Spec. No.	Title
ASTM (Cont'd)	
B167	Nickel-Chromium-Iron Alloys (UNS N06600, N06601, N06603, N06690, N06693, N06025, N06045, and N06696), Nickel-Chromium-Cobalt-Molybdenum Alloy (UNS N06617), and Nickel-Iron-Chromium-Tungsten Alloy (UNS N06674) Seamless Pipe and Tube
B168	Nickel-Chromium-Iron Alloys (UNS N06600, N06601, N06603, N06690, N06693, N06025, N06045, and N06696), Nickel-Chromium-Cobalt-Molybdenum Alloy (UNS N06617), and Nickel-Iron-Chromium-Tungsten Alloy (UNS N06674) Plate, Sheet and Strip
B169	Aluminum Bronze Sheet, Strip, and Rolled Bar
B171	Copper-Alloy Plate and Sheet for Pressure Vessels, Condensers, and Heat Exchangers
B187	Copper, Bus Bar, Rod, and Shapes and General Purpose Rod, Bar, and Shapes
B209	Aluminum and Aluminum-Alloy Sheet and Plate
B210	Aluminum and Aluminum-Alloy Drawn Seamless Tubes
B211	Aluminum and Aluminum-Alloy Rolled or Cold Finished Bar, Rod, and Wire
B221	Aluminum and Aluminum-Alloy Extruded Bars, Rods, Wire, Profiles, and Tubes
B241	Aluminum and Aluminum-Alloy Seamless Pipe and Seamless Extruded Tube
B247	Aluminum and Aluminum-Alloy Die Forgings, Hand Forgings, and Rolled Ring Forgings
B265	Titanium and Titanium Alloy Strip, Sheet, and Plate
B280	Seamless Copper Tube for Air Conditioning and Refrigeration Field Service
B283	Copper and Copper-Alloy Die Forgings (Hot-Pressed)
B333	Nickel-Molybdenum Alloy Plate, Sheet, and Strip
B335	Nickel-Molybdenum Alloy Rod
B345	Aluminum and Aluminum-Alloy Seamless Pipe and Seamless Extruded Tube for Gas and Oil Transmission and Distribution Piping Systems
B348	Titanium and Titanium Alloy Bars and Billets
B361	Factory-Made Wrought Aluminum and Aluminum-Alloy Welding Fittings
B363	Seamless and Welded Unalloyed Titanium and Titanium Alloy Welding Fittings
B366	Factory-Made Wrought Nickel and Nickel Alloy Fittings
B367	Titanium and Titanium Alloy Castings
B371	Copper-Zinc-Silicon Alloy Rod
B381	Titanium and Titanium Alloy Forgings
B407	Nickel-Iron-Chromium Alloy Seamless Pipe and Tube
B408	Nickel-Iron-Chromium Alloy Rod and Bar
B409	Nickel-Iron-Chromium Alloy Plate, Sheet, and Strip
B423	Nickel-Iron-Chromium-Molybdenum-Copper Alloy (UNS N08825, N08221, and N06845) Seamless Pipe and Tube
B424	Ni-Fe-Cr-Mo-Cu Alloy (UNS N08825, UNS N08221, and UNS N06845) Plate, Sheet, and Strip
B425	Ni-Fe-Cr-Mo-Cu Alloy (UNS N08825, UNS N08221, and UNS N06845) Rod and Bar
B435	UNS N06002, UNS N06230, UNS N12160, and UNS R30556 Plate, Sheet, and Strip
B443	Nickel-Chromium-Molybdenum-Columbium Alloy (UNS N06625) and Nickel-Chromium-Molybdenum-Silicon Alloy (UNS N06219) Plate, Sheet, and Strip
B444	Nickel-Chromium-Molybdenum-Columbium Alloys (UNS N06625 and UNS N06852) and Nickel-Chromium-Molybdenum-Silicon Alloy (UNS N06219) Pipe and Tube
B446	Nickel-Chromium-Molybdenum-Columbium Alloy (UNS N06625), Nickel-Chromium-Molybdenum-Silicon Alloy (UNS N06219), and Nickel-Chromium-Molybdenum-Tungsten Alloy (UNS N06650) Rod and Bar
B462	Forged or Rolled Nickel Alloy Pipe Flanges, Forged Fittings, and Valves and Parts for Corrosive High-Temperature Service
B463	UNS N08020 Alloy Plate, Sheet, and Strip
B464	Welded UNS N08020 Alloy Pipe
B466	Seamless Copper-Nickel Pipe and Tube
B467	Welded Copper-Nickel Pipe
B474	Electric Fusion Welded Nickel and Nickel Alloy Pipe
B491	Aluminum and Aluminum-Alloy Extruded Round Tubes for General-Purpose Applications
B493	Zirconium and Zirconium Alloy Forgings
B514	Welded Nickel-Iron-Chromium Alloy Pipe
B515	Welded UNS N08120, UNS N08800, UNS N08810, and UNS N08811 Alloy Tubes
B517	Welded Nickel-Chromium-Iron-Alloy (UNS N06600, UNS N06603, UNS N06025, and UNS N06045) Pipe
B523	Seamless and Welded Zirconium and Zirconium Alloy Tubes
B550	Zirconium and Zirconium Alloy Bar and Wire
B551	Zirconium and Zirconium Alloy Strip, Sheet, and Plate
B564	Nickel Alloy Forgings
B572	UNS N06002, UNS N06230, UNS N12160, and UNS R30556 Rod
B574	Low-Carbon Nickel-Chromium-Molybdenum, Low-Carbon Nickel-Molybdenum-Chromium, Low-Carbon Nickel-Molybdenum-Chromium-Tantalum, Low-Carbon Nickel-Chromium-Molybdenum-Copper, and Low-Carbon Nickel-Chromium-Molybdenum-Tungsten Alloy Rod

Specification Index for Appendix A (Cont'd)

Spec. No.	Title
ASTM (Cont'd)	
B575	Low-Carbon Nickel-Chromium-Molybdenum, Low-Carbon Nickel-Chromium-Molybdenum-Copper, Low-Carbon Nickel-Chromium-Molybdenum-Tantalum, Low-Carbon Nickel-Chromium-Molybdenum-Tungsten, and Low-Carbon Nickel-Molybdenum-Chromium Alloy Plate, Sheet and Strip
B581	Nickel-Chromium-Iron-Molybdenum-Copper Alloy Rod
B582	Nickel-Chromium-Iron-Molybdenum-Copper Alloy Plate, Sheet, and Strip
B584	Copper Alloy Sand Castings for General Applications
B619	Welded Nickel and Nickel-Cobalt Alloy Pipe
B620	Nickel-Iron-Chromium-Molybdenum Alloy (UNS N08320) Plate, Sheet, and Strip
B621	Nickel-Iron-Chromium-Molybdenum Alloy (UNS N08320) Rod
B622	Seamless Nickel and Nickel-Cobalt Alloy Pipe and Tube
B625	UNS N08925, UNS N08031, UNS N08932, UNS N08926, UNS N08354, UNS N08830, and UNS R20033 Plate, Sheet, and Strip
B626	Welded Nickel and Nickel-Cobalt Alloy Tube
B649	Ni-Fe-Cr-Mo-Cu-N Low-Carbon Alloys (UNS N08925, UNS N08031, UNS N08034, UNS N08354, and UNS N08926), and Cr-Ni-Fe-N Low-Carbon Alloy (UNS R20033) Bar and Wire, and Ni-Cr-Fe-Mo-N Alloy (UNS N08936) Wire
B658	Seamless and Welded Zirconium and Zirconium Alloy Pipe
B668	UNS N08028 Seamless Pipe and Tube
B675	UNS N08367 Welded Pipe
B688	Chromium-Nickel-Molybdenum-Iron (UNS N08367) Plate, Sheet, and Strip
B690	Iron-Nickel-Chromium-Molybdenum Alloy (UNS N08367) Seamless Pipe and Tube
B704	Welded UNS N06625, UNS N06219 and UNS N08825 Alloy Tubes
B705	Nickel-Alloy (UNS N06625, N06219 and N08825) Welded Pipe
B709	Iron-Nickel-Chromium-Molybdenum Alloy (UNS N08028) Plate, Sheet, and Strip
B725	Welded Nickel (UNS N02200/UNS N02201) and Nickel Copper Alloy (UNS N04400) Pipe
B729	Seamless UNS N08020, UNS N08026, and UNS N08024 Nickel-Alloy Pipe and Tube
B804	UNS N08367 and UNS N08926 Welded Pipe
B861	Titanium and Titanium Alloy Seamless Pipe
B862	Titanium and Titanium Alloy Welded Pipe
E112	Standard Test Methods for Determining Average Grain Size
F3125	High Strength Structural Bolts, Steel and Alloy Steel, Heat Treated, 120 ksi (830 MPa) and 150 ksi (1040 MPa) Minimum Tensile Strength
API	
5L	Line Pipe
CSA	
Z245.1	Steel Pipe

GENERAL NOTE: It is not practical to refer to a specific edition of each standard throughout the Code text. Instead, the approved edition references, along with the names and addresses of the sponsoring organizations, are shown in Appendix E.

NOTES FOR TABLES A-1, A-1M, A-1A, A-1B, A-2, AND A-2M (20)

GENERAL NOTES:

(a) The allowable stress values, P-Number assignments, weld joint and casting quality factors, and minimum temperatures in Tables A-1, A-1A, A-1B, A-2, and A-2M, together with the referenced Notes in the stress tables, are requirements of this Code.

(b) Notes (1) through (7) are referenced in column headings and in body headings for material type and product form; Notes (8) and following are referenced in the Notes column for specific materials. Notes marked with an asterisk (*) restate requirements found in the text of the Code.

(c) The stress values given in ksi as shown in Tables A-1 and A-2, and given in MPa as shown in Tables A-1M and A-2M, may be used. The values stated in ksi are not exact equivalents to the values stated in MPa. Therefore, for any given material, the user of the Code should use only the ksi or the MPa values.

(d) For copper and copper alloys, the following symbols are used in the Temper column: H = drawn; H01 = quarter hard; H02 = half hard; H06 = extra hard; H55 = light drawn; H58 = drawn, general purpose; H80 = hard drawn; HR50 = drawn, stress relieved; M20 = hot rolled; O25 = hot rolled, annealed; O50 = light annealed; O60 = soft annealed; O61 = annealed; WO50 = welded, annealed; and WO61 = welded, fully finished, annealed.

(e) For nickel and nickel alloys, the following abbreviations are used in the Class column: ann., annealed; C.D., cold worked; forg., forged; H.F., hot finished; H.R., hot rolled; H.W., hot worked; plt., plate; R., rolled; rel., relieved; sol., solution; str., stress; and tr., treated.

(f) In Table A-1M, the following abbreviations are used in the Product Form column: forg., forgings; ftg., fittings; pl., plate; shps., shapes; sht., sheet; smls., seamless; struct., structural; and wld., welded.

NOTES:

(1) *The stress values in Tables A-1 and A-1M, and the design stress values in Tables A-2 and A-2M, are basic allowable stresses in tension in accordance with para. 302.3.1(a). For pressure design, the stress values from Tables A-1 and A-1M are multiplied by the appropriate quality factor E (E_c from Table A-1A or E_j from Table A-1B). Stress values in shear and bearing are stated in para. 302.3.1(b); those in compression in para. 302.3.1(c).

(2) *The quality factors for castings E_c in Table A-1A are basic factors in accordance with para. 302.3.3(b). The quality factors for longitudinal weld joints E_j in Table A-1B are basic factors in accordance with para. 302.3.4(a). See paras. 302.3.3(c) and 302.3.4(b) for enhancement of quality factors. See also para. 302.3.1(a), footnote 1.

(3) The stress values for austenitic stainless steels in these Tables may not be applicable if the material has been given a final heat treatment other than that required by the material specification or by reference to Note (30) or (31).

(4a) *In Table A-1, stress values printed in *italics* exceed two-thirds of the expected yield strength at temperature. Stress values in **boldface** are equal to 90% of expected yield strength at temperature. See paras. 302.3.2(d)(3) and 302.3.2(e).

(4b) *In Table A-1M, stress values printed in *italics* are tensile-controlled values. Yield-controlled stress values are in normal font and time-dependent stress values are in **boldface.**

(5) *See ASME BPVC, Section IX, QW-200.3 for a description of P-Number groupings. P-Numbers are indicated by number or by a number followed by a letter (e.g., 8, 5B, or 11A).

(6) *The minimum temperature shown is that design minimum temperature for which the material is normally suitable without impact testing other than that required by the material specification. However, the use of a material at a design minimum temperature colder than −29°C (−20°F) is established by rules elsewhere in this Code, including para. 323.2.2 and other impact test requirements. For carbon steels with a letter designation in the Min. Temp. column, see para. 323.2.2(e) and the applicable curve and Notes in Figure 323.2.2A.

(7) The letter “a” indicates alloys that are not recommended for welding and that, if welded, must be individually qualified. The letter “b” indicates copper base alloys that must be individually qualified.

(8) *There are restrictions on the use of this material in the text of the Code as follows:

(a) See para. 305.2.1; temperature limits are −29°C to 186°C (−20°F to 366°F).

(b) See para. 305.2.2; pipe shall be safeguarded when used outside the temperature limits in Note (8a).

(c) See Table 323.2.2, box B-2.

(d) See para. 323.4.2(a).

(e) See para. 323.4.2(b).

(f) See para. 309.2.1.

(g) See para. 309.2.2.

(9) *For pressure–temperature ratings of components made in accordance with standards listed in Table 326.1, see para. 326.2.1. Stress values in Tables A-1 and A-1M may be used to calculate ratings for unlisted components, and special ratings for listed components, as permitted by para. 303.

(9a) Component standards listed in Table 326.1 impose the following restrictions on this material when used as a forging: composition, properties, heat treatment, and grain size shall conform to this specification; manufacturing procedures, tolerances, tests, certification, and markings shall be in accordance with ASTM B564.

(10) *This casting quality factor is applicable only when proper supplementary examination has been performed (see para. 302.3.3).
(11) *For use under this Code, radiography shall be performed after heat treatment.
(12) *Certain forms of this material, as stated in Table 323.2.2, must be impact tested to qualify for service below −29°C (−20°F). Alternatively, if provisions for impact testing are included in the material specification as supplementary requirements and are invoked, the material may be used down to the temperature at which the test was conducted in accordance with the specification.
(13) Properties of this material vary with thickness or size. Stress values are based on minimum properties for the thickness listed.
(14) For use in Code piping at the stated stress values, the required minimum tensile and yield properties must be verified by tensile test. If such tests are not required by the material specification, they shall be specified in the purchase order.
(15) These stress values are established from a consideration of strength only and will be satisfactory for average service. For bolted joints where freedom from leakage over a long period of time without retightening is required, lower stress values may be necessary as determined from the flexibility of the flange and bolts and corresponding relaxation properties.
(16) DELETED.
(17) DELETED.
(18) DELETED.
(19) *This specification includes requirements for random radiographic inspection for mill quality control. If the 0.90 joint factor is to be used, the welds shall meet the requirements of Table 341.3.2 for longitudinal butt welds with spot radiography in accordance with Table 302.3.4. This shall be a matter of special agreement between purchaser and manufacturer.
(20) For pipe sizes ≥DN 200 (NPS 8) with wall thicknesses ≥Sch 140, the specified minimum tensile strength is 483 MPa (70 ksi).
(21) For material thickness >127 mm (5 in.), the specified minimum tensile strength is 483 MPa (70 ksi).
(21a) For material thickness >127 mm (5 in.), the specified minimum tensile strength is 448 MPa (65 ksi).
(22) The minimum tensile strength for weld (qualification) and stress values shown shall be multiplied by 0.90 for pipe having an outside diameter less than 51 mm (2 in.) and a D/t value less than 15. This requirement may be waived if it can be shown that the welding procedure to be used will consistently produce welds that meet the listed minimum tensile strength of 165 MPa (24 ksi).
(23) DELETED.
(24) Yield strength is not stated in the material specification. The value shown is based on yield strengths of materials with similar characteristics.
(25) This steel may develop embrittlement after service at approximately 316°C (600°F) and higher temperature.
(26) This unstabilized grade of stainless steel increasingly tends to precipitate intergranular carbides as the carbon content increases above 0.03%. See also para. F323.4(c)(2).
(27) For temperatures above 427°C (800°F), these stress values apply only when the carbon content is 0.04% or higher.
(28) For temperatures above 538°C (1,000°F), these stress values apply only when the carbon content is 0.04% or higher.
(29) The stress values above 538°C (1,000°F) listed here shall be used only when the steel's austenitic micrograin size, as defined in ASTM E112, is No. 6 or less (coarser grain). Otherwise, the lower stress values listed for the same material, specification, and grade shall be used.
(30) For temperatures above 538°C (1,000°F), these stress values may be used only if the material has been heat treated by heating to a minimum temperature of 1 093°C (2,000°F) and quenching in water or rapidly cooling by other means.
(31) For temperatures above 538°C (1,000°F), these stress values may be used only if the material has been heat treated by heating to a minimum temperature of 1 038°C (1,900°F) and quenching in water or rapidly cooling by other means.
(32) Stress values shown are for the lowest strength base material permitted by the specification to be used in the manufacture of this grade of fitting. If a higher strength base material is used, the higher stress values for that material may be used in design.
(33) For welded construction with work hardened grades, use the stress values for annealed material; for welded construction with precipitation hardened grades, use the special stress values for welded construction given in the Tables.
(34) If material is welded, brazed, or soldered, the allowable stress values for the annealed condition shall be used.
(35) This steel is intended for use at high temperatures; it may have low ductility and/or low impact properties at room temperature after being used above the temperature indicated by para. F323.4(c)(4).
(36) The specification permits this material to be furnished without solution heat treatment or with other than a solution heat treatment. When the material has not been solution heat treated, the minimum temperature shall be −29°C (−20°F) unless the material is impact tested in accordance with para. 323.3.
(37) Impact requirements for seamless fittings shall be governed by those listed in this Table for the particular base material specification in the grades permitted (A312, A240, and A182). When A276 materials are used in the manufacture of these fittings, the Notes, minimum temperatures, and allowable stresses for comparable grades of A240 materials shall apply.
(38) DELETED.
(39) This material when used below −29°C (−20°F) shall be impact tested if the carbon content is above 0.10%.
(40) *This casting quality factor can be enhanced by supplementary examination in accordance with para. 302.3.3(c) and Table 302.3.3C. The higher factor from Table 302.3.3C may be substituted for this factor in pressure design equations.
(41) Design stresses for the cold drawn temper are based on hot rolled properties until required data on cold drawn are submitted.

(42) This is a product specification. No design stresses are necessary. Limitations on metal temperature for materials covered by this specification are as follows:

Grade(s)	Metal Temperature, °C (°F)
1	−29 to 482 (−20 to 900)
2, 2H, and 2HM	−48 to 593 (−55 to 1,100)
3	−29 to 593 (−20 to 1,100)
6	−29 to 427 (−20 to 800)
7	−48 to 593 (−55 to 1,100)
7L	−101 to 593 (−150 to 1,100)
7M	−48 to 593 (−55 to 1,100)
7ML	−73 to 593 (−100 to 1,100)
8FA [see Note (39)]	−29 to 427 (−20 to 800)
8MA and 8TA	−198 to 816 (−325 to 1,500)
8, 8A, and 8CA	−254 to 816 (−425 to 1,500)

(42a) DELETED.

(42b) This is a product specification. No design stresses are necessary. For limitations on usage, see paras. 309.2.1 and 309.2.2.

(43) *The stress values given for this material are not applicable when either welding or thermal cutting is employed [see para. 323.4.2(c)].

(44) DELETED.

(45) Stress values shown are applicable for “die” forgings only.

(46) Lines of allowable stresses in Tables A-1 and A-1M for all materials in A312 include heavily cold worked (HCW) material as defined in A312, para. 6.1.4.

(47) If no welding is employed in fabrication of piping from these materials, the stress values may be increased to 230 MPa (33.3 ksi).

(48) The stress value to be used for this gray iron material at its upper temperature limit of 232°C (450°F) is the same as that shown in the 204°C (400°F) column.

(49) If the chemical composition of this Grade is such as to render it hardenable, qualification under P-No. 6 is required.

(50) This material is grouped in P-No. 7 because its hardenability is low.

(51) This material may require special consideration for welding qualification. See ASME BPVC, Section IX, QW/QB-422. For use in this Code, a qualified WPS is required for each strength level of material.

(52) Copper-silicon alloys are not always suitable when exposed to certain media and high temperature, particularly above 100°C (212°F). The user should satisfy himself/herself that the alloy selected is satisfactory for the service for which it is to be used.

(53) Stress relief heat treatment is required for service above 232°C (450°F).

(54) The maximum operating temperature is arbitrarily set at 260°C (500°F) because hard temper adversely affects design stress in the creep rupture temperature ranges.

(55) Pipe produced to this specification is not intended for high temperature service. The stress values apply to either nonexpanded or cold expanded material in the as-rolled, normalized, or normalized and tempered condition.

(56) Because of thermal instability, this material is not recommended for service above 427°C (800°F).

(57) Conversion of carbides to graphite may occur after prolonged exposure to temperatures over 427°C (800°F). See para. F323.4(b)(2).

(58) Conversion of carbides to graphite may occur after prolonged exposure to temperatures over 468°C (875°F). See para. F323.4(b)(3).

(59) For temperatures above 482°C (900°F), consider the advantages of killed steel. See para. F323.4(b)(4).

(60) For all design temperatures, the maximum hardness shall be Rockwell C35 immediately under the thread roots. The hardness shall be taken on a flat area at least 3 mm ($^1/_8$ in.) across, prepared by removing threads. No more material than necessary shall be removed to prepare the area. Hardness determination shall be made at the same frequency as tensile tests.

(61) Annealed at approximately 982°C (1,800°F).

(62) Annealed at approximately 1 121°C (2,050°F).

(63) For stress relieved tempers (T351, T3510, T3511, T451, T4510, T4511, T651, T6510, T6511), stress values for material in the listed temper shall be used.

(64) The minimum tensile strength of the reduced section tensile specimen in accordance with ASME BPVC, Section IX, QW-462.1, shall not be less than 758 MPa (110.0 ksi).

(65) The minimum temperature shown in Tables A-1 and A-1M is for the heaviest wall meeting the specified mechanical property requirements in the specification. The minimum temperature for lighter walls shall be as shown in the following tabulation:

Impact Test Temperature (°C) for Plate Thicknesses Shown

Spec. No. and Grade	Max. 51 mm	Over 51 mm to 76 mm
A203 A	−68	−59
A203 B	−68	−59
A203 D	−101	−87
A203 E	−101	−87

Impact Test Temperature (°F) for Plate Thicknesses Shown

Spec. No. and Grade	Max. 2 in.	Over 2 in. to 3 in.
A203 A	−90	−75
A203 B	−90	−75
A203 D	−150	−125
A203 E	−150	−125

(66) Stress values shown are 90% of those for the corresponding core material.

(67) For use under this Code, the heat treatment requirements for pipe manufactured to A671, A672, and A691 shall be as required by para. 331 for the particular material being used.

(68) The tension test specimen from plate 12.7 mm ($^1/_2$ in.) and thicker is machined from the core and does not include the cladding alloy; therefore, the stress values listed are those for materials less than 12.7 mm.

(69) This material may be used only in nonpressure applications.

(70) Alloy 625 (UNS N06625) in the annealed condition is subject to severe loss of impact strength at room temperature after exposure in the range of 538°C to 760°C (1,000°F to 1,400°F).

(71) These materials are normally microalloyed with Cb, V, and/or Ti. Supplemental specifications agreed to by manufacturer and purchaser commonly establish chemistry more restrictive than the base specification, as well as plate rolling specifications and requirements for weldability (i.e., C-equivalent) and toughness.

(72) For service temperature >454°C (850°F), weld metal shall have a carbon content >0.05%.

(73) Heat treatment is required after welding for all products of zirconium Grade R60705. See Table 331.1.1.

(74) Mechanical properties of fittings made from forging stock shall meet the minimum tensile requirements of one of the bar, forging, or rod specifications listed in Table 2 of B366 for which tensile testing is required.

(75) Stress values shown are for materials in the normalized and tempered condition, or when the heat treatment is unknown. If material is annealed, use the following values above 510°C (950°F):

Temp., °C	**538**	**566**	**593**	**621**	**649**
S, MPa	55.1	39.3	26.2	16.5	9.6

Temp., °F	**1,000**	**1,050**	**1,100**	**1,150**	**1,200**
S, ksi	8.0	5.7	3.8	2.4	1.4

(76) DELETED.

(77) The pipe grades listed below, produced in accordance with CSA (Canadian Standards Association) Z245.1, shall be considered as equivalents to API 5L and treated as listed materials.

Grade Equivalents

API 5L	**CSA Z245.1**
B	241
X42	290
X46	317
X52	359
X56	386
X60	414
X65	448
X70	483
X80	550

(78) Not permitted for the P4 and P5 materials in Table 302.3.5 for Elevated Temperature Fluid Service.

(79) For use under this Code, impact testing shall be performed in accordance with para. 323.3 at the design minimum temperature but not warmer than −29°C (−20°F).

Table A-1 Basic Allowable Stresses in Tension for Metals (20)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

							Specified Min. Strength, ksi		Basic Allowable Stress, *S*, ksi, at Metal Temperature, °F [Notes (1), (4a)]						
Material	Spec. No.	Type/ Grade	UNS No.	Class/ Condition/ Temper	Notes	Min. Temp., °F (6)	Tensile	Yield	Min. Temp. to 100	200	300	400	500	600	650
Iron — Castings															
Gray	A48	20	F11401	...	(8e) (48)	−20	20	...	2.0	2.0	2.0	2.0	...	...	...
Gray	A278	20	F11401	...	(8e) (48)	−20	20	...	2.0	2.0	2.0	2.0	...	...	...
Gray	A126	A	F11501	...	(8e) (9) (48)	−20	21	...	2.0	2.0	2.0	2.0	...	...	...
Gray	A48	25	F11701	...	(8e) (48)	−20	25	...	2.5	2.5	2.5	2.5	...	...	...
Gray	A278	25	F11701	...	(8e) (48)	−20	25	...	2.5	2.5	2.5	2.5	...	...	...
Gray	A48	30	F12101	...	(8e) (48)	−20	30	...	3.0	3.0	3.0	3.0	...	...	...
Gray	A278	30	F12101	...	(8e) (48)	−20	30	...	3.0	3.0	3.0	3.0	...	...	...
Gray	A126	B	F12102	...	(8e) (9) (48)	−20	31	...	3.0	3.0	3.0	3.0	...	...	...
Gray	A48	35	F12401	...	(8e) (48)	−20	35	...	3.5	3.5	3.5	3.5	...	...	...
Gray	A278	35	F12401	...	(8e) (48)	−20	35	...	3.5	3.5	3.5	3.5	...	...	...
Gray	A48	40	F12801	...	(8e) (9) (48)	−20	40	...	4.0	4.0	4.0	4.0	...	...	...
Gray	A126	C	F12802	...	(8e) (9) (48)	−20	41	...	4.0	4.0	4.0	4.0	...	...	...
Gray	A278	40	F12803	...	(8e) (53)	−20	40	...	4.0	4.0	4.0	4.0	4.0	4.0	4.0
Gray	A48	45	F13101	...	(8e) (48)	−20	45	...	4.5	4.5	4.5	4.5	...	...	...
Gray	A48	50	F13501	...	(8e) (48)	−20	50	...	5.0	5.0	5.0	5.0	...	...	...
Gray	A278	50	F13502	...	(8e) (53)	−20	50	...	5.0	5.0	5.0	5.0	5.0	5.0	5.0
Gray	A48	55	F13801	...	(8e) (48)	−20	55	...	5.5	5.5	5.5	5.5	...	...	...
Gray	A48	60	F14101	...	(8e) (48)	−20	60	...	6.0	6.0	6.0	6.0	...	...	...
Gray	A278	60	F14102	...	(8e) (53)	−20	60	...	6.0	6.0	6.0	6.0	6.0	6.0	6.0
Cupola malleable	A197	...	F22000	...	(8e) (9)	−20	40	30	8.0	8.0	8.0	8.0	8.0	8.0	8.0
Malleable	A47	32510	F22200	...	(8e) (9)	−20	50	32.5	10.0	10.0	10.0	10.0	10.0	10.0	10.0
Ferritic ductile	A395	60-40-18	F32800	...	(8d) (9)	−20	60	40	20.0	19.0	17.9	16.9	15.9	14.9	14.1
Austenitic ductile	A571	D-2M	F43010	1	(8d)	−20	65	30	20.0	...	...	...	...	...	...
Ductile	A536	65-45-12	F33100	...	(8d) (9)	−20	65	45	21.7	21.7	21.7	21.7	21.6	...	...

Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

Material	Spec. No.	Type/ Grade	UNS No.	Class/ Condition/ Temper	Size, in.	P-No. (5)	Notes	Min. Temp., °F (6)	Specified Min. Strength, ksi Tensile	Yield	Basic Allowable Stress, S, ksi, at Metal Temperature, °F [Notes (1), (4a)] Min. Temp. to 100	200
Carbon Steel — Pipes and Tubes												
A285 Gr. A	A134	A285A	K01700	...	...	1	(8b) (57)	B	45	24	15.0	14.7
A285 Gr. A	A672	A45	K01700	...	...	1	(57) (59) (67)	B	45	24	15.0	14.7
Butt weld	API 5L	A25	...	...	...	1	(8a) (77)	−20	45	25	15.0	15.0
Smls & ERW	API 5L	A25	...	...	...	1	(57) (59) (77)	B	45	25	15.0	15.0
...	A179	...	K01200	...	...	1	(57) (59)	−20	47	26	15.7	15.7
Type F	A53	A	K02504	...	...	1	(8a)	20	48	30	16.0	16.0
...	A139	A	...	...	...	1	(8b)	A	48	30	16.0	16.0
...	A587	...	K11500	...	...	1	(57) (59)	−20	48	30	16.0	16.0
...	A53	A	K02504	...	...	1	(57) (59)	B	48	30	16.0	16.0
...	A106	A	K02501	...	...	1	(57)	B	48	30	16.0	16.0
...	A135	A	...	...	...	1	(57) (59)	B	48	30	16.0	16.0
...	A369	FPA	K02501	...	...	1	(57)	B	48	30	16.0	16.0
...	API 5L	A	...	...	...	1	(57) (59)	B	48	30	16.0	16.0
A285 Gr. B	A134	A285B	K02200	...	...	1	(8b) (57)	B	50	27	16.7	16.5
A285 Gr. B	A672	A50	K02200	...	...	1	(57) (59) (67)	B	50	27	16.7	16.5
A285 Gr. C	A134	A285C	K02801	...	...	1	(8b) (57)	A	55	30	18.3	18.3
...	A524	II	K02104	...	...	1	(57)	−20	55	30	18.3	18.3
...	A333	1	K03008	...	...	1	(57) (59)	−50	55	30	18.3	18.3
...	A334	1	K03008	...	...	1	(57) (59)	−50	55	30	18.3	18.3
A285 Gr. C	A671	CA55	K02801	...	...	1	(59) (67)	A	55	30	18.3	18.3
A285 Gr. C	A672	A55	K02801	...	...	1	(57) (59) (67)	A	55	30	18.3	18.3
A516 Gr. 55	A672	C55	K01800	...	...	1	(57) (67)	C	55	30	18.3	18.3
A516 Gr. 60	A671	CC60	K02100	...	...	1	(57) (67)	C	60	32	20.0	19.5
A515 Gr. 60	A671	CB60	K02401	...	...	1	(57) (67)	B	60	32	20.0	19.5
A515 Gr. 60	A672	B60	K02401	...	...	1	(57) (67)	B	60	32	20.0	19.5
A516 Gr. 60	A672	C60	K02100	...	...	1	(57) (67)	C	60	32	20.0	19.5
...	A139	B	K03003	...	...	1	(8b)	A	60	35	20.0	20.0
...	A135	B	K03018	...	...	1	(57) (59)	B	60	35	20.0	20.0
...	A524	I	K02104	...	...	1	(57)	−20	60	35	20.0	20.0

Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

Basic Allowable Stress, *S*, ksi, at Metal Temperature, °F [Notes (1), (4a)]															
300	400	500	600	650	700	750	800	850	900	950	1,000	1,050	1,100	Type/ Grade	Spec. No.
														Carbon Steel — Pipes and Tubes	
14.2	13.7	13.0	12.3	11.9	11.5	10.7	9.2	7.9	5.9	...	...	...	...	...	A134
14.2	13.7	13.0	12.3	11.9	11.5	10.7	9.2	7.9	5.9	4.0	2.5	1.6	1.0	A45	A672
14.7	14.2	...	...	...	...	...	...	...	...	...	...	...	...	A25	API 5L
14.7	14.2	...	...	...	...	...	...	...	...	...	...	...	...	A25	API 5L
15.3	14.8	14.1	13.3	12.8	12.4	10.7	9.2	7.9	5.9	4.0	2.5	1.6	1.0	...	A179
16.0	16.0	...	...	...	...	...	...	...	...	...	...	...	...	A	A53
16.0	...	...	...	...	...	...	...	...	...	...	...	...	...	A	A139
16.0	16.0	16.0	15.3	14.6	12.5	10.7	9.2	7.9	...	...	...	...	...	...	A587
16.0	16.0	16.0	15.3	14.6	12.5	10.7	9.2	7.9	5.9	4.0	2.5	1.6	1.0	A	A53
16.0	16.0	16.0	15.3	14.6	12.5	10.7	9.2	7.9	5.9	4.0	2.5	1.6	1.0	A	A106
16.0	16.0	16.0	15.3	14.6	12.5	10.7	9.2	7.9	5.9	4.0	2.5	1.6	1.0	A	A135
16.0	16.0	16.0	15.3	14.6	12.5	10.7	9.2	7.9	5.9	4.0	2.5	1.6	1.0	FPA	A369
16.0	16.0	16.0	15.3	14.6	12.5	10.7	9.2	7.9	5.9	4.0	2.5	1.6	1.0	A	API 5L
15.9	15.4	14.7	13.8	13.3	12.5	10.7	9.2	7.9	5.9	...	...	...	...	...	A134
15.9	15.4	14.7	13.8	13.3	12.5	10.7	9.2	7.9	5.9	4.0	2.5	1.6	1.0	A50	A672
17.7	17.1	16.3	15.3	14.8	14.3	13.0	10.8	8.7	5.9	...	...	...	...	...	A134
17.7	17.1	16.3	15.3	14.8	14.3	13.0	10.8	8.7	5.9	4.0	2.5	...	...	II	A524
17.7	17.1	16.3	15.3	14.8	14.3	13.0	10.8	8.7	5.9	4.0	2.5	1.6	1.0	1	A333
17.7	17.1	16.3	15.3	14.8	14.3	13.0	10.8	8.7	5.9	4.0	2.5	1.6	1.0	1	A334
17.7	17.1	16.3	15.3	14.8	14.3	13.0	10.8	8.7	5.9	4.0	2.5	1.6	1.0	CA55	A671
17.7	17.1	16.3	15.3	14.8	14.3	13.0	10.8	8.7	5.9	4.0	2.5	1.6	1.0	A55	A672
17.7	17.1	16.3	15.3	14.8	14.3	13.0	10.8	8.7	5.9	4.0	2.5	1.6	1.0	C55	A672
18.9	18.2	17.4	16.4	15.8	15.3	13.0	10.8	8.7	5.9	4.0	2.5	...	...	CC60	A671
18.9	18.2	17.4	16.4	15.8	15.3	13.0	10.8	8.7	5.9	4.0	2.5	1.6	1.0	CB60	A671
18.9	18.2	17.4	16.4	15.8	15.3	13.0	10.8	8.7	5.9	4.0	2.5	1.6	1.0	B60	A672
18.9	18.2	17.4	16.4	15.8	15.3	13.0	10.8	8.7	5.9	4.0	2.5	1.6	1.0	C60	A672
20.0	...	...	...	...	...	...	...	...	...	...	...	...	...	B	A139
20.0	19.9	19.0	17.9	17.3	16.7	13.9	11.4	8.7	5.9	4.0	2.5	...	...	B	A135
20.0	19.9	19.0	17.9	17.3	16.7	13.9	11.4	8.7	5.9	4.0	2.5	...	...	I	A524

Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

Material	Spec. No.	Type/ Grade	UNS No.	Class/ Condition/ Temper	Size, in.	P-No. (5)	Notes	Min. Temp., °F (6)	Specified Min. Strength, ksi: Tensile	Specified Min. Strength, ksi: Yield	Basic Allowable Stress, *S*, ksi, at Metal Temperature, °F [Notes (1), (4a)]: Min. Temp. to 100	200
Carbon Steel — Pipes and Tubes												
...	A53	B	K03005	...	...	1	(57) (59)	B	60	35	20.0	20.0
...	A106	B	K03006	...	...	1	(57)	B	60	35	20.0	20.0
...	A333	6	K03006	...	...	1	(57)	−50	60	35	20.0	20.0
...	A334	6	K03006	...	...	1	(57)	−50	60	35	20.0	20.0
...	A369	FPB	K03006	...	...	1	(57)	−20	60	35	20.0	20.0
...	A381	Y35	...	...	...	1	...	A	60	35	20.0	20.0
...	API 5L	B	...	...	...	1	(57) (59) (77)	B	60	35	20.0	20.0
...	A139	C	K03004	...	...	1	(8b)	A	60	42	20.0	20.0
...	A139	D	K03010	...	...	1	(8b)	A	60	46	20.0	20.0
...	API 5L	X42	...	...	...	1	(55) (77)	A	60	42	20.0	20.0
...	A381	Y42	...	...	...	1	...	A	60	42	20.0	20.0
...	A381	Y48	...	...	...	1	...	A	62	48	20.7	20.7
...	API 5L	X46	...	...	...	1	(55) (77)	A	63	46	21.0	21.0
...	A381	Y46	...	...	...	1	...	A	63	46	21.0	21.0
...	A381	Y50	...	...	...	1	...	A	64	50	21.3	21.3
A516 Gr. 65	A671	CC65	K02403	...	...	1	(57) (67)	B	65	35	21.7	21.4
A515 Gr. 65	A671	CB65	K02800	...	...	1	(57) (67)	A	65	35	21.7	21.4
A515 Gr. 65	A672	B65	K02800	...	...	1	(57) (67)	A	65	35	21.7	21.4
A516 Gr. 65	A672	C65	K02403	...	...	1	(57) (67)	B	65	35	21.7	21.4
...	A139	E	K03012	...	...	1	(8b)	A	66	52	22.0	22.0
...	API 5L	X52	...	...	...	1	(55) (77)	A	66	52	22.0	22.0
...	A381	Y52	...	...	...	1	...	A	66	52	22.0	22.0
A516 Gr. 70	A671	CC70	K02700	...	...	1	(57) (67)	B	70	38	23.3	23.2
A515 Gr. 70	A671	CB70	K03101	...	...	1	(57) (67)	A	70	38	23.3	23.2
A515 Gr. 70	A672	B70	K03101	...	...	1	(57) (67)	A	70	38	23.3	23.2
A516 Gr. 70	A672	C70	K02700	...	...	1	(57) (67)	B	70	38	23.3	23.2
...	A106	C	K03501	...	...	1	(57)	B	70	40	23.3	23.3
A537 Cl. 1	A671	CD70	K12437	...	≤2$\frac{1}{2}$ thk.	1	(67)	D	70	50	23.3	23.3
A537 Cl. 1	A672	D70	K12437	...	≤2$\frac{1}{2}$ thk.	1	(67)	D	70	50	23.3	23.3
A537 Cl. 1	A691	CMSH-70	K12437	...	≤2$\frac{1}{2}$ thk.	1	(67)	D	70	50	23.3	23.3
...	API 5L	X56	...	...	...	1	(51) (55) (71) (77)	A	71	56	23.7	23.7
...	A381	Y56	...	...	...	1	(51) (55) (71)	A	71	56	23.7	23.7

Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

Basic Allowable Stress, *S*, ksi, at Metal Temperature, °F [Notes (1), (4a)]															
300	400	500	600	650	700	750	800	850	900	950	1,000	1,050	1,100	Type/ Grade	Spec. No.
Carbon Steel — Pipes and Tubes (Cont'd)															
20.0	19.9	19.0	17.9	17.3	16.7	13.9	11.4	8.7	5.9	4.0	2.5	1.6	1.0	B	A53
20.0	19.9	19.0	17.9	17.3	16.7	13.9	11.4	8.7	5.9	4.0	2.5	1.6	1.0	B	A106
20.0	19.9	19.0	17.9	17.3	16.7	13.9	11.4	8.7	5.9	4.0	2.5	1.6	1.0	6	A333
20.0	19.9	19.0	17.9	17.3	16.7	13.9	11.4	8.7	5.9	4.0	2.5	1.6	1.0	6	A334
20.0	19.9	19.0	17.9	17.3	16.7	13.9	11.4	8.7	5.9	4.0	2.5	1.6	1.0	FPB	A369
20.0	19.9	19.0	17.9	17.3	16.7	13.9	11.4	8.7	5.9	4.0	2.5	1.6	1.0	Y35	A381
20.0	19.9	19.0	17.9	17.3	16.7	13.9	11.4	8.7	5.9	4.0	2.5	1.6	1.0	B	API 5L
20.0	...	...	...	...	...	...	...	...	...	...	...	...	...	C	A139
20.0	...	...	...	...	...	...	...	...	...	...	...	...	...	D	A139
20.0	20.0	...	...	...	...	...	...	...	...	...	...	...	...	X42	API 5L
20.0	20.0	...	...	...	...	...	...	...	......	...	...	...	...	Y42	A381
20.7	20.7	20.7	20.7	18.7	...	...	...	...	...	...	...	...	...	Y48	A381
21.0	21.0	...	...	...	...	...	...	...	...	...	...	...	...	X46	API 5L
21.0	21.0	...	...	...	...	...	...	...	...	...	...	...	...	Y46	A381
21.3	21.3	21.3	21.3	18.7	...	...	...	...	...	...	...	...	...	Y50	A381
20.6	19.9	19.0	17.9	17.3	16.7	13.9	11.4	8.7	5.9	4.0	2.5	...	...	CC65	A671
20.6	19.9	19.0	17.9	17.3	16.7	13.9	11.4	8.7	5.9	4.0	2.5	1.6	1.0	CB65	A671
20.6	19.9	19.0	17.9	17.3	16.7	13.9	11.4	8.7	5.9	4.0	2.5	1.6	1.0	B65	A672
20.6	19.9	19.0	17.9	17.3	16.7	13.9	11.4	8.7	5.9	4.0	2.5	1.6	1.0	C65	A672
22.0	...	...	...	...	...	...	...	...	...	...	...	...	...	E	A139
22.0	22.0	...	...	...	...	...	...	...	...	...	...	...	...	X52	API 5L
22.0	22.0	...	...	...	...	...	...	...	...	...	...	...	...	Y52	A381
22.4	21.6	20.6	19.4	18.8	18.1	14.8	12.0	9.3	6.7	4.0	2.5	...	...	CC70	A671
22.4	21.6	20.6	19.4	18.8	18.1	14.8	12.0	9.3	6.7	4.0	2.5	1.6	1.0	CB70	A671
22.4	21.6	20.6	19.4	18.8	18.1	14.8	12.0	9.3	6.7	4.0	2.5	1.6	1.0	B70	A672
22.4	21.6	20.6	19.4	18.8	18.1	14.8	12.0	9.3	6.7	4.0	2.5	1.6	1.0	C70	A672
23.3	22.8	21.7	20.4	19.8	18.3	14.8	12.0	...	...	...	...	...	...	C	A106
22.8	22.7	22.7	22.4	21.9	18.3	...	...	...	...	...	...	...	...	CD70	A671
22.8	22.7	22.7	22.4	21.9	18.3	...	...	...	...	...	...	...	...	D70	A672
22.8	22.7	22.7	22.4	21.9	18.3	...	...	...	...	...	...	...	...	CMSH-70	A691
23.7	23.7	...	...	...	...	...	...	...	...	...	...	...	...	X56	API 5L
23.7	23.7	...	...	...	...	...	...	...	...	...	...	...	...	Y56	A381

Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

Material	Spec. No.	Type/ Grade	UNS No.	Class/ Condition/ Temper	Size, in.	P-No. (5)	Notes	Min. Temp., °F (6)	Specified Min. Strength, ksi: Tensile	Specified Min. Strength, ksi: Yield	Basic Allowable Stress, S, ksi, at Metal Temperature, °F [Notes (1), (4a)]: Min. Temp. to 100	200
Carbon Steel — Pipes and Tubes												
A299 Gr. A	A671	CK75	K02803	...	>1 thk.	1	(57) (67)	A	75	40	25.0	24.4
A299 Gr. A	A672	N75	K02803	...	>1 thk.	1	(57) (67)	A	75	40	25.0	24.4
A299 Gr. A	A691	CMS-75	K02803	...	>1 thk.	1	(57) (67)	A	75	40	25.0	24.4
A299 Gr. A	A671	CK75	K02803	...	≤1 thk.	1	(57) (67)	A	75	42	25.0	25.0
A299 Gr. A	A672	N75	K02803	...	≤1 thk.	1	(57) (67)	A	75	42	25.0	25.0
A299 Gr. A	A691	CMS-75	K02803	...	≤1 thk.	1	(57) (67)	A	75	42	25.0	25.0
...	API 5L	X60	...	...	...	1	(51) (55) (71) (77)	A	75	60	25.0	25.0
...	API 5L	X65	...	...	...	1	(51) (55) (71) (77)	A	77	65	25.7	25.7
...	API 5L	X70	...	...	...	1	(51) (55) (71) (77)	A	82	70	27.3	27.3
...	API 5L	X80	...	...	...	1	(51) (55) (71) (77)	A	90	80	30.0	30.0
...	A381	Y60	...	...	...	1	(51) (71)	A	75	60	25.0	25.0
Carbon Steel — Pipes (Structural Grade)												
A1011 Gr. 30	A134	A1011SS30	K02502	...	...	1	(8a) (8c)	−20	49	30	15.0	15.0
A1011 Gr. 33	A134	A1011SS33	K02502	...	...	1	(8a) (8c)	−20	52	33	15.9	15.9
A1011 Gr. 36	A134	A1011SS36-T1	K02502	...	...	1	(8a) (8c)	−20	53	36	16.3	16.3
A1011 Gr. 40	A134	A1011SS40	K02502	...	...	1	(8a) (8c)	−20	55	40	16.9	16.9
A36	A134	A36	K02600	...	...	1	(8a) (8c)	−20	58	36	17.8	17.8
A283 Gr. D	A134	A283D	K02702	...	...	1	(8a) (8c)	−20	60	33	18.4	18.4
A1011 Gr. 45	A134	A1011SS45	K02507	...	...	1	(8a) (8c)	−20	60	45	18.4	18.4
A1011 Gr. 50	A134	A1011SS50	K02507	...	...	1	(8a) (8c)	−20	65	50	19.9	19.9
Carbon Steel — Plates, Bars, Shapes, and Sheets												
...	A285	A	K01700	...	...	1	(57) (59)	B	45	24	15.0	14.7
...	A285	B	K02200	...	...	1	(57) (59)	B	50	27	16.7	16.5
...	A516	55	K01800	...	...	1	(57)	C	55	30	18.3	18.3
...	A285	C	K02801	...	...	1	(57) (59)	A	55	30	18.3	18.3

Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

Basic Allowable Stress, *S*, ksi, at Metal Temperature, °F [Notes (1), (4a)]															
300	400	500	600	650	700	750	800	850	900	950	1,000	1,050	1,100	Type/ Grade	Spec. No.
														Carbon Steel — Pipes and Tubes (Cont'd)	
23.6	22.8	21.7	20.4	19.8	19.1	15.7	12.6	9.3	6.7	4.0	2.5	1.6	1.0	CK75	A671
23.6	22.8	21.7	20.4	19.8	19.1	15.7	12.6	9.3	6.7	4.0	2.5	1.6	1.0	N75	A672
23.6	22.8	21.7	20.4	19.8	19.1	15.7	12.6	9.3	6.7	4.0	2.5	1.6	1.0	CMS-75	A691
24.8	23.9	22.8	21.5	20.8	19.6	...	...	...	...	...	...	...	...	CK75	A671
24.8	23.9	22.8	21.5	20.8	19.6	...	...	...	...	...	...	...	...	N75	A672
24.8	23.9	22.8	21.5	20.8	19.6	...	...	...	...	...	...	...	...	CMS-75	A691
25.0	25.0	...	...	...	...	...	...	...	...	...	...	...	...	X60	API 5L
25.7	25.7	...	...	...	...	...	...	...	...	...	...	...	...	X65	API 5L
27.3	27.3	...	...	...	...	...	...	...	...	...	...	...	...	X70	API 5L
30.0	30.0	...	...	...	...	...	...	...	...	...	...	...	...	X80	API 5L
25.0	25.0	...	...	...	...	...	...	...	...	...	...	...	...	Y60	A381
														Carbon Steel — Pipes (Structural Grade)	
15.0	15.0	...	...	...	...	...	...	...	...	...	...	...	...	A1011SS30	A134
15.9	15.9	...	...	...	...	...	...	...	...	...	...	...	...	A1011SS33	A134
16.3	16.3	...	...	...	...	...	...	...	...	...	...	...	...	A1011SS36-T1	A134
16.9	16.9	...	...	...	...	...	...	...	...	...	...	...	...	A1011SS40	A134
17.8	17.8	...	...	...	...	...	...	...	...	...	...	...	...	A36	A134
17.9	...	...	...	...	...	...	...	...	...	...	...	...	...	A283D	A134
18.4	18.4	...	...	...	...	...	...	...	...	...	...	...	...	A1011SS45	A134
19.9	19.9	...	...	...	...	...	...	...	...	...	...	...	...	1011SS50	A134
														Carbon Steel — Plates, Bars, Shapes, and Sheets	
14.2	13.7	13.0	12.3	11.9	11.5	10.7	9.2	7.9	5.9	4.0	2.5	1.6	1.0	A	A285
15.9	15.4	14.7	13.8	13.3	12.5	10.7	9.2	7.9	5.9	4.0	2.5	1.6	1.0	B	A285
17.7	17.1	16.3	15.3	14.8	14.3	13.0	10.8	8.7	5.9	4.0	2.5	...	...	55	A516
17.7	17.1	16.3	15.3	14.8	14.3	13.0	10.8	8.7	5.9	4.0	2.5	1.6	1.0	C	A285

Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

Material	Spec. No.	Type/ Grade	UNS No.	Class/ Condition/ Temper	Size, in.	P-No. (5)	Notes	Min. Temp., °F (6)	Specified Min. Strength, ksi: Tensile	Specified Min. Strength, ksi: Yield	Basic Allowable Stress, S, ksi, at Metal Temperature, °F [Notes (1), (4a)]: Min. Temp. to 100	200
Carbon Steel — Plates, Bars, Shapes, and Sheets												
...	A516	60	K02100	...	...	1	(57)	C	60	32	20.0	19.5
...	A515	60	K02401	...	...	1	(57)	B	60	32	20.0	19.5
...	A696	B	K03200	...	...	1	(57)	A	60	35	20.0	20.0
...	A516	65	K02403	...	...	1	(57)	B	65	35	21.7	21.4
...	A515	65	K02800	...	...	1	(57)	A	65	35	21.7	21.4
...	A516	70	K02700	...	...	1	(57)	B	70	38	23.3	23.2
...	A515	70	K03101	...	...	1	(57)	A	70	38	23.3	23.2
...	A696	C	K03200	...	...	1	(57)	A	70	40	23.3	23.3
...	A537	...	K12437	1	≤2$\frac{1}{2}$ thk.	1	...	D	70	50	23.3	23.3
...	A299	A	K02803	...	>1 thk.	1	(57)	A	75	40	25.0	24.4
...	A299	A	K02803	...	≤1 thk.	1	(57)	A	75	42	25.0	25.0
Carbon Steel — Plates, Bars, Shapes, and Sheets (Structural)												
...	A1011	SS30	K02502	...	...	1	(8c) (57)	A	49	30	15.0	15.0
...	A1011	SS33	K02502	...	...	1	(8c) (57)	A	52	33	15.9	15.9
...	A1011	SS36-T1	K02502	...	...	1	(8c) (57)	A	53	36	16.3	16.3
...	A283	C	K02401	...	...	1	(8c) (57)	A	55	30	16.8	16.8
...	A1011	SS40	K02502	...	...	1	(8c) (57)	A	55	40	16.8	16.8
...	A36	...	K02600	...	...	1	(8c)	A	58	36	17.8	17.8
...	A283	D	K02702	...	...	1	(8c) (57)	A	60	33	18.4	18.4
...	A1011	SS45	K02507	...	...	1	(8c) (57)	A	60	45	18.4	18.4
...	A1011	SS50	K02507	...	...	1	(8c) (57)	A	65	50	19.9	19.9
...	A992	...	...	...	...	1	(8c) (57)	A	65	50	19.9	19.9
Carbon Steel — Forgings and Fittings												
...	A350	LF1	K03009	...	...	1	(9) (57) (59)	−20	60	30	20.0	18.3
...	A181	...	K03502	60	...	1	(9) (57) (59)	A	60	30	20.0	18.3
...	A420	WPL6	K03006	...	...	1	(57)	−50	60	35	20.0	20.0
...	A234	WPB	K03006	...	...	1	(57) (59)	B	60	35	20.0	20.0
...	A694	F42	K03014	...	...	1	(9)	−20	60	42	20.0	20.0

Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

Basic Allowable Stress, *S*, ksi, at Metal Temperature, °F [Notes (1), (4a)]															
300	400	500	600	650	700	750	800	850	900	950	1,000	1,050	1,100	Type/ Grade	Spec. No.
														Carbon Steel — Plates, Bars, Shapes, and Sheets (Cont'd)	
18.9	18.2	17.4	16.4	15.8	15.3	13.0	10.8	8.7	5.9	4.0	2.5	...	...	60	A516
18.9	18.2	17.4	16.4	15.8	15.3	13.0	10.8	8.7	5.9	4.0	2.5	...	...	60	A515
20.0	19.9	19.0	17.9	17.3	15.6	...	...	...	...	...	...	...	...	B	A696
20.6	19.9	19.0	17.9	17.3	16.7	13.9	11.4	8.7	5.9	4.0	2.5	...	...	65	A516
20.6	19.9	19.0	17.9	17.3	16.7	13.9	11.4	8.7	5.9	4.0	2.5	...	...	65	A515
22.4	21.6	20.6	19.4	18.8	18.1	14.8	12.0	9.3	6.7	4.0	2.5	...	...	70	A516
22.4	21.6	20.6	19.4	18.8	18.1	14.8	12.0	9.3	6.7	4.0	2.5	...	...	70	A515
23.3	22.8	21.7	20.5	19.7	18.3	...	...	...	...	...	...	...	...	C	A696
22.8	22.7	22.7	22.4	21.9	18.3	...	...	...	...	...	...	...	...	Cl. 1	A537
23.6	22.8	21.7	20.4	19.8	19.1	15.7	12.6	9.3	6.7	4.0	2.5	1.6	1.0	A	A299
24.8	23.9	22.8	21.5	20.8	19.6	15.7	12.6	9.3	6.7	4.0	2.5	1.6	1.0	A	A299
														Carbon Steel — Plates, Bars, Shapes, and Sheets (Structural)	
15.0	15.0	15.0	14.1	13.4	11.5	9.8	...	...	...	...	...	...	...	30	A1011
15.9	15.9	15.9	15.5	13.4	11.5	9.8	...	...	...	...	...	...	...	33	A1011
16.3	16.3	16.3	16.3	13.4	11.5	9.8	...	...	...	...	...	...	...	36	A1011
16.3	15.7	15.0	14.1	13.6	13.2	12.0	...	...	...	...	...	...	...	C	A283
16.8	16.8	16.8	16.8	16.8	14.4	12.0	...	...	...	...	...	...	...	40	A1011
17.8	17.8	17.8	16.9	16.4	14.4	...	...	...	...	...	...	...	...	...	A36
17.9	17.3	16.5	15.5	15.0	14.5	12.8	...	...	...	...	...	...	...	D	A283
18.4	18.4	18.4	18.4	18.4	15.5	12.8	...	...	...	...	...	...	...	45	A1011
19.9	19.9	19.9	19.9	18.9	15.5	12.8	...	...	...	...	...	...	...	50	A1011
19.9	19.9	19.9	19.9	18.9	15.5	12.8	10.5	...	...	...	...	...	...	...	A992
														Carbon Steel — Forgings and Fittings	
17.7	17.1	16.3	15.3	14.8	14.3	13.8	11.4	8.7	5.9	4.0	2.5	...	...	LF1	A350
17.7	17.1	16.3	15.3	14.8	14.3	13.8	11.4	8.7	5.9	4.0	2.5	1.6	1.0	Cl. 60	A181
20.0	19.9	19.0	17.9	17.3	16.7	13.9	11.4	8.7	5.9	4.0	2.5	...	...	WPL6	A420
20.0	19.9	19.0	17.9	17.3	16.7	13.9	11.4	8.7	5.9	4.0	2.5	1.6	1.0	WPB	A234
20.0	20.0	19.7	...	...	...	...	...	...	...	...	...	...	...	F42	A694

Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

Material	Spec. No.	Type/ Grade	UNS No.	Class/ Condition/ Temper	Size, in.	P-No. (5)	Notes	Min. Temp., °F (6)	Specified Min. Strength, ksi: Tensile	Yield	Basic Allowable Stress, S, ksi, at Metal Temperature, °F [Notes (1), (4a)]: Min. Temp. to 100	200
Carbon Steel — Forgings and Fittings												
...	A707	L1	K02302	1	...	1	(9)	−20	60	42	20.0	20.0
...	A707	L2	K03301	1	...	1	(9)	−50	60	42	20.0	20.0
...	A707	L3	K12510	1	...	1	(9)	−50	60	42	20.0	20.0
...	A860	WPHY 42	...	...	...	1	...	−50	60	42	20.0	20.0
...	A694	F46	K03014	...	...	1	(9)	−20	63	46	21.0	21.0
...	A860	WPHY 46	...	...	...	1	...	−50	63	46	21.0	21.0
...	A694	F52	K03014	...	...	1	(9)	−20	66	52	22.0	22.0
...	A707	L1	K02302	2	...	1	(9)	−20	66	52	22.0	22.0
...	A707	L2	K03301	2	...	1	(9)	−50	66	52	22.0	22.0
...	A707	L3	K12510	2	...	1	(9)	−50	66	52	22.0	22.0
...	A860	WPHY 52	...	...	...	1	...	−50	66	52	22.0	22.0
...	A350	LF2	K03011	1	...	1	(9) (57)	−50	70	36	23.3	22.0
...	A350	LF2	K03011	2	...	1	(9) (57)	0	70	36	23.3	22.0
...	A105	...	K03504	...	...	1	(9) (57) (59)	−20	70	36	23.3	22.0
...	A181	...	K03502	70	...	1	(9) (57) (59)	A	70	36	23.3	22.0
...	A234	WPC	K03501	...	...	1	(57) (59)	B	70	40	23.3	23.3
...	A694	F56	K03014	...	...	1	(9)	−20	71	56	23.7	23.7
...	A694	F60	K03014	...	...	1	(9)	−20	75	60	25.0	25.0
...	A707	L2	K03301	3	...	1	(9)	−50	75	60	25.0	25.0
...	A707	L3	K12510	3	...	1	(9)	−50	75	60	25.0	25.0
...	A860	WPHY 60	...	...	...	1	...	−50	75	60	25.0	25.0
...	A694	F65	K03014	...	...	1	(9)	−20	77	65	25.7	25.7
...	A860	WPHY 65	...	...	...	1	...	−50	77	65	25.7	25.7
...	A694	F70	K03014	...	...	1	(9) (79)	...	82	70	27.3	27.3
...	A860	WPHY 70	...	...	...	1	...	−50	82	70	27.3	27.3
Carbon Steel — Castings												
...	A216	WCA	J02502	...	...	1	(57)	−20	60	30	20.0	18.3
...	A352	LCB	J03003	...	...	1	(9) (57)	−50	65	35	21.7	21.4
...	A352	LCC	J02505	...	...	1	(9)	−50	70	40	23.3	23.3
...	A216	WCB	J03002	...	...	1	(9) (57)	−20	70	36	23.3	22.0
...	A216	WCC	J02503	...	...	1	(9) (57)	−20	70	40	23.3	23.3

Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

Basic Allowable Stress, *S*, ksi, at Metal Temperature, °F [Notes (1), (4a)]															
300	400	500	600	650	700	750	800	850	900	950	1,000	1,050	1,100	Type/ Grade	Spec. No.
														Carbon Steel — Forgings and Fittings (Cont'd)	
20.0	20.0	19.7	...	...	...	...	...	...	...	...	...	...	...	L1	A707
20.0	20.0	19.7	...	...	...	...	...	...	...	...	...	...	...	L2	A707
20.0	20.0	19.7	...	...	...	...	...	...	...	...	...	...	...	L3	A707
20.0	20.0	19.7	...	...	...	...	...	...	...	...	...	...	...	WPHY 42	A860
21.0	21.0	21.0	...	...	...	...	...	...	...	...	...	...	...	F46	A694
21.0	21.0	21.0	...	...	...	...	...	...	...	...	...	...	...	WPHY 46	A860
22.0	22.0	22.0	...	...	...	...	...	...	...	...	...	...	...	F52	A694
22.0	22.0	22.0	...	...	...	...	...	...	...	...	...	...	...	L1	A707
22.0	22.0	22.0	...	...	...	...	...	...	...	...	...	...	...	L2	A707
22.0	22.0	22.0	...	...	...	...	...	...	...	...	...	...	...	L3	A707
22.0	22.0	22.0	...	...	...	...	...	...	...	...	...	...	...	WPHY 52	A860
21.2	20.5	19.6	18.4	17.8	17.2	14.8	12.0	9.3	6.7	4.0	2.5	...	...	LF2 Cl. 1	A350
21.2	20.5	19.6	18.4	17.8	17.2	14.8	12.0	9.3	6.7	4.0	2.5	...	...	LF2 Cl. 2	A350
21.2	20.5	19.6	18.4	17.8	17.2	14.8	12.0	9.3	6.7	4.0	2.5	1.6	1.0	...	A105
21.2	20.5	19.6	18.4	17.8	17.2	14.8	12.0	9.3	6.7	4.0	2.5	1.6	1.0	Cl. 70	A181
23.3	22.8	21.7	20.4	19.8	18.3	14.8	12.0	...	...	...	...	...	...	WPC	A234
23.7	23.7	23.7	...	...	...	...	...	...	...	...	...	...	...	F56	A694
25.0	25.0	25.0	...	...	...	...	...	...	...	...	...	...	...	F60	A694
25.0	25.0	25.0	...	...	...	...	...	...	...	...	...	...	...	L2	A707
25.0	25.0	25.0	...	...	...	...	...	...	...	...	...	...	...	L3	A707
25.0	25.0	25.0	...	...	...	...	...	...	...	...	...	...	...	WPHY 60	A860
25.7	25.7	25.7	...	...	...	...	...	...	...	...	...	...	...	F65	A694
25.7	25.7	25.7	...	...	...	...	...	...	...	...	...	...	...	WPHY 65	A860
27.3	27.3	...	...	...	...	...	...	...	...	...	...	...	...	F70	A694
27.3	27.3	...	...	...	...	...	...	...	...	...	...	...	...	WPHY 70	A860
														Carbon Steel — Castings	
17.7	17.1	16.3	15.3	14.8	14.3	13.8	11.4	8.7	5.9	4.0	2.5	1.6	1.0	WCA	A216
20.6	19.9	19.0	17.9	17.3	16.7	13.9	11.4	9.0	6.3	4.0	2.5	1.6	1.0	LCB	A352
23.3	22.8	21.7	20.4	19.8	19.2	...	...	...	...	...	...	...	...	LCC	A352
21.2	20.5	19.6	18.4	17.8	17.2	14.8	12.0	9.3	6.7	4.0	2.5	1.6	1.0	WCB	A216
23.3	22.8	21.7	20.4	19.8	18.3	14.8	12.0	9.3	6.7	4.0	2.5	...	...	WCC	A216

Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

Nominal Composition	Spec. No.	Type/ Grade	UNS No.	Class/ Condition/ Temper	Size, in.	P-No. (5)	Notes	Min. Temp., °F (6)	Specified Min. Strength, ksi: Tensile	Specified Min. Strength, ksi: Yield	Basic Allowable Stress, S, ksi, at Metal Temperature, °F [Notes (1), (4a)]: Min. Temp. to 100	200
Low and Intermediate Alloy Steel — Pipes												
½Cr–½Mo	A335	P2	K11547	...	...	3	...	−20	55	30	18.3	18.3
½Cr–½Mo A387 Gr. 2 Cl. 1	A691	½CR	K12143	...	...	3	(11) (67)	−20	55	33	18.3	18.3
C–½Mo	A335	P1	K11522	...	...	3	(58)	−20	55	30	18.3	18.3
C–½Mo	A369	FP1	K11522	...	...	3	(58)	−20	55	30	18.3	18.3
½Cr–½Mo	A369	FP2	K11547	...	...	3	...	−20	55	30	18.3	18.3
1Cr–½Mo A387 Gr. 12 Cl. 1	A691	1CR	K11757	...	...	4	(11) (67)	−20	55	33	18.3	18.3
½Cr–½Mo	A426	CP2	J11547	...	...	3	(10)	−20	60	30	20.0	18.8
1½Si–½Mo	A335	P15	K11578	...	...	3	...	−20	60	30	20.0	18.8
C–½Mo–Si	A426	CP15	J11522	...	...	3	(10)	−20	60	30	20.0	18.8
1Cr–½Mo	A426	CP12	J11562	...	...	4	(10)	−20	60	30	20.0	18.1
5Cr–1½Si–½Mo	A426	CP5b	J51545	...	...	5B	(10)	−20	60	30	20.0	18.1
3Cr–Mo	A426	CP21	J31545	...	...	5A	(10)	−20	60	30	20.0	18.7
¾Cr–¾Ni–Cu–Al	A333	4	K11267	...	...	4	...	−150	60	35	20.0	19.1
2Cr–½Mo	A369	FP3b	K21509	...	...	4	...	−20	60	30	20.0	18.7
1Cr–½Mo	A335	P12	K11562	...	...	4	...	−20	60	32	20.0	19.3
1Cr–½Mo	A369	FP12	K11562	...	...	4	...	−20	60	32	20.0	19.3
1¼Cr–½Mo–Si	A335	P11	K11597	...	...	4	...	−20	60	30	20.0	18.5
1¼Cr–½Mo–Si	A369	FP11	K11597	...	...	4	...	−20	60	30	20.0	18.5
1¼Cr–½Mo–Si A387 Gr. 11 Cl. 1	A691	1¼CR	K11789	...	...	4	(11) (67)	−20	60	35	20.0	20.0
5Cr–½Mo A387 Gr. 5 Cl. 1	A691	5CR	K41545	...	...	5B	(11) (67)	−20	60	30	20.0	18.1
5Cr–½Mo	A335	P5	K41545	...	...	5B	...	−20	60	30	20.0	18.1
5Cr–½Mo–Si	A335	P5b	K51545	...	...	5B	...	−20	60	30	20.0	18.1
5Cr–½Mo–Ti	A335	P5c	K41245	...	...	5B	...	−20	60	30	20.0	18.1
5Cr–½Mo	A369	FP5	K41545	...	...	5B	...	−20	60	30	20.0	18.1
9Cr–1Mo	A335	P9	K90941	...	...	5B	...	−20	60	30	20.0	18.1
9Cr–1Mo	A369	FP9	K90941	...	...	5B	...	−20	60	30	20.0	18.1
9Cr–1Mo A387 Gr. 9 Cl. 1	A691	9CR	K90941	...	...	5B	(11) (67)	−20	60	30	20.0	18.1

Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

Basic Allowable Stress, *S*, ksi, at Metal Temperature, °F [Notes (1), (4a)]																	
300	400	500	600	650	700	750	800	850	900	950	1,000	1,050	1,100	1,150	1,200	Type/ Grade	Spec. No.
												Low and Intermediate Alloy Steel — Pipes					
18.0	17.4	16.9	16.4	16.1	15.7	15.4	14.9	14.5	13.9	9.2	5.9	...	...	...	...	P2	A335
18.3	18.3	18.3	18.0	17.7	17.3	16.9	16.4	15.9	14.3	9.2	5.9	...	...	...	...	½CR	A691
18.0	17.4	16.9	16.4	16.1	15.7	15.4	14.9	14.5	13.7	8.2	4.8	4.0	2.4	...	...	P1	A335
18.0	17.4	16.9	16.4	16.1	15.7	15.4	14.9	14.5	13.7	8.2	4.8	4.0	2.4	...	...	FP1	A369
18.0	17.4	16.9	16.4	16.1	15.7	15.4	14.9	14.5	13.9	9.2	5.9	4.1	2.5	...	...	FP2	A369
17.6	17.6	17.2	16.8	16.5	16.3	16.0	15.7	15.4	15.0	11.3	7.2	4.5	2.8	1.8	1.1	1CR	A691
18.0	17.4	16.9	16.4	16.1	15.7	15.4	14.9	14.5	13.9	9.2	5.9	4.0	2.4	...	...	CP2	A426
18.2	17.7	17.3	16.8	16.6	16.3	15.9	15.4	13.8	12.5	10.0	6.3	4.0	2.4	...	...	P15	A335
18.2	17.7	17.3	16.8	16.6	16.3	15.9	15.4	13.8	12.5	10.0	6.3	4.0	2.4	...	...	CP15	A426
17.0	16.2	15.7	15.2	15.0	14.8	14.6	14.3	14.0	13.6	11.3	7.2	4.5	2.8	1.8	1.1	CP12	A426
17.4	17.2	17.1	16.8	16.6	16.3	15.9	15.4	14.3	10.9	8.0	5.8	4.2	2.9	1.8	1.0	CP5b	A426
18.2	18.0	17.9	17.9	17.9	17.9	17.9	17.7	16.0	12.0	9.0	7.0	5.5	4.0	2.7	1.5	CP21	A426
18.2	17.3	16.4	15.5	15.0	...	...	...	...	...	...	...	...	...	...	...	4	A333
18.2	18.0	17.9	17.9	17.9	17.9	17.9	17.7	17.5	12.5	10.0	6.2	4.2	2.6	1.4	1.0	FP3b	A369
18.1	17.3	16.7	16.3	16.0	15.8	15.5	15.3	14.9	14.5	11.3	7.2	4.5	2.8	1.8	1.1	P12	A335
18.1	17.3	16.7	16.3	16.0	15.8	15.5	15.3	14.9	14.5	11.3	7.2	4.5	2.8	1.8	1.1	FP12	A369
17.6	16.8	16.2	15.7	15.4	15.1	14.8	14.4	14.0	13.6	9.3	6.3	4.2	2.8	1.9	1.2	P11	A335
17.6	16.8	16.2	15.7	15.4	15.1	14.8	14.4	14.0	13.6	9.3	6.3	4.2	2.8	1.9	1.2	FP11	A369
20.0	19.6	18.9	18.3	18.0	17.6	17.2	16.8	16.4	13.7	9.3	6.3	4.2	2.8	1.9	1.2	1¼CR	A691
17.4	17.2	17.1	16.8	16.6	16.3	15.9	15.4	14.3	10.9	8.0	5.8	4.2	2.9	1.8	1.0	5CR	A691
17.4	17.2	17.1	16.8	16.6	16.3	15.9	15.4	14.3	10.9	8.0	5.8	4.2	2.9	1.8	1.0	P5	A335
17.4	17.2	17.1	16.8	16.6	16.3	15.9	15.4	14.3	10.9	8.0	5.8	4.2	2.9	1.8	1.0	P5b	A335
17.4	17.2	17.1	16.8	16.6	16.3	15.9	15.4	14.3	10.9	8.0	5.8	4.2	2.9	1.8	1.0	P5c	A335
17.4	17.2	17.1	16.8	16.6	16.3	15.9	15.4	14.3	10.9	8.0	5.8	4.2	2.9	1.8	1.0	FP5	A369
17.4	17.2	17.1	16.8	16.6	16.3	15.9	15.4	14.8	14.1	10.6	7.4	5.0	3.3	2.2	1.5	P9	A335
17.4	17.2	17.1	16.8	16.6	16.3	15.9	15.4	14.8	14.1	10.6	7.4	5.0	3.3	2.2	1.5	FP9	A369
17.4	17.2	17.1	16.8	16.6	16.3	15.9	15.4	14.8	14.1	10.6	7.4	5.0	3.3	2.2	1.5	9CR	A691

Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

Nominal Composition	Spec. No.	Type/ Grade	UNS No.	Class/ Condition/ Temper	Size, in.	P-No. (5)	Notes	Min. Temp., °F (6)	Specified Min. Strength, ksi: Tensile	Specified Min. Strength, ksi: Yield	Basic Allowable Stress, *S*, ksi, at Metal Temperature, °F [Notes (1), (4a)]: Min. Temp. to 100	200
Low and Intermediate Alloy Steel — Pipes												
3Cr–1Mo	A335	P21	K31545	...	...	5A	...	−20	60	30	20.0	18.7
3Cr–1Mo	A369	FP21	K31545	...	...	5A	...	−20	60	30	20.0	18.7
3Cr–1Mo A387 Gr. 21 Cl. 1	A691	3CR	K31545	...	...	5A	(11) (67)	−20	60	30	20.0	18.5
2¼Cr–1Mo A387 Gr. 22 Cl. 1	A691	2¼CR	K21590	...	...	5A	(11) (67) (72) (75)	−20	60	30	20.0	18.7
2¼Cr–1Mo	A369	FP22	K21590	...	...	5A	(72) (75)	−20	60	30	20.0	18.7
2¼Cr–1Mo	A335	P22	K21590	...	...	5A	(72) (75)	−20	60	30	20.0	18.7
2Ni–1Cu	A333	9	K22035	...	...	9A	...	−100	63	46	21.0	...
2Ni–1Cu	A334	9	K22035	...	...	9A	...	−100	63	46	21.0	...
2¼Ni	A333	7	K21903	...	...	9A	...	−100	65	35	21.7	21.4
2¼Ni	A334	7	K21903	...	...	9A	...	−100	65	35	21.7	21.4
3½Ni	A333	3	K31918	...	...	9B	...	−150	65	35	21.7	21.4
3½Ni	A334	3	K31918	...	...	9B	...	−150	65	35	21.7	21.4
C–½Mo	A426	CP1	J12521	...	...	3	(10) (58)	−20	65	35	21.7	21.7
C–½Mo A204 Gr. A	A672	L65	K11820	...	...	3	(11) (58) (67)	−20	65	37	21.7	21.7
C–½Mo A204 Gr. A	A691	CM-65	K11820	...	...	3	(11) (58) (67)	−20	65	37	21.7	21.7
2¼Ni A203 Gr. B	A671	CFB70	K22103	...	...	9A	(11) (65) (67)	−20	70	40	23.3	...
3½Ni A203 Gr. E	A671	CFE70	K32018	...	...	9B	(11) (65) (67)	−20	70	40	23.3	...
C–½Mo A204 Gr. B	A672	L70	K12020	...	...	3	(11) (58) (67)	−20	70	40	23.3	23.3
C–½Mo A204 Gr. B	A691	CM-70	K12020	...	...	3	(11) (58) (67)	−20	70	40	23.3	23.3
1¼Cr–½Mo	A426	CP11	J12072	...	...	4	(10)	−20	70	40	23.3	23.3
2¼Cr–1Mo	A426	CP22	J21890	...	...	5A	(10) (72)	−20	70	40	23.3	23.3
C–½Mo A204 Gr. C	A672	L75	K12320	...	...	3	(11) (58) (67)	−20	75	43	25.0	25.0
C–½Mo A204 Gr. C	A691	CM-75	K12320	...	...	3	(11) (58) (67)	−20	75	43	25.0	25.0
9Cr–1Mo–V	A335	P91	K90901	...	≤3 thk.	15E	...	−20	85	60	28.3	28.3
9Cr–1Mo–V	A691	91	K90901	...	≤3 thk.	15E	(11) (67)	−20	85	60	28.3	28.3
5Cr–½Mo	A426	CP5	J42045	...	...	5B	(10)	−20	90	60	30.0	29.9
9Cr–1Mo	A426	CP9	J82090	...	...	5B	(10)	−20	90	60	30.0	29.9
9Ni	A333	8	K81340	...	...	11A	(47)	−320	100	75	33.3	33.3

Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

Basic Allowable Stress, *S*, ksi, at Metal Temperature, °F [Notes (1), (4a)]																	
300	400	500	600	650	700	750	800	850	900	950	1,000	1,050	1,100	1,150	1,200	Type/ Grade	Spec. No.
Low and Intermediate Alloy Steel — Pipes (Cont'd)																	
18.2	18.0	17.9	17.9	17.9	17.9	17.9	17.7	16.0	12.0	9.0	7.0	5.5	4.0	2.7	1.5	P21	A335
18.2	18.0	17.9	17.9	17.9	17.9	17.9	17.7	16.0	12.0	9.0	7.0	5.5	4.0	2.7	1.5	FP21	A369
18.2	18.0	17.9	17.9	17.9	17.9	17.9	17.7	16.0	12.0	9.0	7.0	5.5	4.0	2.7	1.5	3CR	A691
18.2	18.0	17.9	17.9	17.9	17.9	17.9	17.7	17.1	13.6	10.8	8.0	5.7	3.8	2.4	1.4	2¼CR	A691
18.2	18.0	17.9	17.9	17.9	17.9	17.9	17.7	17.1	13.6	10.8	8.0	5.7	3.8	2.4	1.4	FP22	A369
18.2	18.0	17.9	17.9	17.9	17.9	17.9	17.7	17.1	13.6	10.8	8.0	5.7	3.8	2.4	1.4	P22	A335
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	9	A333
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	9	A334
20.6	19.9	18.9	17.5	16.7	15.7	13.9	11.4	9.0	6.5	4.5	2.5	1.6	1.0	...	...	7	A333
20.6	19.9	18.9	17.5	16.7	15.7	13.9	11.4	9.0	6.5	4.5	2.5	1.6	1.0	...	...	7	A334
20.6	19.9	18.9	17.5	16.7	15.7	13.9	11.4	9.0	6.5	4.5	2.5	1.6	1.0	...	...	3	A333
20.6	19.9	18.9	17.5	16.7	15.7	13.9	11.4	9.0	6.5	4.5	2.5	1.6	1.0	...	...	3	A334
21.0	20.3	19.7	19.1	18.7	18.4	17.9	17.4	16.9	13.7	8.2	4.8	4.0	2.4	...	...	CP1	A426
21.7	21.5	20.8	20.2	19.8	19.4	19.0	18.4	17.9	13.7	8.2	4.8	4.0	2.4	...	...	L65	A672
21.7	21.5	20.8	20.2	19.8	19.4	19.0	18.4	17.9	13.7	8.2	4.8	4.0	2.4	...	...	CM-65	A691
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	CFB70	A671
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	CFE70	A671
23.3	23.2	22.5	21.8	21.4	21.0	20.5	19.9	19.3	13.7	8.2	4.8	4.0	2.4	...	...	L70	A672
23.3	23.2	22.5	21.8	21.4	21.0	20.5	19.9	19.3	13.7	8.2	4.8	4.0	2.4	...	...	CM-70	A691
23.3	22.5	21.7	20.9	20.5	20.1	19.7	19.2	18.7	13.7	9.3	6.3	4.2	2.8	1.9	1.2	CP11	A426
22.6	22.6	22.6	22.6	22.6	22.6	22.6	22.6	21.9	15.8	11.4	7.8	5.1	3.2	2.0	1.2	CP22	A426
25.0	25.0	24.2	23.4	23.0	22.6	22.0	21.4	20.7	13.7	8.2	4.8	4.0	2.4	...	...	L75	A672
25.0	25.0	24.2	23.4	23.0	22.6	22.0	21.4	20.7	13.7	8.2	4.8	4.0	2.4	...	...	CM-75	A691
28.3	28.2	28.1	27.7	27.3	26.7	25.9	24.9	23.7	22.3	20.7	18.0	14.0	10.3	7.0	4.3	P91	A335
28.3	28.2	28.1	27.7	27.3	26.7	25.9	24.9	23.7	22.3	20.7	18.0	14.0	10.3	7.0	4.3	91	A691
29.1	28.8	28.7	28.3	27.9	27.3	26.5	25.5	24.2	16.4	11.0	7.4	5.0	3.3	2.2	1.5	CP5	A426
29.1	28.8	28.7	28.3	27.9	27.3	26.5	25.5	24.2	16.4	11.0	7.4	5.0	3.8	2.2	1.5	CP9	A426
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	8	A333

Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

Nominal Composition	Spec. No.	Type/ Grade	UNS No.	Class/ Condition/ Temper	Size, in.	P-No. (5)	Notes	Min. Temp., °F (6)	Specified Min. Strength, ksi: Tensile	Specified Min. Strength, ksi: Yield	Basic Allowable Stress, S, ksi, at Metal Temperature, °F [Notes (1), (4a)]: Min. Temp. to 100	200
Low and Intermediate Alloy Steel — Pipes												
9Ni	A334	8	K81340	...	...	11A	...	−320	100	75	33.3	33.3
Low and Intermediate Alloy Steel — Plates												
½Cr–½Mo	A387	2	K12143	1	...	3	...	−20	55	33	18.3	18.3
1Cr–½Mo	A387	12	K11757	1	...	4	...	−20	55	33	18.3	18.0
9Cr–1Mo	A387	9	K90941	1	...	5B	...	−20	60	30	20.0	18.1
1¼Cr–½Mo–Si	A387	11	K11789	1	...	4	...	−20	60	35	20.0	20.0
5Cr–½Mo	A387	5	K41545	1	...	5B	...	−20	60	30	20.0	18.1
3Cr–1Mo	A387	21	K31545	1	...	5A	...	−20	60	30	20.0	18.3
2¼Cr–1Mo	A387	22	K21590	1	...	5A	(72)	−20	60	30	20.0	18.7
2¼Ni	A203	A	K21703	...	...	9A	(12) (65)	−20	65	37	21.7	21.7
3½Ni	A203	D	K31718	...	...	9B	(12) (65)	−20	65	37	21.7	21.7
C–½Mo	A204	A	K11820	...	...	3	(58)	−20	65	37	21.7	21.7
1Cr–½Mo	A387	12	K11757	2	...	4	...	−20	65	40	21.7	21.3
2¼Ni	A203	B	K22103	...	...	9A	(12) (65)	−20	70	40	23.3	23.3
3½Ni	A203	E	K32018	...	...	9B	(12) (65)	−20	70	40	23.3	23.3
½Cr–½Mo	A387	2	K12143	2	...	3	...	−20	70	45	23.3	23.3
C–½Mo	A204	B	K12020	...	...	3	(58)	−20	70	40	23.3	23.3
Mn–½Mo	A302	A	K12021	...	...	3	...	−20	75	45	25.0	25.0
C–½Mo	A204	C	K12320	...	...	3	(58)	−20	75	43	25.0	25.0
1¼Cr–½Mo–Si	A387	11	K11789	2	...	4	...	−20	75	45	25.0	25.0
5Cr–½Mo	A387	5	K41545	2	...	5B	...	−20	75	45	25.0	24.9
3Cr–1Mo	A387	21	K31545	2	...	5A	...	−20	75	45	25.0	25.0
2¼Cr–1Mo	A387	22	K21590	2	...	5A	(72)	−20	75	45	25.0	25.0
Mn–½Mo	A302	B	K12022	...	...	3	...	−20	80	50	26.7	26.7
Mn–½Mo–½Ni	A302	C	K12039	...	...	3	...	−20	80	50	26.7	26.7
Mn–½Mo–¾Ni	A302	D	K12054	...	...	3	...	−20	80	50	26.7	26.7
9Cr–1Mo–V	A387	91	K90901	2	≤3 thk.	15E	...	−20	85	60	28.3	28.3
8Ni	A553	II	K71340	...	...	11A	(47)	−275	100	85	33.3	...
5Ni–¼Mo	A645	A	K41583	...	...	11A	...	−275	95	65	31.7	31.7
9Ni	A553	I	K81340	...	...	11A	(47)	−320	100	85	33.3	33.3
9Ni	A353	...	K81340	...	...	11A	(47)	−320	100	75	33.3	33.3

Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

Basic Allowable Stress, *S*, ksi, at Metal Temperature, °F [Notes (1), (4a)]																	
300	400	500	600	650	700	750	800	850	900	950	1,000	1,050	1,100	1,150	1,200	Type/ Grade	Spec. No.
Low and Intermediate Alloy Steel — Pipes (Cont'd)																	
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	8	A334
Low and Intermediate Alloy Steel — Plates																	
18.3	18.3	18.3	18.0	17.7	17.3	16.9	16.4	15.9	14.3	9.2	5.9	...	...	...	...	2 Cl. 1	A387
17.6	17.6	17.2	16.8	16.5	16.3	16.0	15.7	15.4	15.0	11.3	7.2	4.5	2.8	1.8	1.1	12 Cl. 1	A387
17.4	17.2	17.1	16.8	16.6	16.3	15.9	15.4	14.8	14.1	10.6	7.4	5.0	3.3	2.2	1.5	9 Cl. 1	A387
20.0	19.6	18.9	18.3	18.0	17.6	17.2	16.8	16.4	13.7	9.3	6.3	4.2	2.8	1.9	1.2	11 Cl. 1	A387
17.4	17.2	17.1	16.8	16.6	16.3	15.9	15.4	14.3	10.9	8.0	5.8	4.2	2.9	1.8	1.0	5 Cl. 1	A387
17.5	17.0	16.6	16.2	16.0	15.8	15.5	15.2	14.9	12.0	9.0	7.0	5.5	4.0	2.7	1.5	21 Cl. 1	A387
18.2	18.0	17.9	17.9	17.9	17.9	17.9	17.7	17.1	13.6	10.8	8.0	5.7	3.8	2.4	1.4	22 Cl. 1	A387
21.7	21.1	20.0	18.5	17.6	16.6	13.9	11.4	9.0	6.5	4.5	2.5	...	...	...	...	A	A203
21.7	21.1	20.0	18.5	17.6	16.6	13.9	11.4	9.0	6.5	4.5	2.5	...	...	...	...	D	A203
21.7	21.5	20.8	20.2	19.8	19.4	19.0	18.4	17.9	13.7	8.2	4.8	4.0	2.4	...	...	A	A204
20.8	20.8	20.8	20.3	20.0	19.7	19.4	19.1	18.6	18.0	11.3	7.2	4.5	2.8	1.8	1.1	12 Cl. 2	A387
23.3	22.8	21.6	20.0	19.0	16.9	13.9	11.4	9.0	6.5	4.5	2.5	...	...	...	...	B	A203
23.3	22.8	21.6	20.0	19.0	18.0	14.8	12.0	9.3	6.5	4.5	2.5	...	...	...	...	E	A203
23.3	23.3	23.3	23.3	23.3	23.3	23.1	22.4	21.7	20.9	9.2	5.9	...	...	...	...	2 Cl. 2	A387
23.3	23.2	22.5	21.8	21.4	21.0	20.5	19.9	19.3	13.7	8.2	4.8	4.0	2.4	...	...	B	A204
25.0	25.0	25.0	25.0	24.9	24.4	23.9	23.2	20.0	13.7	8.2	4.8	...	...	...	...	A	A302
25.0	25.0	24.2	23.4	23.0	22.6	22.0	21.4	20.7	13.7	8.2	4.8	4.0	2.4	...	...	C	A204
25.0	25.0	24.4	23.5	23.1	22.6	22.2	21.6	20.2	13.7	9.3	6.3	4.2	2.8	1.9	1.2	11 Cl. 2	A387
24.2	24.0	24.0	23.6	23.2	22.7	16.5	16.0	15.1	10.9	8.0	5.8	4.2	2.9	1.8	1.0	5 Cl. 2	A387
24.2	24.2	24.2	24.2	24.2	24.2	24.2	24.2	18.1	13.1	9.5	6.8	4.9	3.2	2.4	1.3	21 Cl. 2	A387
24.3	24.1	24.0	23.8	23.6	23.4	23.0	22.5	21.9	15.8	11.4	7.8	5.1	3.2	2.0	1.2	22 Cl. 2	A387
26.7	26.7	26.7	26.7	26.7	26.7	26.5	25.7	20.0	13.7	8.2	4.8	...	...	...	...	B	A302
26.7	26.7	26.7	26.7	26.7	26.7	26.5	25.7	20.0	13.7	8.2	4.8	...	...	...	...	C	A302
26.7	26.7	26.7	26.7	26.7	26.7	26.5	25.7	20.0	13.7	8.2	4.8	...	...	...	...	D	A302
28.3	28.2	28.1	27.7	27.3	26.7	25.9	24.9	23.7	22.3	20.7	18.0	14.0	10.3	7.0	4.3	91 Cl. 2	A387
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	II	A553
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	A	A645
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	I	A553
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	A353

Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

Nominal Composition	Spec. No.	Type/ Grade	UNS No.	Class/ Condition/ Temper	Size, in.	P-No. (5)	Notes	Min. Temp., °F (6)	Specified Min. Strength, ksi: Tensile	Specified Min. Strength, ksi: Yield	Basic Allowable Stress, *S*, ksi, at Metal Temperature, °F [Notes (1), (4a)]: Min. Temp. to 100	200
Low and Intermediate Alloy Steel — Forgings and Fittings												
C–½Mo	A234	WP1	K12821	...	...	3	(58)	−20	55	30	18.3	18.3
1Cr–½Mo	A182	F12	K11562	1	...	4	(9)	−20	60	32	20.0	19.3
1Cr–½Mo	A234	WP12	K12062	1	...	4	...	−20	60	32	20.0	19.3
1¼Cr–½Mo–Si	A182	F11	K11597	1	...	4	(9)	−20	60	30	20.0	18.5
1¼Cr–½Mo–Si	A234	WP11	K11597	1	...	4	...	−20	60	30	20.0	18.5
2¼Cr–1Mo	A182	F22	K21590	1	...	5A	(9) (72) (75)	−20	60	30	20.0	18.7
2¼Cr–1Mo	A234	WP22	K21590	1	...	5A	(72)	−20	60	30	20.0	18.7
5Cr–½Mo	A234	WP5	K41545	...	...	5B	...	−20	60	30	20.0	18.1
9Cr–1Mo	A234	WP9	K90941	...	...	5B	...	−20	60	30	20.0	18.1
3½Ni	A420	WPL3	K31918	...	...	9B	...	−150	65	35	21.7	21.4
3½Ni	A350	LF3	K32025	...	...	9B	(9)	−150	70	37.5	23.3	22.9
½Cr–½Mo	A182	F2	K12122	...	...	3	(9)	−20	70	40	23.3	23.3
C–½Mo	A182	F1	K12822	...	...	3	(9) (58)	−20	70	40	23.3	23.3
1Cr–½Mo	A182	F12	K11564	2	...	4	(9)	−20	70	40	23.3	22.9
1Cr–½Mo	A234	WP12	K12062	2	...	4	...	−20	70	40	23.3	22.9
1¼Cr–½Mo–Si	A182	F11	K11572	2	...	4	(9)	−20	70	40	23.3	23.3
1¼Cr–½Mo–Si	A234	WP11	K11572	2	...	4	...	−20	70	40	23.3	23.3
5Cr–½Mo	A182	F5	K41545	...	...	5B	(9)	−20	70	40	23.3	23.3
3Cr–1Mo	A182	F21	K31545	...	...	5A	(9)	−20	75	45	25.0	25.0
2¼Cr–1Mo	A182	F22	K21590	3	...	5A	(9) (72)	−20	75	45	25.0	25.0
2¼Cr–1Mo	A234	WP22	K21590	3	...	5A	(72)	−20	75	45	25.0	25.0
9Cr–1Mo	A182	F9	K90941	...	...	5B	(9)	−20	85	55	28.3	28.3

Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

Basic Allowable Stress, *S*, ksi, at Metal Temperature, °F [Notes (1), (4a)]																	
300	400	500	600	650	700	750	800	850	900	950	1,000	1,050	1,100	1,150	1,200	Type/ Grade	Spec. No.
Low and Intermediate Alloy Steel — Forgings and Fittings																	
18.0	17.4	16.9	16.4	16.1	15.7	15.4	14.9	14.5	13.7	8.2	4.8	4.0	2.4	...	...	WP1	A234
18.1	17.3	16.7	16.3	16.0	15.8	15.5	15.3	14.9	14.5	11.3	7.2	4.5	2.8	1.8	1.1	F12 Cl. 1	A182
18.1	17.3	16.7	16.3	16.0	15.8	15.5	15.3	14.9	14.5	11.3	7.2	4.5	2.8	1.8	1.1	WP12 Cl. 1	A234
17.6	16.8	16.2	15.7	15.4	15.1	14.8	14.4	14.0	13.6	9.3	6.3	4.2	2.8	1.9	1.2	F11 Cl. 1	A182
17.6	16.8	16.2	15.7	15.4	15.1	14.8	14.4	14.0	13.6	9.3	6.3	4.2	2.8	1.9	1.2	WP11 Cl. 1	A234
18.2	18.0	17.9	17.9	17.9	17.9	17.9	17.7	17.1	13.6	10.8	8.0	5.7	3.8	2.4	1.4	F22 Cl. 1	A182
18.2	18.0	17.9	17.9	17.9	17.9	17.9	17.7	17.1	13.6	10.8	8.0	5.7	3.8	2.4	1.4	WP22 Cl. 1	A234
17.4	17.2	17.1	16.8	16.6	16.3	15.9	15.4	14.3	10.9	8.0	5.8	4.2	2.9	1.8	1.0	WP5	A234
17.4	17.2	17.1	16.8	16.6	16.3	15.9	15.4	14.8	14.1	11.0	7.4	5.0	3.3	2.2	1.5	WP9	A234
20.6	19.9	18.9	17.5	16.7	...	...	...	...	...	...	...	...	...	...	...	WPL3	A420
22.1	21.4	20.3	18.8	17.9	...	...	...	...	...	...	...	...	...	...	...	LF3	A350
23.3	23.2	22.5	21.8	21.4	21.0	20.5	19.9	19.3	18.6	9.2	5.9	...	...	...	...	F2	A182
23.3	23.2	22.5	21.8	21.4	21.0	20.5	19.9	19.3	13.7	8.2	4.8	4.0	2.4	...	...	F1	A182
22.4	21.7	20.9	20.3	20.0	19.7	19.4	19.1	18.6	18.0	11.3	7.2	4.5	2.8	1.8	1.1	F12 Cl. 2	A182
22.4	21.7	20.9	20.3	20.0	19.7	19.4	19.1	18.6	18.0	11.3	7.2	4.5	2.8	1.8	1.1	WP12 Cl. 2	A234
23.3	22.5	21.7	20.9	20.5	20.1	19.7	19.2	18.7	13.7	9.3	6.3	4.2	2.8	1.9	1.2	F11 Cl. 2	A182
23.3	22.5	21.7	20.9	20.5	20.1	19.7	19.2	18.7	13.7	9.3	6.3	4.2	2.8	1.9	1.2	WP11 Cl. 2	A234
22.6	22.4	22.4	22.0	21.7	21.2	20.6	19.8	14.3	10.9	8.0	5.8	4.2	2.9	1.8	1.0	F5	A182
24.3	24.1	24.0	23.8	23.6	23.4	23.0	22.5	18.1	13.1	9.5	6.8	4.9	3.2	2.4	1.3	F21	A182
24.2	24.2	24.2	24.2	24.2	24.2	24.2	24.2	21.9	15.8	11.4	7.8	5.1	3.2	2.0	1.2	F22 Cl. 3	A182
24.2	24.2	24.2	24.2	24.2	24.2	24.2	24.2	21.9	15.8	11.4	7.8	5.1	3.2	2.0	1.2	WP22 Cl. 3	A234
27.4	27.2	27.1	26.8	26.3	25.8	25.0	24.0	22.9	15.2	10.6	7.4	5.0	3.3	2.2	1.5	F9	A182

Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

Nominal Composition	Spec. No.	Type/ Grade	UNS No.	Class/ Condition/ Temper	Size, in.	P-No. (5)	Notes	Min. Temp., °F (6)	Specified Min. Strength, ksi: Tensile	Specified Min. Strength, ksi: Yield	Basic Allowable Stress, S, ksi, at Metal Temperature, °F [Notes (1), (4a)]: Min. Temp. to 100	200
Low and Intermediate Alloy Steel — Forgings and Fittings												
9Cr–1Mo–V	A182	F91	K90901	...	≤3 thk.	15E	...	−20	85	60	28.3	28.3
9Cr–1Mo–V	A234	WP91	K90901	...	≤3 thk.	15E	...	−20	85	60	28.3	28.3
5Cr–½Mo	A182	F5a	K42544	...	...	5B	(9)	−20	90	65	30.0	29.9
9Ni	A420	WPL8	K81340	...	...	11A	(47)	−320	100	75	33.3	33.3
Low and Intermediate Alloy Steel — Castings												
C–½Mo	A352	LC1	J12522	...	...	3	(9) (58)	−75	65	35	21.7	21.7
C–½Mo	A217	WC1	J12524	...	...	3	(9) (58)	−20	65	35	21.7	21.7
2½Ni	A352	LC2	J22500	...	...	9A	(9)	−100	70	40	23.3	23.3
3½Ni	A352	LC3	J31550	...	...	9B	(9)	−150	70	40	23.3	23.3
1Ni–½Cr–½Mo	A217	WC4	J12082	...	...	4	(9)	−20	70	40	23.3	23.3
¾Ni–1Mo–¾Cr	A217	WC5	J22000	...	...	4	(9)	−20	70	40	23.3	23.3
1¼Cr–½Mo	A217	WC6	J12072	...	...	4	(9)	−20	70	40	23.3	23.3
2¼Cr–1Mo	A217	WC9	J21890	...	...	5A	(9)	−20	70	40	23.3	23.3
5Cr–½Mo	A217	C5	J42045	...	...	5B	(9)	−20	90	60	30.0	29.9
9Cr–1Mo	A217	C12	J82090	...	...	5B	(9)	−20	90	60	30.0	29.9

Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

Basic Allowable Stress, *S*, ksi, at Metal Temperature, °F [Notes (1), (4a)]

300	400	500	600	650	700	750	800	850	900	950	1,000	1,050	1,100	1,150	1,200	Type/ Grade	Spec. No.
								Low and Intermediate Alloy Steel — Forgings and Fittings (Cont'd)									
28.3	28.2	28.1	27.7	27.3	26.7	25.9	24.9	23.7	22.3	20.7	18.0	14.0	10.3	7.0	4.3	F91	A182
28.3	28.2	28.1	27.7	27.3	26.7	25.9	24.9	23.7	22.3	20.7	18.0	14.0	10.3	7.0	4.3	WP91	A234
29.1	28.8	28.7	28.3	27.9	27.3	26.5	25.5	14.3	10.9	8.0	5.8	4.2	2.9	1.8	1.0	F5a	A182
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	WPL8	A420
												Low and Intermediate Alloy Steel — Castings					
21.0	20.3	19.7	19.1	18.7	18.4	...	...	...	...	...	...	...	...	...	...	LC1	A352
21.0	20.3	19.7	19.1	18.7	18.4	17.9	17.4	16.9	13.7	8.2	4.8	4.0	2.4	...	...	WC1	A217
23.3	22.8	21.6	20.0	19.0	...	...	...	...	...	...	...	...	...	...	...	LC2	A352
23.3	22.8	21.6	20.0	19.0	...	...	...	...	...	...	...	...	...	...	...	LC3	A352
23.3	23.3	23.0	22.4	22.1	21.7	21.2	20.6	19.8	14.3	9.2	5.9	...	...	...	...	WC4	A217
23.3	23.3	23.0	22.4	22.1	21.7	21.2	20.6	19.8	14.3	9.2	5.9	4.0	2.4	...	...	WC5	A217
23.3	22.5	21.7	20.9	20.5	20.1	19.7	19.2	18.7	13.7	9.3	6.3	4.2	2.8	1.9	1.2	WC6	A217
22.6	22.6	22.6	22.6	22.6	22.6	22.6	22.6	21.9	15.8	11.4	7.8	5.1	3.2	2.0	1.2	WC9	A217
29.1	28.8	28.7	28.3	27.9	27.3	26.5	25.5	14.3	10.9	8.0	5.8	4.2	2.9	1.8	1.0	C5	A217
29.1	28.8	28.7	28.3	27.9	27.3	26.5	25.5	24.2	15.2	10.6	7.4	5.0	3.3	2.2	1.5	C12	A217

Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

Nominal Composition	Product Form	Spec. No.	Type/ Grade	UNS No.	Class/ Condition/ Temper	Size, in.	P-No. (5)	Notes	Min. Temp., °F (6)	Specified Min. Strength, ksi: Tensile	Specified Min. Strength, ksi: Yield	Basic Allowable Stress, S, ksi, at Metal Temperature, °F [Notes (1), (4a)]: Min. Temp. to 100	200	300	400
Stainless Steel — Pipes and Tubes (3)(4a)															
18Cr–10Ni–Ti	Smls. pipe	A312	TP321	S32100	...	>3/8 thk.	8	(28)	–425	70	25	16.7	*16.7*	*16.7*	*16.7*
18Cr–10Ni–Ti	Smls. pipe	A376	TP321	S32100	...	>3/8 thk.	8	(28) (36)	–425	70	25	16.7	*16.7*	*16.7*	*16.7*
18Cr–8Ni	Tube	A213	TP304L	S30403	...	...	8	(14) (36)	–425	70	25	16.7	*16.7*	*16.7*	**15.8**
18Cr–8Ni	Tube	A269	TP304L	S30403	...	...	8	(14) (36)	–425	70	25	16.7	*16.7*	*16.7*	**15.8**
18Cr–8Ni	Tube	A270	TP304L	S30403	...	...	8	(14)	–425	70	25	16.7	*16.7*	*16.7*	**15.8**
18Cr–8Ni	Pipe	A312	TP304L	S30403	...	...	8	...	–425	70	25	16.7	*16.7*	*16.7*	**15.8**
18Cr–8Ni	Pipe	A358	304L	S30403	...	...	8	(36)	–425	70	25	16.7	*16.7*	*16.7*	**15.8**
16Cr–12Ni–2Mo	Tube	A213	TP316L	S31603	...	...	8	(14) (36)	–425	70	25	16.7	*16.7*	*16.7*	**15.7**
16Cr–12Ni–2Mo	Tube	A269	TP316L	S31603	...	...	8	(14) (36)	–425	70	25	16.7	*16.7*	*16.7*	**15.7**
16Cr–12Ni–2Mo	Tube	A270	TP316L	S31603	...	...	8	(14)	–425	70	25	16.7	*16.7*	*16.7*	**15.7**
16Cr–12Ni–2Mo	Pipe	A312	TP316L	S31603	...	...	8	...	–425	70	25	16.7	*16.7*	*16.7*	**15.7**
16Cr–12Ni–2Mo	Pipe	A358	316L	S31603	...	...	8	(36)	–425	70	25	16.7	*16.7*	*16.7*	**15.7**
16Cr–12Ni–2Mo–Ti	Tube	A213	TP316Ti	S31635	...	...	8	(30)	–325	75	30	20.0	*20.0*	*20.0*	**19.3**
18Cr–10Ni–Ti	Smls. pipe	A312	TP321	S32100	...	>3/8 thk.	8	(28) (30)	–425	70	25	16.7	*16.7*	*16.7*	*16.7*
18Cr–10Ni–Ti	Smls. pipe	A376	TP321	S32100	...	>3/8 thk.	8	(28) (30) (36)	–425	70	25	16.7	*16.7*	*16.7*	*16.7*
18Cr–10Ni–Ti	Smls. pipe	A312	TP321H	S32109	...	>3/8 thk.	8	(30)	–325	70	25	16.7	*16.7*	*16.7*	*16.7*
18Cr–10Ni–Ti	Smls. pipe	A376	TP321H	S32109	...	>3/8 thk.	8	(30) (36)	–325	70	25	16.7	*16.7*	*16.7*	*16.7*
25Cr–12Ni	...	A451	CPH8	J93400	...	...	8	(26) (28) (35)	–325	65	28	18.7	*18.7*	*18.5*	*18.0*
25Cr–20Ni	...	A451	CPK20	J94202	...	...	8	(12) (28) (35) (39)	–325	65	28	18.7	*18.7*	*18.5*	*18.0*
11Cr–Ti	Tube	A268	TP409	S40900	...	...	7	(35)	–20	60	30	20.0	...	...	...
18Cr–Ti	Tube	A268	TP430Ti	S43036	...	...	7	(35) (49)	–20	60	40	20.0	...	...	...
16Cr–14Ni–2Mo	...	A451	CPF10MC	J92971	...	...	8	(28)	–325	70	30	20.0	...	...	...
12Cr–Al	Tube	A268	TP405	S40500	...	...	7	(35)	–20	60	30	20.0	20.0	19.6	19.3
13Cr	Tube	A268	TP410	S41000	...	...	6	(35)	–20	60	30	20.0	20.0	19.6	19.3
17Cr	Tube	A268	TP430	S43000	...	...	7	(35) (49)	–20	60	35	20.0	20.0	19.6	19.3
18Cr–13Ni–3Mo	Pipe	A312	TP317L	S31703	...	...	8	...	–325	75	30	20.0	*20.0*	*20.0*	**18.9**
25Cr–20Ni	Pipe	A312	TP310S	S31008	...	...	8	(28) (35)	–325	75	30	20.0	*20.0*	*20.0*	*20.0*
25Cr–20Ni	...	A358	310S	S31008	...	...	8	(28) (35) (36)	–325	75	30	20.0	*20.0*	*20.0*	*20.0*
25Cr–20Ni	Pipe	A409	TP310S	S31008	...	...	8	(28) (31) (35) (36)	–325	75	30	20.0	*20.0*	*20.0*	*20.0*
18Cr–10Ni–Ti	Smls. pipe	A312	TP321	S32100	...	≤3/8 thk.	8	(28)	–425	75	30	20.0	*20.0*	*20.0*	*20.0*
18Cr–10Ni–Ti	Wld. pipe	A312	TP321	S32100	...	...	8	(28)	–425	75	30	20.0	*20.0*	*20.0*	*20.0*
18Cr–10Ni–Ti	Wld. pipe	A358	321	S32100	...	...	8	(28) (36)	–425	75	30	20.0	*20.0*	*20.0*	*20.0*
18Cr–10Ni–Ti	Smls. pipe	A376	TP321	S32100	...	≤3/8 thk.	8	(28) (36)	–425	75	30	20.0	*20.0*	*20.0*	*20.0*
18Cr–10Ni–Ti	Wld. pipe	A409	TP321	S32100	...	...	8	(28) (36)	–425	75	30	20.0	*20.0*	*20.0*	*20.0*
23Cr–12Ni	Pipe	A312	TP309	...	...	...	8	(28) (35) (39)	–325	75	30	20.0	*20.0*	*20.0*	*20.0*

Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

Basic Allowable Stress, *S*, ksi, at Metal Temperature, °F [Notes (1), (4a)]																					
500	600	650	700	750	800	850	900	950	1,000	1,050	1,100	1,150	1,200	1,250	1,300	1,350	1,400	1,450	1,500	Type/ Grade	Spec. No.
Stainless Steel — Pipes and Tubes (3)(4a)																					
16.1	**15.2**	**14.9**	**14.6**	**14.3**	**14.1**	**13.9**	**13.8**	**13.6**	**13.5**	9.6	6.9	5.0	3.6	2.6	1.7	1.1	0.8	0.5	0.3	TP321	A312
16.1	**15.2**	**14.9**	**14.6**	**14.3**	**14.1**	**13.9**	**13.8**	**13.6**	**13.5**	9.6	6.9	5.0	3.6	2.6	1.7	1.1	0.8	0.5	0.3	TP321	A376
14.7	**14.0**	**13.7**	**13.5**	**13.3**	**13.0**	**12.8**	*12.6*	*12.3*	12.0	6.3	5.1	4.0	3.2	2.6	2.1	1.7	1.1	1.0	0.9	TP304L	A213
14.7	**14.0**	**13.7**	**13.5**	**13.3**	**13.0**	**12.8**	*12.6*	*12.3*	12.0	6.3	5.1	4.0	3.2	2.6	2.1	1.7	1.1	1.0	0.9	TP304L	A269
14.7	**14.0**	**13.7**	**13.5**	**13.3**	**13.0**	**12.8**	*12.6*	*12.3*	12.0	6.3	5.1	4.0	3.2	2.6	2.1	1.7	1.1	1.0	0.9	TP304L	A270
14.7	**14.0**	**13.7**	**13.5**	**13.3**	**13.0**	**12.8**	*12.6*	*12.3*	12.0	6.3	5.1	4.0	3.2	2.6	2.1	1.7	1.1	1.0	0.9	TP304L	A312
14.7	**14.0**	**13.7**	**13.5**	**13.3**	**13.0**	**12.8**	*12.6*	*12.3*	12.0	6.3	5.1	4.0	3.2	2.6	2.1	1.7	1.1	1.0	0.9	304L	A358
14.8	**14.0**	**13.7**	**13.5**	**13.2**	**12.9**	**12.7**	**12.4**	**12.1**	**11.8**	**11.6**	*11.4*	*8.8*	6.4	4.7	3.5	2.5	1.8	1.3	1.0	TP316L	A213
14.8	**14.0**	**13.7**	**13.5**	**13.2**	**12.9**	**12.7**	**12.4**	**12.1**	**11.8**	**11.6**	*11.4*	*8.8*	6.4	4.7	3.5	2.5	1.8	1.3	1.0	TP316L	A269
14.8	**14.0**	**13.7**	**13.5**	**13.2**	**12.9**	**12.7**	**12.4**	**12.1**	**11.8**	**11.6**	*11.4*	*8.8*	6.4	4.7	3.5	2.5	1.8	1.3	1.0	TP316L	A270
14.8	**14.0**	**13.7**	**13.5**	**13.2**	**12.9**	**12.7**	**12.4**	**12.1**	**11.8**	**11.6**	*11.4*	*8.8*	6.4	4.7	3.5	2.5	1.8	1.3	1.0	TP316L	A312
14.8	**14.0**	**13.7**	**13.5**	**13.2**	**12.9**	**12.7**	**12.4**	**12.1**	**11.8**	**11.6**	*11.4*	*8.8*	6.4	4.7	3.5	2.5	1.8	1.3	1.0	316L	A358
17.8	**16.8**	**16.5**	**16.2**	**16.1**	**15.9**	**15.8**	**15.7**	**15.5**	**15.3**	**15.1**	12.3	9.8	7.4	5.5	4.1	3.1	2.3	1.7	1.3	TP316Ti	A213
16.1	**15.2**	**14.9**	**14.6**	**14.3**	**14.1**	**13.9**	**13.8**	**13.6**	**13.5**	12.3	9.1	6.9	5.4	4.1	3.2	2.5	1.9	1.5	1.1	TP321	A312
16.1	**15.2**	**14.9**	**14.6**	**14.3**	**14.1**	**13.9**	**13.8**	**13.6**	**13.5**	12.3	9.1	6.9	5.4	4.1	3.2	2.5	1.9	1.5	1.1	TP321	A376
16.1	**15.2**	**14.9**	**14.6**	**14.3**	**14.1**	**13.9**	**13.8**	**13.6**	**13.5**	12.3	9.1	6.9	5.4	4.1	3.2	2.5	1.9	1.5	1.1	TP321H	A312
16.1	**15.2**	**14.9**	**14.6**	**14.3**	**14.1**	**13.9**	**13.8**	**13.6**	**13.5**	12.3	9.1	6.9	5.4	4.1	3.2	2.5	1.9	1.5	1.1	TP321H	A376
17.7	**17.1**	**16.7**	**16.3**	**15.9**	**15.4**	*14.9*	*14.4*	*13.9*	11.1	8.5	6.5	5.0	3.8	2.9	2.3	1.8	1.3	0.9	0.8	CPH8	A451
17.7	**17.1**	**16.7**	**16.3**	**15.9**	**15.4**	*14.9*	*14.4*	*13.9*	11.3	9.8	8.5	7.3	6.0	4.8	3.5	2.4	1.6	1.1	0.8	CPK20	A451
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	TP409	A268
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	TP430Ti	A268
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	CPF10MC	A451
19.0	18.5	18.1	17.7	17.1	16.4	15.6	14.3	8.4	4.0	...	...	...	...	...	...	...	...	...	...	TP405	A268
19.0	18.5	18.1	17.7	17.1	16.4	15.6	12.3	8.8	6.4	4.4	2.9	1.8	1.0	...	...	...	...	...	...	TP410	A268
19.0	18.5	18.1	17.7	17.1	16.4	15.6	12.0	9.2	6.5	4.5	3.2	2.4	1.8	...	...	...	...	...	...	TP430	A268
17.7	**16.9**	**16.5**	**16.2**	**15.8**	**15.5**	**15.2**	...	...	...	...	...	...	...	...	...	...	...	...	...	TP317L	A312
19.3	**18.5**	**18.2**	**17.9**	**17.7**	**17.4**	*17.2*	*16.9*	*15.9*	9.9	7.1	5.0	3.6	2.5	1.5	0.8	0.5	0.4	0.3	0.2	TP310S	A312
19.3	**18.5**	**18.2**	**17.9**	**17.7**	**17.4**	*17.2*	*16.9*	*15.9*	9.9	7.1	5.0	3.6	2.5	1.5	0.8	0.5	0.4	0.3	0.2	310S	A358
19.3	**18.5**	**18.2**	**17.9**	**17.7**	**17.4**	*17.2*	*16.9*	*15.9*	9.9	7.1	5.0	3.6	2.5	1.5	0.8	0.5	0.4	0.3	0.2	TP310S	A409
19.3	**18.3**	**17.8**	**17.5**	**17.2**	**16.9**	**16.7**	**16.5**	**16.4**	**16.2**	9.6	6.9	5.0	3.6	2.6	1.7	1.1	0.8	0.5	0.3	TP321	A312
19.3	**18.3**	**17.8**	**17.5**	**17.2**	**16.9**	**16.7**	**16.5**	**16.4**	**16.2**	9.6	6.9	5.0	3.6	2.6	1.7	1.1	0.8	0.5	0.3	TP321	A312
19.3	**18.3**	**17.8**	**17.5**	**17.2**	**16.9**	**16.7**	**16.5**	**16.4**	**16.2**	9.6	6.9	5.0	3.6	2.6	1.7	1.1	0.8	0.5	0.3	321	A358
19.3	**18.3**	**17.8**	**17.5**	**17.2**	**16.9**	**16.7**	**16.5**	**16.4**	**16.2**	9.6	6.9	5.0	3.6	2.6	1.7	1.1	0.8	0.5	0.3	TP321	A376
19.3	**18.3**	**17.8**	**17.5**	**17.2**	**16.9**	**16.7**	**16.5**	**16.4**	**16.2**	9.6	6.9	5.0	3.6	2.6	1.7	1.1	0.8	0.5	0.3	TP321	A409
19.4	**18.8**	**18.5**	**18.2**	**18.0**	**17.7**	*17.5*	*17.2*	*16.9*	13.8	10.3	7.6	5.5	4.0	3.0	2.2	1.7	1.3	1.0	0.8	TP309	A312

Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

Nominal Composition	Product Form	Spec. No.	Type/ Grade	UNS No.	Class/ Condition/ Temper	Size, in.	P-No. (5)	Notes	Min. Temp., °F (6)	Specified Min. Strength, ksi: Tensile	Specified Min. Strength, ksi: Yield	Basic Allowable Stress, S, ksi, at Metal Temperature, °F [Notes (1), (4a)]: Min. Temp. to 100	200	300	400
Stainless Steel — Pipes and Tubes (3)(4a)															
23Cr–12Ni	...	A358	309S	S30908	...	...	8	(28) (31) (35) (36)	−325	75	30	20.0	*20.0*	*20.0*	*20.0*
18Cr–8Ni	...	A451	CPF8	J92600	...	...	8	(26) (28)	−425	70	30	20.0	*20.0*	*20.0*	**18.6**
18Cr–10Ni–Cb	Pipe	A312	TP347	S34700	...	...	8	...	−425	75	30	20.0	*20.0*	*20.0*	*20.0*
18Cr–10Ni–Cb	Pipe	A358	347	S34700	...	...	8	(30) (36)	−425	75	30	20.0	*20.0*	*20.0*	*20.0*
18Cr–10Ni–Cb	Pipe	A376	TP347	S34700	...	...	8	(30) (36)	−425	75	30	20.0	*20.0*	*20.0*	*20.0*
18Cr–10Ni–Cb	Pipe	A409	TP347	S34700	...	...	8	(30) (36)	−425	75	30	20.0	*20.0*	*20.0*	*20.0*
18Cr–10Ni–Cb	Pipe	A312	TP348	S34800	...	...	8	...	−325	75	30	20.0	*20.0*	*20.0*	*20.0*
18Cr–10Ni–Cb	Pipe	A358	348	S34800	...	...	8	(30) (36)	−325	75	30	20.0	*20.0*	*20.0*	*20.0*
18Cr–10Ni–Cb	Pipe	A376	TP348	S34800	...	...	8	(30) (36)	−325	75	30	20.0	*20.0*	*20.0*	*20.0*
18Cr–10Ni–Cb	Pipe	A409	TP348	S34800	...	...	8	(30) (36)	−325	75	30	20.0	*20.0*	*20.0*	*20.0*
25Cr–12Ni	...	A451	CPH10	J93402	...	...	8	(12) (14) (28) (35) (39)	−325	70	30	20.0	*20.0*	*19.9*	*19.4*
25Cr–12Ni	...	A451	CPH20	J93402	...	...	8	(12) (14) (28) (35) (39)	−325	70	30	20.0	*20.0*	*19.9*	*19.4*
25Cr–20Ni	Pipe	A312	TP310H	S31009	...	...	8	(29) (35) (39)	−325	75	30	20.0	*20.0*	*20.0*	*20.0*
18Cr–10Ni–Cb	...	A451	CPF8C	J92710	...	...	8	(28)	−325	70	30	20.0	*20.0*	*20.0*	*18.6*
18Cr–10Ni–Ti	Smls. pipe	A312	TP321	S32100	...	≤$^3/_8$ thk.	8	(28) (30)	−425	75	30	20.0	*20.0*	*20.0*	*20.0*
18Cr–10Ni–Ti	Wld. pipe	A312	TP321	S32100	...	...	8	(28) (30)	−425	75	30	20.0	*20.0*	*20.0*	*20.0*
18Cr–10Ni–Ti	Wld. pipe	A358	321	S32100	...	...	8	(28) (30) (36)	−425	75	30	20.0	*20.0*	*20.0*	*20.0*
18Cr–10Ni–Ti	Smls. pipe	A376	TP321	S32100	...	≤$^3/_8$ thk.	8	(28) (30) (36)	−425	75	30	20.0	*20.0*	*20.0*	*20.0*
18Cr–10Ni–Ti	Wld. pipe	A409	TP321	S32100	...	...	8	(28) (30) (36)	−425	75	30	20.0	*20.0*	*20.0*	*20.0*
18Cr–10Ni–Ti	Smls. pipe	A312	TP321H	S32109	...	≤$^3/_8$ thk.	8	(30)	−325	75	30	20.0	*20.0*	*20.0*	*20.0*
18Cr–10Ni–Ti	Wld. pipe	A312	TP321H	S32109	...	...	8	(30)	−325	75	30	20.0	*20.0*	*20.0*	*20.0*
18Cr–10Ni–Ti	Wld. pipe	A358	321H	S32109	...	...	8	(30) (36)	−325	75	30	20.0	*20.0*	*20.0*	*20.0*
18Cr–10Ni–Ti	Smls. pipe	A376	TP321H	S32109	...	≤$^3/_8$ thk.	8	(30) (36)	−325	75	30	20.0	*20.0*	*20.0*	*20.0*
16Cr–12Ni–2Mo	Tube	A213	TP316	S31600	...	...	8	(14) (26) (28) (31) (36)	−425	75	30	20.0	*20.0*	*20.0*	**19.3**
16Cr–12Ni–2Mo	Tube	A269	TP316	S31600	...	...	8	(14) (26) (28) (31) (36)	−425	75	30	20.0	*20.0*	*20.0*	**19.3**
16Cr–12Ni–2Mo	Tube	A270	TP316	S31600	...	...	8	(14) (26) (28)	−425	75	30	20.0	*20.0*	*20.0*	**19.3**
16Cr–12Ni–2Mo	Pipe	A312	TP316	S31600	...	...	8	(26) (28)	−425	75	30	20.0	*20.0*	*20.0*	**19.3**
16Cr–12Ni–2Mo	Pipe	A358	316	S31600	...	...	8	(26) (28) (31) (36)	−425	75	30	20.0	*20.0*	*20.0*	**19.3**
16Cr–12Ni–2Mo	Pipe	A376	TP316	S31600	...	...	8	(26) (28) (31) (36)	−425	75	30	20.0	*20.0*	*20.0*	**19.3**

Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

Basic Allowable Stress, *S*, ksi, at Metal Temperature, °F [Notes (1), (4a)]																					
500	600	650	700	750	800	850	900	950	1,000	1,050	1,100	1,150	1,200	1,250	1,300	1,350	1,400	1,450	1,500	Type/ Grade	Spec. No.
															Stainless Steel — Pipes and Tubes (3)(4a)						(Cont'd)
19.4	**18.8**	**18.5**	**18.2**	**18.0**	**17.7**	*17.5*	*17.2*	*16.9*	13.8	10.3	7.6	5.5	4.0	3.0	2.2	1.7	1.3	1.0	0.8	309S	A358
17.5	**16.6**	**16.2**	**15.8**	**15.5**	**15.2**	*14.9*	*14.6*	*14.3*	*12.2*	9.5	7.5	6.0	4.8	3.9	3.3	2.7	2.3	2.0	1.7	CPF8	A451
20.0	**19.3**	**19.0**	**18.7**	**18.5**	**18.3**	*18.2*	*18.1*	*18.1*	*16.0*	*12.1*	9.1	6.1	4.4	3.3	2.2	1.5	1.2	0.9	0.8	TP347	A312
20.0	**19.3**	**19.0**	**18.7**	**18.5**	**18.3**	*18.2*	*18.1*	*18.1*	*16.0*	*12.1*	9.1	6.1	4.4	3.3	2.2	1.5	1.2	0.9	0.8	347	A358
20.0	**19.3**	**19.0**	**18.7**	**18.5**	**18.3**	*18.2*	*18.1*	*18.1*	*16.0*	*12.1*	9.1	6.1	4.4	3.3	2.2	1.5	1.2	0.9	0.8	TP347	A376
20.0	**19.3**	**19.0**	**18.7**	**18.5**	**18.3**	*18.2*	*18.1*	*18.1*	*16.0*	*12.1*	9.1	6.1	4.4	3.3	2.2	1.5	1.2	0.9	0.8	TP347	A409
20.0	**19.3**	**19.0**	**18.7**	**18.5**	**18.3**	*18.2*	*18.1*	*18.1*	*16.0*	*12.1*	9.1	6.1	4.4	3.3	2.2	1.5	1.2	0.9	0.8	TP348	A312
20.0	**19.3**	**19.0**	**18.7**	**18.5**	**18.3**	*18.2*	*18.1*	*18.1*	*16.0*	*12.1*	9.1	6.1	4.4	3.3	2.2	1.5	1.2	0.9	0.8	348	A358
20.0	**19.3**	**19.0**	**18.7**	**18.5**	**18.3**	*18.2*	*18.1*	*18.1*	*16.0*	*12.1*	9.1	6.1	4.4	3.3	2.2	1.5	1.2	0.9	0.8	TP348	A376
20.0	**19.3**	**19.0**	**18.7**	**18.5**	**18.3**	*18.2*	*18.1*	*18.1*	*16.0*	*12.1*	9.1	6.1	4.4	3.3	2.2	1.5	1.2	0.9	0.8	TP348	A409
18.9	**18.3**	**17.9**	**17.5**	**17.0**	**16.5**	*16.0*	*15.4*	*14.9*	11.1	8.5	6.5	5.0	3.8	2.9	2.3	1.8	1.3	0.9	0.8	CPH10	A451
18.9	**18.3**	**17.9**	**17.5**	**17.0**	**16.5**	*16.0*	*15.4*	*14.9*	11.1	8.5	6.5	5.0	3.8	2.9	2.3	1.8	1.3	0.9	0.8	CPH20	A451
19.3	**18.5**	**18.2**	**17.9**	**17.7**	**17.4**	*17.2*	*16.9*	*16.7*	13.8	10.3	7.6	5.5	4.0	3.0	2.2	1.7	1.3	1.0	0.8	TP310H	A312
17.5	**16.6**	**16.2**	**15.8**	**15.5**	**15.2**	*14.9*	*14.6*	*14.3*	*14.0*	*12.1*	*9.1*	6.1	4.4	3.3	2.2	1.5	1.2	0.9	0.8	CPF8C	A451
19.3	**18.3**	**17.8**	**17.5**	**17.2**	**16.9**	**16.7**	**16.5**	**16.4**	**16.2**	12.3	9.1	6.9	5.4	4.1	3.2	2.5	1.9	1.5	1.1	TP321	A312
19.3	**18.3**	**17.8**	**17.5**	**17.2**	**16.9**	**16.7**	**16.5**	**16.4**	**16.2**	12.3	9.1	6.9	5.4	4.1	3.2	2.5	1.9	1.5	1.1	TP321	A312
19.3	**18.3**	**17.8**	**17.5**	**17.2**	**16.9**	**16.7**	**16.5**	**16.4**	**16.2**	12.3	9.1	6.9	5.4	4.1	3.2	2.5	1.9	1.5	1.1	321	A358
19.3	**18.3**	**17.8**	**17.5**	**17.2**	**16.9**	**16.7**	**16.5**	**16.4**	**16.2**	12.3	9.1	6.9	5.4	4.1	3.2	2.5	1.9	1.5	1.1	TP321	A376
19.3	**18.3**	**17.8**	**17.5**	**17.2**	**16.9**	**16.7**	**16.5**	**16.4**	**16.2**	12.3	9.1	6.9	5.4	4.1	3.2	2.5	1.9	1.5	1.1	TP321	A409
19.3	**18.3**	**17.8**	**17.5**	**17.2**	**16.9**	**16.7**	**16.5**	**16.4**	**16.2**	12.3	9.1	6.9	5.4	4.1	3.2	2.5	1.9	1.5	1.1	TP321H	A312
19.3	**18.3**	**17.8**	**17.5**	**17.2**	**16.9**	**16.7**	**16.5**	**16.4**	**16.2**	12.3	9.1	6.9	5.4	4.1	3.2	2.5	1.9	1.5	1.1	TP321H	A312
19.3	**18.3**	**17.8**	**17.5**	**17.2**	**16.9**	**16.7**	**16.5**	**16.4**	**16.2**	12.3	9.1	6.9	5.4	4.1	3.2	2.5	1.9	1.5	1.1	321H	A358
19.3	**18.3**	**17.8**	**17.5**	**17.2**	**16.9**	**16.7**	**16.5**	**16.4**	**16.2**	12.3	9.1	6.9	5.4	4.1	3.2	2.5	1.9	1.5	1.1	TP321H	A376
18.0	**17.0**	**16.6**	**16.3**	**16.1**	**15.9**	**15.7**	**15.6**	**15.4**	**15.3**	*15.1*	*12.4*	*9.8*	7.4	5.5	4.1	3.1	2.3	1.7	1.3	TP316	A213
18.0	**17.0**	**16.6**	**16.3**	**16.1**	**15.9**	**15.7**	**15.6**	**15.4**	**15.3**	*15.1*	*12.4*	9.8	7.4	5.5	4.1	3.1	2.3	1.7	1.3	TP316	A269
18.0	**17.0**	**16.6**	**16.3**	**16.1**	**15.9**	**15.7**	**15.6**	**15.4**	**15.3**	*15.1*	*12.4*	9.8	7.4	5.5	4.1	3.1	2.3	1.7	1.3	TP316	A270
18.0	**17.0**	**16.6**	**16.3**	**16.1**	**15.9**	**15.7**	**15.6**	**15.4**	**15.3**	*15.1*	*12.4*	9.8	7.4	5.5	4.1	3.1	2.3	1.7	1.3	TP316	A312
18.0	**17.0**	**16.6**	**16.3**	**16.1**	**15.9**	**15.7**	**15.6**	**15.4**	**15.3**	*15.1*	*12.4*	9.8	7.4	5.5	4.1	3.1	2.3	1.7	1.3	316	A358
18.0	**17.0**	**16.6**	**16.3**	**16.1**	**15.9**	**15.7**	**15.6**	**15.4**	**15.3**	*15.1*	*12.4*	9.8	7.4	5.5	4.1	3.1	2.3	1.7	1.3	TP316	A376

Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

Nominal Composition	Product Form	Spec. No.	Type/ Grade	UNS No.	Class/ Condition/ Temper	Size, in.	P-No. (5)	Notes	Min. Temp., °F (6)	Specified Min. Strength, ksi: Tensile	Yield	Basic Allowable Stress, S, ksi, at Metal Temperature, °F [Notes (1), (4a)]: Min. Temp. to 100	200	300	400
Stainless Steel — Pipes and Tubes (3)(4a)															
16Cr–12Ni–2Mo	Pipe	A409	TP316	S31600	...	...	8	(26) (28) (31) (36)	−425	75	30	20.0	*20.0*	*20.0*	**19.3**
18Cr–13Ni–3Mo	Pipe	A312	TP317	S31700	...	...	8	(26) (28)	−325	75	30	20.0	*20.0*	*20.0*	**19.3**
18Cr–13Ni–3Mo	Pipe	A409	TP317	S31700	...	...	8	(26) (28) (31) (36)	−325	75	30	20.0	*20.0*	*20.0*	**19.3**
16Cr–12Ni–2Mo	Pipe	A376	TP316H	S31609	...	...	8	(26) (31) (36)	−325	75	30	20.0	*20.0*	*20.0*	**19.3**
16Cr–12Ni–2Mo	Pipe	A312	TP316H	S31609	...	...	8	(26)	−325	75	30	20.0	*20.0*	*20.0*	**19.3**
18Cr–10Ni–Cb	Pipe	A376	TP347H	S34709	...	...	8	(30) (36)	−325	75	30	20.0	*20.0*	*20.0*	*20.0*
18Cr–10Ni–Cb	Pipe	A312	TP347	S34700	...	...	8	(28)	−425	75	30	20.0	*20.0*	*20.0*	*20.0*
18Cr–10Ni–Cb	Pipe	A358	347	S34700	...	...	8	(28) (30) (36)	−425	75	30	20.0	*20.0*	*20.0*	*20.0*
18Cr–10Ni–Cb	Pipe	A376	TP347	S34700	...	...	8	(28) (30) (36)	−425	75	30	20.0	*20.0*	*20.0*	*20.0*
18Cr–10Ni–Cb	Pipe	A409	TP347	S34700	...	...	8	(28) (30) (36)	−425	75	30	20.0	*20.0*	*20.0*	*20.0*
18Cr–10Ni–Cb	Pipe	A312	TP348	S34800	...	...	8	(28)	−325	75	30	20.0	*20.0*	*20.0*	*20.0*
18Cr–10Ni–Cb	Pipe	A358	348	S34800	...	...	8	(28) (30) (36)	−325	75	30	20.0	*20.0*	*20.0*	*20.0*
18Cr–10Ni–Cb	Pipe	A376	TP348	S34800	...	...	8	(28) (30) (36)	−325	75	30	20.0	*20.0*	*20.0*	*20.0*
18Cr–10Ni–Cb	Pipe	A409	TP348	S34800	...	...	8	(28) (30) (36)	−325	75	30	20.0	*20.0*	*20.0*	*20.0*
18Cr–10Ni–Cb	Pipe	A312	TP347H	S34709	...	...	8	...	−325	75	30	20.0	*20.0*	*20.0*	*20.0*
18Cr–10Ni–Cb	Pipe	A312	TP348H	S34809	...	...	8	...	−325	75	30	20.0	*20.0*	*20.0*	*20.0*
18Cr–8Ni	Tube	A213	TP304	S30400	...	...	8	(14) (26) (28) (31) (36)	−425	75	30	20.0	*20.0*	*20.0*	**18.6**
18Cr–8Ni	Tube	A269	TP304	S30400	...	...	8	(14) (26) (28) (31) (36)	−425	75	30	20.0	*20.0*	*20.0*	**18.6**
18Cr–8Ni	Tube	A270	TP304	S30400	...	...	8	(14) (26) (28)	−425	75	30	20.0	*20.0*	*20.0*	**18.6**
18Cr–8Ni	Pipe	A312	TP304	S30400	...	...	8	(26) (28)	−425	75	30	20.0	*20.0*	*20.0*	**18.6**
18Cr–8Ni	Pipe	A358	304	S30400	...	...	8	(26) (28) (31) (36)	−425	75	30	20.0	*20.0*	*20.0*	**18.6**
18Cr–8Ni	Pipe	A376	TP304	S30400	...	...	8	(20) (26) (28) (31) (36)	−425	75	30	20.0	*20.0*	*20.0*	**18.6**
18Cr–8Ni	Pipe	A376	TP304H	S30409	...	...	8	(26) (31) (36)	−325	75	30	20.0	*20.0*	*20.0*	**18.6**
18Cr–8Ni	Pipe	A409	TP304	S30400	...	...	8	(26) (28) (31) (36)	−425	75	30	20.0	*20.0*	*20.0*	**18.6**
18Cr–8Ni	Pipe	A312	TP304H	S30409	...	...	8	(26)	−325	75	30	20.0	*20.0*	*20.0*	**18.6**
18Cr–12Ni–2Mo	...	A451	CPF8M	J92900	...	...	8	(26) (28)	−425	70	30	20.0	*20.0*	*18.9*	**17.0**
44Fe–25Ni–21Cr–Mo	Tube	A249	...	N08904	...	...	45	...	−325	71	31	20.7	*20.7*	**20.4**	**18.7**
44Fe–25Ni–21Cr–Mo	Pipe	A312	...	N08904	...	...	45	...	−325	71	31	20.7	*20.7*	**20.4**	**18.7**
20Cr–Cu	Tube	A268	TP443	S44300	...	...	a	(7) (35)	−20	70	40	23.3	23.3	23.3	23.3

Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

Basic Allowable Stress, *S*, ksi, at Metal Temperature, °F [Notes (1), (4a)]																					
500	600	650	700	750	800	850	900	950	1,000	1,050	1,100	1,150	1,200	1,250	1,300	1,350	1,400	1,450	1,500	Type/ Grade	Spec. No.
															Stainless Steel — Pipes and Tubes (3)(4a)						(Cont'd)
18.0	17.0	16.6	16.3	16.1	15.9	15.7	15.6	15.4	15.3	15.1	12.4	9.8	7.4	5.5	4.1	3.1	2.3	1.7	1.3	TP316	A409
18.0	17.0	16.6	16.3	16.1	15.9	15.7	15.6	15.4	15.3	15.1	12.4	9.8	7.4	5.5	4.1	3.1	2.3	1.7	1.3	TP317	A312
18.0	17.0	16.6	16.3	16.1	15.9	15.7	15.6	15.4	15.3	15.1	12.4	9.8	7.4	5.5	4.1	3.1	2.3	1.7	1.3	TP317	A409
18.0	17.0	16.6	16.3	16.1	15.9	15.7	15.6	15.4	15.3	15.1	12.4	9.8	7.4	5.5	4.1	3.1	2.3	1.7	1.3	TP316H	A376
18.0	17.0	16.6	16.3	16.1	15.9	15.7	15.6	15.4	15.3	15.1	12.4	9.8	7.4	5.5	4.1	3.1	2.3	1.7	1.3	TP316H	A312
20.0	19.3	19.0	18.7	18.5	18.3	18.2	18.1	18.1	18.1	17.4	14.1	10.5	7.9	5.9	4.4	3.2	2.5	1.8	1.3	TP347H	A376
20.0	19.3	19.0	18.7	18.5	18.3	18.2	18.1	18.1	18.1	17.4	14.1	10.5	7.9	5.9	4.4	3.2	2.5	1.8	1.3	TP347	A312
20.0	19.3	19.0	18.7	18.5	18.3	18.2	18.1	18.1	18.1	17.4	14.1	10.5	7.9	5.9	4.4	3.2	2.5	1.8	1.3	347	A358
20.0	19.3	19.0	18.7	18.5	18.3	18.2	18.1	18.1	18.1	17.4	14.1	10.5	7.9	5.9	4.4	3.2	2.5	1.8	1.3	TP347	A376
20.0	19.3	19.0	18.7	18.5	18.3	18.2	18.1	18.1	18.1	17.4	14.1	10.5	7.9	5.9	4.4	3.2	2.5	1.8	1.3	TP347	A409
20.0	19.3	19.0	18.7	18.5	18.3	18.2	18.1	18.1	18.1	17.4	14.1	10.5	7.9	5.9	4.4	3.2	2.5	1.8	1.3	TP348	A312
20.0	19.3	19.0	18.7	18.5	18.3	18.2	18.1	18.1	18.1	17.4	14.1	10.5	7.9	5.9	4.4	3.2	2.5	1.8	1.3	348	A358
20.0	19.3	19.0	18.7	18.5	18.3	18.2	18.1	18.1	18.1	17.4	14.1	10.5	7.9	5.9	4.4	3.2	2.5	1.8	1.3	TP348	A376
20.0	19.3	19.0	18.7	18.5	18.3	18.2	18.1	18.1	18.1	17.4	14.1	10.5	7.9	5.9	4.4	3.2	2.5	1.8	1.3	TP348	A409
20.0	19.3	19.0	18.7	18.5	18.3	18.2	18.1	18.1	18.1	17.4	14.1	10.5	7.9	5.9	4.4	3.2	2.5	1.8	1.3	TP347H	A312
20.0	19.3	19.0	18.7	18.5	18.3	18.2	18.1	18.1	18.1	17.4	14.1	10.5	7.9	5.9	4.4	3.2	2.5	1.8	1.3	TP348H	A312
17.5	16.6	16.2	15.8	15.5	15.2	14.9	14.6	14.3	14.0	12.4	9.8	7.7	6.1	4.7	3.7	2.9	2.3	1.8	1.4	TP304	A213
17.5	16.6	16.2	15.8	15.5	15.2	14.9	14.6	14.3	14.0	12.4	9.8	7.7	6.1	4.7	3.7	2.9	2.3	1.8	1.4	TP304	A269
17.5	16.6	16.2	15.8	15.5	15.2	14.9	14.6	14.3	14.0	12.4	9.8	7.7	6.1	4.7	3.7	2.9	2.3	1.8	1.4	TP304	A270
17.5	16.6	16.2	15.8	15.5	15.2	14.9	14.6	14.3	14.0	12.4	9.8	7.7	6.1	4.7	3.7	2.9	2.3	1.8	1.4	TP304	A312
17.5	16.6	16.2	15.8	15.5	15.2	14.9	14.6	14.3	14.0	12.4	9.8	7.7	6.1	4.7	3.7	2.9	2.3	1.8	1.4	304	A358
17.5	16.6	16.2	15.8	15.5	15.2	14.9	14.6	14.3	14.0	12.4	9.8	7.7	6.1	4.7	3.7	2.9	2.3	1.8	1.4	TP304	A376
17.5	16.6	16.2	15.8	15.5	15.2	14.9	14.6	14.3	14.0	12.4	9.8	7.7	6.1	4.7	3.7	2.9	2.3	1.8	1.4	TP304H	A376
17.5	16.6	16.2	15.8	15.5	15.2	14.9	14.6	14.3	14.0	12.4	9.8	7.7	6.1	4.7	3.7	2.9	2.3	1.8	1.4	TP304	A409
17.5	16.6	16.2	15.8	15.5	15.2	14.9	14.6	14.3	14.0	12.4	9.8	7.7	6.1	4.7	3.7	2.9	2.3	1.8	1.4	TP304H	A312
15.8	15.0	14.7	14.4	14.2	14.1	13.9	13.7	13.4	13.1	11.5	8.9	6.9	5.4	4.3	3.4	2.8	2.3	1.9	1.6	CPF8M	A451
17.1	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	A249
17.1	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	A312
23.3	23.3	14.6	12.5	10.7	9.2	7.9	5.9	4.0	2.5	...	...	...	...	...	...	...	...	...	...	TP443	A268

Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

Nominal Composition	Product Form	Spec. No.	Type/ Grade	UNS No.	Class/ Condition/ Temper	Size, in.	P-No. (5)	Notes	Min. Temp., °F (6)	Specified Min. Strength, ksi: Tensile	Yield	Basic Allowable Stress, S, ksi, at Metal Temperature, °F [Notes (1), (4a)]: Min. Temp. to 100	200	300	400
Stainless Steel — Pipes and Tubes (3)(4a)															
27Cr	Tube	A268	TP446-1	S44600	...	...	10I	(35)	−20	70	40	23.3	23.3	22.5	21.9
12Cr	Wld. pipe	A1053	50	S41003	...	...	7	...	−20	70	50	23.3	23.3	23.3	22.8
25Cr–8Ni–N	...	A451	CPE20N	J92802	...	...	8	(35) (39)	−325	80	40	26.7	26.7	26.7	26.7
23Cr–4Ni–Mo–Cu–N	...	A789	...	S32304	...	...	10H	(25)	−60	87	58	29.0	27.9	26.1	24.7
23Cr–4Ni–Mo–Cu–N	...	A790	...	S32304	...	...	10H	(25)	−60	87	58	29.0	27.9	26.1	24.7
23Cr–4Ni–Mo–Cu–N	Wld. pipe	A928	2304	S32304	...	...	10H	(25)	−60	87	58	29.0	27.9	26.1	24.7
20Cr–18Ni–6Mo	Pipe	A813	...	S31254	...	...	8	...	−325	94	44	29.3	*29.3*	**28.9**	**26.7**
20Cr–18Ni–6Mo	Pipe	A814	...	S31254	...	...	8	...	−325	94	44	29.3	*29.3*	**28.9**	**26.7**
13Cr	...	A426	CPCA15	J91150	...	...	6	(10) (35)	−20	90	65	30.0	...	...	...
20Cr–18Ni–6Mo	Wld. pipe	A358	...	S31254	...	>3/16	8	...	−325	95	45	30.0	*30.0*	**29.6**	**27.3**
20Cr–18Ni–6Mo	Wld pipe	A358	...	S31254	...	≤3/16	8	...	−325	100	45	30.0	*30.0*	**29.6**	**27.3**
22Cr–5Ni–3Mo–N	...	A789	...	S31803	...	...	10H	(25)	−60	90	65	30.0	30.0	28.9	27.8
22Cr–5Ni–3Mo–N	...	A790	...	S31803	...	...	10H	(25)	−60	90	65	30.0	30.0	28.9	27.8
22Cr–5Ni–3Mo–N	Wld pipe	A928	...	S31803	...	...	10H	(25)	−60	90	65	30.0	30.0	28.9	27.8
20Cr–18Ni–6Mo	Tube	A249	...	S31254	...	>3/16 thk.	8	...	−325	95	45	30.0	*30.0*	**29.5**	**27.3**
20Cr–18Ni–6Mo	Tube	A249	...	S31254	...	≤3/16 thk.	8	...	−325	98	45	30.0	*30.0*	**29.5**	**27.3**
20Cr–18Ni–6Mo	Pipe	A312	...	S31254	...	>3/16 thk.	8	...	−325	95	45	30.0	*30.0*	**29.5**	**27.3**
20Cr–18Ni–6Mo	Pipe	A312	...	S31254	...	≤3/16 thk.	8	...	−325	98	45	30.0	*30.0*	**29.5**	**27.3**
26Cr–4Ni–Mo	...	A790	...	S32900	...	...	10H	(25)	−20	90	70	30.0	...	...	...
46Fe–24Ni–21Cr–6Mo–Cu–N	Smls. & wld. pipe	A312	...	N08367	...	>3/16	45	(26)	−325	95	45	30.0	*30.0*	*29.9*	*28.6*
46Fe–24Ni–21Cr–6Mo–Cu–N	Wld. pipe	A358	...	N08367	...	>3/16	45	(26)	−325	95	45	30.0	*30.0*	*29.9*	*28.6*
46Fe–24Ni–21Cr–6Mo–Cu–N	Wld. pipe	A813	...	N08367	...	>3/16	45	(26)	−325	95	45	30.0	*30.0*	*29.9*	*28.6*
46Fe–24Ni–21Cr–6Mo–Cu–N	Wld. pipe	A814	...	N08367	...	>3/16	45	(26)	−325	95	45	30.0	*30.0*	*29.9*	*28.6*
46Fe–24Ni–21Cr–6Mo–Cu–N	Smls. & wld. pipe	A312	...	N08367	...	≤3/16	45	(26)	−325	100	45	30.0	*30.0*	*30.0*	**29.6**
46Fe–24Ni–21Cr–6Mo–Cu–N	Wld. pipe	A358	...	N08367	...	≤3/16	45	(26)	−325	100	45	30.0	*30.0*	*30.0*	**29.6**
46Fe–24Ni–21Cr–6Mo–Cu–N	Wld. pipe	A813	...	N08367	...	≤3/16	45	(26)	−325	100	45	30.0	*30.0*	*30.0*	**29.6**
46Fe–24Ni–21Cr–6Mo–Cu–N	Wld. pipe	A814	...	N08367	...	≤3/16	45	(26)	−325	100	45	30.0	*30.0*	*30.0*	**29.6**
21Cr–5Mn–1½Ni–Cu–N	Tube	A789	...	S32101	...	>3/16	10H	(25)	−20	94	65	31.3	31.3	29.8	28.5
21Cr–5Mn–1½Ni–Cu–N	Pipe	A790	...	S32101	...	>3/16	10H	(25)	−20	94	65	31.3	31.3	29.8	28.5
22Cr–5Ni–3Mo–N	Tube	A789	2205	S32205	...	...	10H	(25)	−60	95	70	31.7	31.7	30.6	29.4
22Cr–5Ni–3Mo–N	Pipe	A790	2205	S32205	...	...	10H	(25)	−60	95	70	31.7	31.7	30.6	29.4
21Cr–5Mn–1½Ni–Cu–N	Tube	A789	...	S32101	...	≤3/16	10H	(25)	−20	101	77	33.7	33.7	32.1	31.0
21Cr–5Mn–1½Ni–Cu–N	Pipe	A790	...	S32101	...	≤3/16	10H	(25)	−20	101	77	33.7	33.7	32.1	31.0

Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

Basic Allowable Stress, *S*, ksi, at Metal Temperature, °F [Notes (1), (4a)]																						
500	600	650	700	750	800	850	900	950	1,000	1,050	1,100	1,150	1,200	1,250	1,300	1,350	1,400	1,450	1,500	Type/ Grade	Spec. No.
																				Stainless Steel — Pipes and Tubes (3)(4a)		(Cont'd)
21.5	20.9	20.6	20.2	19.7	19.1	18.4	17.5	16.4	15.1	...	...	...	...	...	...	...	...	...	...	TP446-1	A268
22.1	21.2	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	50	A1053
26.7	26.7	26.7	26.7	26.7	26.7	26.7	26.7	...	...	...	...	...	...	...	...	...	...	...	...	CPE20N	A451
22.9	19.2	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	A789
22.9	19.2	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	A790
22.9	19.2	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	2304	A928
25.8	**24.7**	**24.3**	**24.1**	**23.9**	**23.8**	**23.6**	...	...	...	...	...	...	...	...	...	...	...	...	...	...	A813
25.8	**24.7**	**24.3**	**24.1**	**23.9**	**23.8**	**23.6**	...	...	...	...	...	...	...	...	...	...	...	...	...	...	A814
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	CPCA15	A426
25.8	**24.7**	**24.3**	**24.1**	**23.9**	**23.7**	**22.8**	...	...	...	...	...	...	...	...	...	...	...	...	...	...	A358
25.8	**24.7**	**24.3**	**24.1**	**23.9**	**23.7**	**22.8**	...	...	...	...	...	...	...	...	...	...	...	...	...	...	A358
27.2	26.9	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	A789
27.2	26.9	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	A790
27.2	26.9	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	A928
25.8	**24.7**	**24.3**	**24.1**	**23.9**	**23.7**	**23.6**	...	...	...	...	...	...	...	...	...	...	...	...	...	...	A249
25.8	**24.7**	**24.3**	**24.1**	**23.9**	**23.7**	**23.6**	...	...	...	...	...	...	...	...	...	...	...	...	...	...	A249
25.8	**24.7**	**24.3**	**24.1**	**23.9**	**23.7**	**23.6**	...	...	...	...	...	...	...	...	...	...	...	...	...	...	A312
25.8	**24.7**	**24.3**	**24.1**	**23.9**	**23.7**	**23.6**	...	...	...	...	...	...	...	...	...	...	...	...	...	...	A312
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	A790
27.7	**26.2**	**25.7**	**25.1**	**24.7**	**24.3**	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	A312
27.7	**26.2**	**25.7**	**25.1**	**24.7**	**24.3**	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	A358
27.7	**26.2**	**25.7**	**25.1**	**24.7**	**24.3**	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	A813
27.7	**26.2**	**25.7**	**25.1**	**24.7**	**24.3**	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	A814
27.7	**26.2**	**25.7**	**25.1**	**24.7**	**24.3**	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	A312
27.7	**26.2**	**25.7**	**25.1**	**24.7**	**24.3**	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	A358
27.7	**26.2**	**25.7**	**25.1**	**24.7**	**24.3**	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	A813
27.7	**26.2**	**25.7**	**25.1**	**24.7**	**24.3**	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	A814
28.5	28.5	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	A789
28.5	28.5	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	A790
28.7	28.4	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	2205	A789
28.7	28.4	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	2205	A790
30.9	30.9	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	A789
30.9	30.9	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	A790

Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

										Specified Min. Strength, ksi		Basic Allowable Stress, *S*, ksi, at Metal Temperature, °F [Notes (1), (4a)]			
Nominal Composition	**Product Form**	**Spec. No.**	**Type/ Grade**	**UNS No.**	**Class/ Condition/ Temper**	**Size, in.**	**P-No. (5)**	**Notes**	**Min. Temp., °F (6)**	**Tensile**	**Yield**	**Min. Temp. to 100**	**200**	**300**	**400**
Stainless Steel — Pipes and Tubes (3)(4a)															
21Cr–3½Ni–1¾Mo–N	...	A789	...	S32003	...	>0.187 thk.	10H	(25)	−60	95	65	31.7	30.7	28.9	28.6
21Cr–3½Ni–1¾Mo–N	...	A790	...	S32003	...	>0.187 thk.	10H	(25)	−60	95	65	31.7	30.7	28.9	28.6
21Cr–3½Ni–1¾Mo–N	Wld pipe	A928	...	S32003	...	>0.187 thk.	10H	(25)	−60	95	65	31.7	30.7	28.9	28.6
22Cr–5Ni–3Mo–N	Wld pipe	A928	2205	S32205	...	...	10H	(25)	−60	95	65	31.7	31.7	30.6	29.4
24Cr–4Ni–3Mn–1.5Mo–N	Smls. & wld. tube	A789	...	S82441	...	≥0.40 thk.	10H	(25)	−60	99	70	32.9	32.9	32.9	32.9
24Cr–4Ni–3Mn–1.5Mo–N	Smls. & wld. pipe	A790	...	S82441	...	≥0.40 thk.	10H	(25)	−60	99	70	32.9	32.9	32.9	32.9
21Cr–3½Ni–1¾Mo–N	...	A789	...	S32003	...	≤0.187 thk.	10H	(25)	−60	100	70	33.3	32.3	30.4	30.1
21Cr–3½Ni–1¾Mo–N	...	A790	...	S32003	...	≤0.187 thk.	10H	(25)	−60	100	70	33.3	32.3	30.4	30.1
21Cr–3½Ni–1¾Mo–N	Wld. pipe	A928	...	S32003	...	≤0.187 thk.	10H	(25)	−60	100	70	33.3	32.3	30.4	30.1
24Cr–4Ni–3Mn–1.5Mo–N	Smls. & wld. tube	A789	...	S82441	...	<0.40 thk.	10H	(25)	−60	107	78	35.8	35.8	35.8	35.8
24Cr–4Ni–3Mn–1.5Mo–N	Smls. & wld. pipe	A790	...	S82441	...	<0.40 thk.	10H	(25)	−60	107	78	35.8	35.8	35.8	35.8
25Cr–8Ni–3Mo–W–Cu–N	...	A789	...	S32760	...	...	10H	(25)	−60	109	80	36.3	35.9	34.4	34.0
25Cr–8Ni–3Mo–W–Cu–N	...	A790	...	S32760	...	...	10H	(25)	−60	109	80	36.3	35.9	34.4	34.0
29Cr–6.5Ni–2Mo–N	Tube	A789	...	S32906	...	≥0.40 thk.	10H	(25)	−60	109	80	36.3	36.3	34.0	33.5
29Cr–6.5Ni–2Mo–N	Pipe	A790	...	S32906	...	≥0.40 thk.	10H	(25)	−60	109	80	36.3	36.3	34.0	33.5
24Cr–17Ni–6Mn–4½Mo–N	...	A358	...	S34565	...	...	8	(36)	−325	115	60	38.3	*38.1*	*35.8*	*34.5*
25Cr–7Ni–4Mo–N	Smls. & wld. tube	A789	...	S32750	...	...	10H	(25)	−60	116	80	38.7	38.5	36.4	35.1
25Cr–7Ni–4Mo–N	Smls. & wld. pipe	A790	2507	S32750	...	...	10H	(25)	−60	116	80	38.7	38.5	36.4	35.1
25Cr–7Ni–4Mo–N	Wld. pipe	A928	2507	S32750	...	...	10H	(25)	−60	116	80	38.7	38.5	36.4	35.1
29Cr–6.5Ni–2Mo–N	Tube	A789	...	S32906	...	<0.40 thk.	10H	(25)	−60	116	94	38.7	38.6	36.8	35.6
29Cr–6.5Ni–2Mo–N	Pipe	A790	...	S32906	...	<0.40 thk.	10H	(25)	−60	116	94	38.7	38.6	36.8	35.6
Stainless Steel — Plates and Sheets (3)(4a)															
18Cr–11Ni	...	A240	305	S30500	...	...	8	(26) (36) (39)	−325	70	25	16.7	...	...	...
12Cr–Al	...	A240	405	S40500	...	...	7	(35)	−20	60	25	16.7	15.3	14.8	14.5
18Cr–8Ni	...	A240	304L	S30403	...	...	8	(36)	−425	70	25	16.7	*16.7*	*16.7*	**15.8**
16Cr–12Ni–2Mo	...	A240	316L	S31603	...	...	8	(36)	−425	70	25	16.7	*16.7*	*16.7*	**15.7**

Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

Basic Allowable Stress, *S*, ksi, at Metal Temperature, °F [Notes (1), (4a)]																					
500	600	650	700	750	800	850	900	950	1,000	1,050	1,100	1,150	1,200	1,250	1,300	1,350	1,400	1,450	1,500	Type/ Grade	Spec. No.
																				Stainless Steel — Pipes and Tubes (3)(4a)	**(Cont'd)**
28.6	28.6	28.6	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	A789
28.6	28.6	28.6	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	A790
28.6	28.6	28.6	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	A928
28.7	28.4	28.3	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	2205	A928
32.9	32.8	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	A789
32.9	32.8	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	A790
30.1	30.1	30.1	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	A789
30.1	30.1	30.1	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	A790
30.1	30.1	30.1	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	A928
35.8	35.7	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	A789
35.8	35.7	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	A790
34.0	34.0	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	A789
34.0	34.0	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	A790
33.0	33.0	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	A789
33.0	33.0	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	A790
33.8	*33.2*	*33.1*	*32.7*	*32.4*	*32.0*	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	A358
34.5	34.3	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	A789
34.5	34.3	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	2507	A790
34.5	34.3	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	2507	A928
35.2	35.2	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	A789
35.2	35.2	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	A790
																				Stainless Steel — Plates and Sheets (3)(4a)	
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	305	A240
14.3	14.0	13.8	13.5	13.1	12.6	12.0	11.3	8.4	4.0	...	...	...	...	...	...	...	...	...	...	405	A240
14.7	**14.0**	**13.7**	**13.5**	**13.3**	**13.0**	**12.8**	*12.6*	*12.3*	12.0	6.3	5.1	4.0	3.2	2.6	2.1	1.7	1.1	1.0	0.9	304L	A240
14.8	**14.0**	**13.7**	**13.5**	**13.2**	**12.9**	**12.7**	**12.4**	**12.1**	**11.8**	**10.8**	*10.2*	*8.8*	6.4	4.7	3.5	2.5	1.8	1.3	1.0	316L	A240

Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

										Specified Min. Strength, ksi		Basic Allowable Stress, *S*, ksi, at Metal Temperature, °F [Notes (1), (4a)]			
Nominal Composition	**Product Form**	**Spec. No.**	**Type/ Grade**	**UNS No.**	**Class/ Condition/ Temper**	**Size, in.**	**P-No. (5)**	**Notes**	**Min. Temp., °F (6)**	**Tensile**	**Yield**	**Min. Temp. to 100**	**200**	**300**	**400**
Stainless Steel — Plates and Sheets (3)(4a)															
18Cr–8Ni	...	A240	302	S30200	...	...	8	(26) (36)	−325	75	30	20.0	*20.0*	*20.0*	**18.6**
12Cr–1Ni	...	A1010	40	S41003	...	...	7	...	−20	66	40	22.0	22.0	22.0	21.5
12Cr–1Ni	...	A1010	50	S41003	...	...	7	...	−20	70	50	23.3	23.3	23.3	22.8
13Cr	...	A240	410S	S41008	...	...	7	(35) (50)	−20	60	30	20.0	18.4	17.8	17.4
13Cr	...	A240	410	S41000	...	...	6	(35)	−20	65	30	20.0	18.4	17.8	17.4
15Cr	...	A240	429	S42900	...	...	6	(35)	−20	65	30	20.0	18.4	17.8	17.4
17Cr	...	A240	430	S43000	...	...	7	(35)	−20	65	30	20.0	18.4	17.8	17.4
18Cr–13Ni–3Mo	...	A240	317L	S31703	...	...	8	(36)	−325	75	30	20.0	*20.0*	*20.0*	**18.9**
25Cr–20Ni	...	A240	310S	S31008	...	...	8	(28) (31) (35) (36)	−325	75	30	20.0	*20.0*	*20.0*	*20.0*
18Cr–10Ni–Ti	Plate, sheet, strip	A240	321	S32100	...	...	8	(28) (31) (36)	−325	75	30	20.0	*20.0*	*20.0*	*20.0*
23Cr–12Ni	...	A240	309S	S30908	...	...	8	(28) (35) (36)	−325	75	30	20.0	*20.0*	*20.0*	*20.0*
18Cr–10Ni–Cb	...	A240	347	S34700	...	...	8	(36)	−425	75	30	20.0	*20.0*	*20.0*	*20.0*
18Cr–10Ni–Cb	...	A240	348	S34800	...	...	8	(36)	−325	75	30	20.0	*20.0*	*20.0*	*20.0*
25Cr–20Ni	...	A240	310H	S31009	...	...	8	(29) (35) (39)	−325	75	30	20.0	*20.0*	*20.0*	*20.0*
18Cr–10Ni–Ti	Plate, sheet, strip	A240	321	S32100	...	...	8	(28) (30) (36)	−325	75	30	20.0	*20.0*	*20.0*	*20.0*
18Cr–10Ni–Ti	Plate, sheet, strip	A240	321H	S32109	...	...	8	(30) (36)	−325	75	30	20.0	*20.0*	*20.0*	*20.0*
16Cr–12Ni–2Mo	...	A240	316	S31600	...	...	8	(26) (28) (36)	−425	75	30	20.0	*20.0*	*20.0*	**19.3**
18Cr–13Ni–3Mo	...	A240	317	S31700	...	...	8	(26) (28) (36)	−325	75	30	20.0	*20.0*	*20.0*	**19.3**
18Cr–10Ni–Cb	...	A240	347	S34700	...	...	8	(28) (36)	−425	75	30	20.0	*20.0*	*20.0*	*20.0*
18Cr–10Ni–Cb	...	A240	348	S34800	...	...	8	(28) (36)	−325	75	30	20.0	*20.0*	*20.0*	*20.0*
18Cr–8Ni	...	A240	304	S30400	...	...	8	(26) (28) (36)	−425	75	30	20.0	*20.0*	*20.0*	**18.6**
44Fe–25Ni–21Cr–Mo	...	A240	904L	N08904	...	...	45	...	−325	71	31	20.7	*20.7*	**20.4**	**18.7**
23Cr–4Ni–Mo–Cu–N	...	A240	2304	S32304	...	...	10H	(25)	−60	87	58	29.0	27.9	26.1	24.7
22Cr–5Ni–3Mo–N	...	A240	...	S31803	...	...	10H	(25)	−60	90	65	30.0	30.0	28.9	27.8
16Cr–4Ni–6Mn	...	A240	201LN	S20153	...	...	8	...	−325	95	45	30.0	*27.6*	*24.7*	*23.4*
20Cr–18Ni–6Mo	...	A240	...	S31254	...	$>\frac{3}{16}$ thk.	8	...	−325	95	45	30.0	*30.0*	**29.6**	**27.4**
20Cr–18Ni–6Mo	...	A240	...	S31254	...	$\leq\frac{3}{16}$ thk.	8	...	−325	98	45	30.0	*30.0*	**29.6**	**27.4**

Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

Basic Allowable Stress, *S*, ksi, at Metal Temperature, °F [Notes (1), (4a)]																					
500	600	650	700	750	800	850	900	950	1,000	1,050	1,100	1,150	1,200	1,250	1,300	1,350	1,400	1,450	1,500	Type/ Grade	Spec. No.
															Stainless Steel — Plates and Sheets (3)(4a) (Cont'd)						
17.5	**16.6**	**16.2**	**15.8**	**15.5**	**15.2**	**14.9**	**14.6**	**14.3**	*14.0*	...	...	...	...	...	...	...	...	...	...	302	A240
20.8	20.0	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	40	A1010
22.1	21.2	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	50	A1010
17.2	16.8	16.6	16.2	15.7	15.1	14.4	12.3	8.8	6.4	4.4	2.9	1.8	1.0	...	...	...	...	...	...	410S	A240
17.2	16.8	16.6	16.2	15.7	15.1	14.4	12.3	8.8	6.4	4.4	2.9	1.8	1.0	...	...	...	...	...	...	410	A240
17.2	16.8	16.6	16.2	15.7	15.1	14.4	12.0	9.2	6.5	4.5	3.2	2.4	1.8	...	...	...	...	...	...	429	A240
17.2	16.8	16.6	16.2	15.7	15.1	14.4	12.0	9.2	6.5	4.5	3.2	2.4	1.8	...	...	...	...	...	...	430	A240
17.7	**16.9**	**16.5**	**16.2**	**15.8**	**15.5**	**15.2**	...	...	...	...	...	...	...	...	...	...	...	...	...	317L	A240
19.3	**18.5**	**18.2**	**17.9**	**17.7**	**17.4**	*17.2*	*16.9*	*15.9*	*9.9*	7.1	5.0	3.6	2.5	1.5	0.8	0.5	0.4	0.3	0.2	310H	A240
19.3	**18.3**	**17.8**	**17.5**	**17.2**	**16.9**	**16.7**	**16.5**	**16.4**	**16.2**	9.6	6.9	5.0	3.6	2.6	1.7	1.1	0.8	0.5	0.3	321	A240
19.4	**18.8**	**18.5**	**18.2**	**18.0**	**17.7**	*17.5*	*17.2*	*16.9*	13.8	10.3	7.6	5.5	4.0	3.0	2.2	1.7	1.3	1.0	0.8	309S	A240
20.0	**19.3**	**19.0**	**18.7**	**18.5**	**18.3**	*18.2*	*18.1*	*18.1*	*16.0*	*12.1*	9.1	6.1	4.4	3.3	2.2	1.5	1.2	0.9	0.8	347	A240
20.0	**19.3**	**19.0**	**18.7**	**18.5**	**18.3**	*18.2*	*18.1*	*18.1*	*16.0*	*12.1*	9.1	6.1	4.4	3.3	2.2	1.5	1.2	0.9	0.8	348	A240
19.3	**18.5**	**18.2**	**17.9**	**17.7**	**17.4**	*17.2*	*16.9*	*16.7*	13.8	10.3	7.6	5.5	4.0	3.0	2.2	1.7	1.3	1.0	0.8	310H	A240
19.3	**18.3**	**17.8**	**17.5**	**17.2**	**16.9**	**16.7**	**16.5**	**16.4**	**16.2**	12.3	9.1	6.9	5.4	4.1	3.2	2.5	1.9	1.5	1.1	321	A240
19.3	**18.3**	**17.8**	**17.5**	**17.2**	**16.9**	**16.7**	**16.5**	**16.4**	**16.2**	12.3	9.1	6.9	5.4	4.1	3.2	2.5	1.9	1.5	1.1	321H	A240
18.0	**17.0**	**16.6**	**16.3**	**16.1**	**15.9**	**15.7**	**15.6**	**15.4**	**15.3**	*15.1*	*12.4*	9.8	7.4	5.5	4.1	3.1	2.3	1.7	1.3	316	A240
18.0	**17.0**	**16.6**	**16.3**	**16.1**	**15.9**	**15.7**	**15.6**	**15.4**	**15.3**	*15.1*	*12.4*	9.8	7.4	5.5	4.1	3.1	2.3	1.7	1.3	317	A240
20.0	**19.3**	**19.0**	**18.7**	**18.5**	**18.3**	**18.2**	**18.1**	**18.1**	**18.1**	**17.4**	14.1	10.5	7.9	5.9	4.4	3.2	2.5	1.8	1.3	347	A240
20.0	**19.3**	**19.0**	**18.7**	**18.5**	**18.3**	**18.2**	**18.1**	**18.1**	**18.1**	**17.4**	14.1	10.5	7.9	5.9	4.4	3.2	2.5	1.8	1.3	348	A240
17.5	**16.6**	**16.2**	**15.8**	**15.5**	**15.2**	**14.9**	**14.6**	**14.3**	*14.0*	*12.4*	9.8	7.7	6.1	4.7	3.7	2.9	2.3	1.8	1.4	304	A240
17.1	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	904L	A240
22.9	19.2	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	2304	A240
27.2	26.9	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	A240
23.0	*22.9*	*22.8*	*22.6*	*22.3*	*21.8*	*21.5*	...	...	...	...	...	...	...	...	...	...	...	...	...	201LN	A240
25.8	**24.7**	**24.3**	**24.1**	**23.9**	**23.7**	**23.6**	...	...	...	...	...	...	...	...	...	...	...	...	...	...	A240
25.8	**24.7**	**24.3**	**24.1**	**23.9**	**23.7**	**23.6**	...	...	...	...	...	...	...	...	...	...	...	...	...	...	A240

Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

Nominal Composition	Product Form	Spec. No.	Type/ Grade	UNS No.	Class/ Condition/ Temper	Size, in.	P-No. (5)	Notes	Min. Temp., °F (6)	Specified Min. Strength, ksi: Tensile	Specified Min. Strength, ksi: Yield	Basic Allowable Stress, S, ksi, at Metal Temperature, °F [Notes (1), (4a)]: Min. Temp. to 100	200	300	400
Stainless Steel — Plates and Sheets (3)(4a)															
46Fe–24Ni–21Cr–6Mo–Cu–N	Plate	A240	...	N08367	...	>3/16	45	(26)	−325	95	45	30.0	*30.0*	*29.9*	*28.6*
46Fe–24Ni–21Cr–6Mo–Cu–N	Sheet & strip	A240	...	N08367	...	≤3/16	45	(26)	−325	100	45	30.0	*30.0*	*30.0*	**29.6**
21Cr–5Mn–1½Ni–Cu–N	...	A240	...	S32101	...	>3/16 thk.	10H	(25)	−20	94	65	31.3	31.3	29.8	28.5
24Cr–4Ni–3Mn–1.5Mo–N	...	A240	...	S82441	...	≥0.40 thk.	10H	(25)	−60	99	70	32.9	32.9	32.9	32.9
21Cr–5Mn–1½Ni–Cu–N	...	A240	...	S32101	...	≤3/16 thk.	10H	(25)	−20	101	77	33.7	33.7	32.1	31.0
22Cr–5Ni–3Mo–N	...	A240	2205	S32205	...	...	10H	(25)	−60	95	65	31.7	31.7	30.6	29.4
21Cr–3½Ni–1¾Mo–N	...	A240	...	S32003	...	>0.187 thk.	10H	(25)	−60	95	65	31.7	30.7	28.9	28.6
21Cr–3½Ni–1¾Mo–N	...	A240	...	S32003	...	≤0.187 thk.	10H	(25)	−60	100	70	33.3	32.3	30.4	30.1
24Cr–4Ni–3Mn–1.5Mo–N	...	A240	...	S82441	...	<0.40 thk.	10H	(25)	−60	107	78	35.8	35.8	35.8	35.8
29Cr–6.5Ni–2Mo–N	...	A240	...	S32906	...	≥0.40 thk.	10H	(25)	−60	109	80	36.3	36.3	34.5	33.5
29Cr–6.5Ni–2Mo–N	...	A240	...	S32906	...	<0.40 thk.	10H	(25)	−60	116	94	38.7	38.6	36.8	35.6
25Cr–8Ni–3Mo–W–Cu–N	...	A240	...	S32760	...	...	10H	(25)	−60	109	80	36.3	36.3	34.8	34.0
25Cr–7Ni–4Mo–N	...	A240	2507	S32750	...	...	10H	(25)	−60	116	80	38.7	38.5	36.4	35.1
Stainless Steel — Forgings and Fittings (3)(4a)															
18Cr–13Ni–3Mo	...	A182	F317L	S31703	...	≤5 thk.	8	(9) (21a)	−325	70	25	16.7	*16.7*	**16.7**	**15.7**
18Cr–8Ni	...	A182	F304L	S30403	...	...	8	(9) (21a)	−425	70	25	16.7	*16.7*	*16.7*	*15.8*
18Cr–8Ni	...	A403	WP304L	S30403	...	...	8	(32) (37)	−425	70	25	16.7	*16.7*	*16.7*	*15.8*
16Cr–12Ni–2Mo	...	A182	F316L	S31603	...	...	8	(9) (21a)	−425	70	25	16.7	*16.7*	*16.7*	**15.7**
16Cr–12Ni–2Mo	...	A403	WP316L	S31603	...	...	8	(32) (37)	−425	70	25	16.7	*16.7*	*16.7*	**15.7**
18Cr–13Ni–3Mo	...	A403	WP317L	S31703	...	...	8	(32) (37)	−325	75	30	20.0	*20.0*	*20.0*	**18.9**
25Cr–20Ni	...	A182	F310	S31000	...	...	8	(9) (35) (39)	−325	75	30	20.0	*20.0*	*20.0*	*20.0*
25Cr–20Ni	...	A403	WP310S	S31008	...	...	8	(28) (32) (35) (37)	−325	75	30	20.0	*20.0*	*20.0*	*20.0*
18Cr–10Ni–Ti	Smls. fittings	A403	WP321	S32100	...	>3/8 thk.	8	(28)	−325	70	25	16.7	*16.7*	*16.7*	*16.7*
18Cr–10Ni–Ti	Forgings	A182	F321	S32100	...	...	8	(9) (21) (28)	−325	75	30	20.0	*20.0*	*20.0*	*20.0*
18Cr–10Ni–Ti	Smls. fittings	A403	WP321	S32100	...	≤3/8 thk.	8	(28)	−325	75	30	20.0	*20.0*	*20.0*	*20.0*
18Cr–10Ni–Ti	Wld. fittings	A403	WP321	S32100	...	...	8	(28)	−325	75	30	20.0	*20.0*	*20.0*	*20.0*

Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

Basic Allowable Stress, *S*, ksi, at Metal Temperature, °F [Notes (1), (4a)]																					
500	600	650	700	750	800	850	900	950	1,000	1,050	1,100	1,150	1,200	1,250	1,300	1,350	1,400	1,450	1,500	Type/ Grade	Spec. No.
																				Stainless Steel — Plates and Sheets (3)(4a)	(Cont'd)
27.7	**26.2**	**25.7**	**25.1**	**24.7**	**24.3**	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	A240
27.7	**26.2**	**25.7**	**25.1**	**24.7**	**24.3**	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	A240
28.5	28.5	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	A240
32.9	32.8	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	A240
30.9	30.9	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	A240
28.7	28.4	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	2205	A240
28.6	28.6	28.6	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	A240
30.1	30.1	30.1	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	A240
35.8	35.7	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	A240
33.0	33.0	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	A240
35.2	35.2	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	A240
33.9	33.9	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	A240
34.5	34.3	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	2507	A240
																				Stainless Steel — Forgings and Fittings (3)(4a)	
14.8	**14.0**	**13.7**	**13.5**	**13.2**	**12.9**	**12.7**	...	...	...	...	...	...	...	...	...	...	...	...	...	F317L	A182
14.7	*14.0*	**13.7**	**13.5**	**13.3**	**13.0**	**12.8**	*12.6*	*12.3*	12.0	6.3	5.1	4.0	3.2	2.6	2.1	1.7	1.1	1.0	0.9	F304L	A182
14.7	*14.0*	**13.7**	**13.5**	**13.3**	**13.0**	**12.8**	*12.6*	*12.3*	12.0	6.3	5.1	4.0	3.2	2.6	2.1	1.7	1.1	1.0	0.9	WP304L	A403
14.8	**14.0**	**13.7**	**13.5**	**13.2**	**12.9**	**12.7**	**12.4**	**12.1**	**11.8**	**10.8**	*10.2*	*8.8*	6.4	4.7	3.5	2.5	1.8	1.3	1.0	F316L	A182
14.8	**14.0**	**13.7**	**13.5**	**13.2**	**12.9**	**12.7**	**12.4**	**12.1**	**11.8**	**10.8**	*10.2*	*8.8*	6.4	4.7	3.5	2.5	1.8	1.3	1.0	WP316L	A403
17.7	**16.9**	**16.5**	**16.2**	**15.8**	**15.5**	**15.2**	...	...	...	...	...	...	...	...	...	...	...	...	...	WP317L	A403
19.3	**18.5**	**18.2**	**17.9**	**17.7**	**17.4**	*17.2*	*16.9*	*15.9*	9.9	7.1	5.0	3.6	2.5	1.5	0.8	0.5	0.4	0.3	0.2	F310	A182
19.3	**18.5**	**18.2**	**17.9**	**17.7**	**17.4**	*17.2*	*16.9*	*15.9*	9.9	7.1	5.0	3.6	2.5	1.5	0.8	0.5	0.4	0.3	0.2	WP310S	A403
16.1	**15.2**	**14.9**	**14.6**	**14.3**	**14.1**	**13.9**	**13.8**	**13.6**	**13.5**	9.6	6.9	5.0	3.6	2.6	1.7	1.1	0.8	0.5	0.3	WP321	A403
19.3	**18.3**	**17.8**	**17.5**	**17.2**	**16.9**	**16.7**	**16.5**	**16.4**	**16.2**	9.6	6.9	5.0	3.6	2.6	1.7	1.1	0.8	0.5	0.3	F321	A182
19.3	**18.3**	**17.8**	**17.5**	**17.2**	**16.9**	**16.7**	**16.5**	**16.4**	**16.2**	9.6	6.9	5.0	3.6	2.6	1.7	1.1	0.8	0.5	0.3	WP321	A403
19.3	**18.3**	**17.8**	**17.5**	**17.2**	**16.9**	**16.7**	**16.5**	**16.4**	**16.2**	9.6	6.9	5.0	3.6	2.6	1.7	1.1	0.8	0.5	0.3	WP321	A403

Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

Nominal Composition	Product Form	Spec. No.	Type/ Grade	UNS No.	Class/ Condition/ Temper	Size, in.	P-No. (5)	Notes	Min. Temp., °F (6)	Specified Min. Strength, ksi		Basic Allowable Stress, S, ksi, at Metal Temperature, °F [Notes (1), (4a)]			
										Tensile	Yield	Min. Temp. to 100	200	300	400
Stainless Steel — Forgings and Fittings (3)(4a)															
23Cr–12Ni	...	A403	WP309	S30900	...	...	8	(28) (32) (35) (37) (39)	−325	75	30	20.0	20.0	20.0	20.0
25Cr–20Ni	...	A182	F310H	S31009	...	...	8	(9) (21) (29) (35) (39)	−325	75	30	20.0	20.0	20.0	20.0
25Cr–20Ni	...	A403	WP310H	S31009	...	...	8	(28) (29) (32) (35) (37) (39)	−325	75	30	20.0	20.0	20.0	20.0
18Cr–10Ni–Cb	...	A182	F347	S34700	...	...	8	(9) (21)	−425	75	30	20.0	20.0	20.0	20.0
18Cr–10Ni–Cb	...	A403	WP347	S34700	...	...	8	(32) (37)	−425	75	30	20.0	20.0	20.0	20.0
18Cr–10Ni–Cb	...	A182	F348	S34800	...	...	8	(9) (21)	−325	75	30	20.0	20.0	20.0	20.0
18Cr–10Ni–Cb	...	A403	WP348	S34800	...	...	8	(32) (37)	−325	75	30	20.0	20.0	20.0	20.0
18Cr–10Ni–Ti	Smls. fittings	A403	WP321	S32100	...	$>\frac{3}{8}$ thk.	8	(28) (30)	−325	70	25	16.7	16.7	16.7	16.7
18Cr–10Ni–Ti	Smls. fittings	A403	WP321H	S32109	...	$>\frac{3}{8}$ thk.	8	(30)	−325	70	25	16.7	16.7	16.7	16.7
18Cr–10Ni–Ti	Forgings	A182	F321	S32100	...	...	8	(9) (21) (28) (30)	−325	75	30	20.0	20.0	20.0	20.0
18Cr–10Ni–Ti	Forgings	A182	F321H	S32109	...	...	8	(9) (21)	−325	75	30	20.0	20.0	20.0	20.0
18Cr–10Ni–Ti	Smls. fittings	A403	WP321	S32100	...	$\leq\frac{3}{8}$ thk.	8	(28) (30)	−325	75	30	20.0	20.0	20.0	20.0
18Cr–10Ni–Ti	Smls. fittings	A403	WP321H	S32109	...	$\leq\frac{3}{8}$ thk.	8	(30)	−325	75	30	20.0	20.0	20.0	20.0
18Cr–10Ni–Ti	Wld. fittings	A403	WP321	S32100	...	...	8	(28) (30)	−325	75	30	20.0	20.0	20.0	20.0
18Cr–10Ni–Ti	Wld. fittings	A403	WP321H	S32109	...	...	8	(30)	−325	75	30	20.0	20.0	20.0	20.0
16Cr–12Ni–2Mo	...	A403	WP316H	S31609	...	...	8	(26) (32) (37)	−325	75	30	20.0	20.0	20.0	**19.3**
16Cr–12Ni–2Mo	...	A182	F316H	S31609	...	...	8	(9) (21) (26)	−325	75	30	20.0	20.0	20.0	**19.3**
18Cr–10Ni–Cb	...	A403	WP347H	S34709	...	...	8	(32) (37)	−325	75	30	20.0	20.0	20.0	20.0
18Cr–10Ni–Cb	...	A182	F347	S34700	...	...	8	(9) (21) (28)	−425	75	30	20.0	20.0	20.0	20.0
18Cr–10Ni–Cb	...	A403	WP347	S34700	...	...	8	(28) (32) (37)	−425	75	30	20.0	20.0	20.0	20.0
18Cr–10Ni–Cb	...	A182	F348	S34800	...	...	8	(9) (21) (28)	−325	75	30	20.0	20.0	20.0	20.0
18Cr–10Ni–Cb	...	A403	WP348	S34800	...	...	8	(28) (32) (37)	−325	75	30	20.0	20.0	20.0	20.0
18Cr–10Ni–Cb	...	A182	F347H	S34709	...	...	8	(9) (21)	−325	75	30	20.0	20.0	20.0	20.0
18Cr–10Ni–Cb	...	A182	F348H	S34809	...	...	8	(9) (21)	−325	75	30	20.0	20.0	20.0	20.0
16Cr–12Ni–2Mo	...	A182	F316	S31600	...	...	8	(9) (21) (26) (28)	−325	75	30	20.0	20.0	20.0	**19.3**
16Cr–12Ni–2Mo	...	A403	WP316	S31600	...	...	8	(26) (28) (32) (37)	−425	75	30	20.0	20.0	20.0	**19.3**
18Cr–13Ni–3Mo	...	A403	WP317	S31700	...	...	8	(26) (28) (32)	−325	75	30	20.0	20.0	20.0	**19.3**

Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

Basic Allowable Stress, *S*, ksi, at Metal Temperature, °F [Notes (1), (4a)]																					
500	600	650	700	750	800	850	900	950	1,000	1,050	1,100	1,150	1,200	1,250	1,300	1,350	1,400	1,450	1,500	Type/ Grade	Spec. No.
														Stainless Steel — Forgings and Fittings (3)(4a)							**(Cont'd)**
19.4	**18.8**	**18.5**	**18.2**	**18.0**	**17.7**	*17.5*	*17.2*	*16.9*	13.8	10.3	7.6	5.5	4.0	3.0	2.2	1.7	1.3	1.0	0.8	WP309	A403
19.3	**18.5**	**18.2**	**17.9**	**17.7**	**17.4**	*17.2*	*16.9*	*16.7*	13.8	10.3	7.6	5.5	4.0	3.0	2.2	1.7	1.3	1.0	0.8	F310H	A182
19.3	**18.5**	**18.2**	**17.9**	**17.7**	**17.4**	*17.2*	*16.9*	*16.7*	13.8	10.3	7.6	5.5	4.0	3.0	2.2	1.7	1.3	1.0	0.8	WP310H	A403
20.0	**19.3**	**19.0**	**18.7**	**18.5**	**18.3**	*18.2*	*18.1*	*18.1*	*16.0*	*12.1*	9.1	6.1	4.4	3.3	2.2	1.5	1.2	0.9	0.8	F347	A182
20.0	**19.3**	**19.0**	**18.7**	**18.5**	**18.3**	*18.2*	*18.1*	*18.1*	*16.0*	*12.1*	9.1	6.1	4.4	3.3	2.2	1.5	1.2	0.9	0.8	WP347	A403
20.0	**19.3**	**19.0**	**18.7**	**18.5**	**18.3**	*18.2*	*18.1*	*18.1*	*16.0*	*12.1*	9.1	6.1	4.4	3.3	2.2	1.5	1.2	0.9	0.8	F348	A182
20.0	**19.3**	**19.0**	**18.7**	**18.5**	**18.3**	*18.2*	*18.1*	*18.1*	*16.0*	*12.1*	9.1	6.1	4.4	3.3	2.2	1.5	1.2	0.9	0.8	WP348	A403
16.1	**15.2**	**14.9**	**14.6**	**14.3**	**14.1**	**13.9**	**13.8**	**13.6**	**13.5**	12.3	9.1	6.9	5.4	4.1	3.2	2.5	1.9	1.5	1.1	WP321	A403
16.1	**15.2**	**14.9**	**14.6**	**14.3**	**14.1**	**13.9**	**13.8**	**13.6**	**13.5**	12.3	9.1	6.9	5.4	4.1	3.2	2.5	1.9	1.5	1.1	WP321H	A403
19.3	**18.3**	**17.8**	**17.5**	**17.2**	**16.9**	**16.7**	**16.5**	**16.4**	**16.2**	12.3	9.1	6.9	5.4	4.1	3.2	2.5	1.9	1.5	1.1	F321	A182
19.3	**18.3**	**17.8**	**17.5**	**17.2**	**16.9**	**16.7**	**16.5**	**16.4**	**16.2**	12.3	9.1	6.9	5.4	4.1	3.2	2.5	1.9	1.5	1.1	F321H	A182
19.3	**18.3**	**17.8**	**17.5**	**17.2**	**16.9**	**16.7**	**16.5**	**16.4**	**16.2**	12.3	9.1	6.9	5.4	4.1	3.2	2.5	1.9	1.5	1.1	WP321	A403
19.3	**18.3**	**17.8**	**17.5**	**17.2**	**16.9**	**16.7**	**16.5**	**16.4**	**16.2**	12.3	9.1	6.9	5.4	4.1	3.2	2.5	1.9	1.5	1.1	WP321H	A403
19.3	**18.3**	**17.8**	**17.5**	**17.2**	**16.9**	**16.7**	**16.5**	**16.4**	**16.2**	12.3	9.1	6.9	5.4	4.1	3.2	2.5	1.9	1.5	1.1	WP321	A403
19.3	**18.3**	**17.8**	**17.5**	**17.2**	**16.9**	**16.7**	**16.5**	**16.4**	**16.2**	12.3	9.1	6.9	5.4	4.1	3.2	2.5	1.9	1.5	1.1	WP321H	A403
18.0	**17.0**	**16.6**	**16.3**	**16.1**	**15.9**	**15.7**	**15.6**	**15.4**	**15.3**	*15.1*	*12.4*	9.8	7.4	5.5	4.1	3.1	2.3	1.7	1.3	WP316H	A403
18.0	**17.0**	**16.6**	**16.3**	**16.1**	**15.9**	**15.7**	**15.6**	**15.4**	**15.3**	*15.1*	*12.4*	9.8	7.4	5.5	4.1	3.1	2.3	1.7	1.3	F316H	A182
20.0	**19.3**	**19.0**	**18.7**	**18.5**	**18.3**	**18.2**	**18.1**	**18.1**	**18.1**	*17.4*	14.1	10.5	7.9	5.9	4.4	3.2	2.5	1.8	1.3	WP347H	A403
20.0	**19.3**	**19.0**	**18.7**	**18.5**	**18.3**	**18.2**	**18.1**	**18.1**	**18.1**	*17.4*	14.1	10.5	7.9	5.9	4.4	3.2	2.5	1.8	1.3	F347	A182
20.0	**19.3**	**19.0**	**18.7**	**18.5**	**18.3**	**18.2**	**18.1**	**18.1**	**18.1**	*17.4*	14.1	10.5	7.9	5.9	4.4	3.2	2.5	1.8	1.3	WP347	A403
20.0	**19.3**	**19.0**	**18.7**	**18.5**	**18.3**	**18.2**	**18.1**	**18.1**	**18.1**	*17.4*	14.1	10.5	7.9	5.9	4.4	3.2	2.5	1.8	1.3	F348	A182
20.0	**19.3**	**19.0**	**18.7**	**18.5**	**18.3**	**18.2**	**18.1**	**18.1**	**18.1**	*17.4*	14.1	10.5	7.9	5.9	4.4	3.2	2.5	1.8	1.3	WP348	A403
20.0	*19.3*	**19.0**	**18.7**	**18.5**	**18.3**	**18.2**	**18.1**	**18.1**	**18.1**	*17.4*	*14.1*	10.5	7.9	5.9	4.4	3.2	2.5	1.8	1.3	F347H	A182
20.0	*19.3*	**19.0**	**18.7**	**18.5**	**18.3**	**18.2**	**18.1**	**18.1**	**18.1**	*17.4*	*14.1*	10.5	7.9	5.9	4.4	3.2	2.5	1.8	1.3	F348H	A182
18.0	**17.0**	**16.6**	**16.3**	**16.1**	**15.9**	**15.7**	**15.6**	**15.4**	**15.3**	*15.1*	*12.4*	9.8	7.4	5.5	4.1	3.1	2.3	1.7	1.3	F316	A182
18.0	**17.0**	**16.6**	**16.3**	**16.1**	**15.9**	**15.7**	**15.6**	**15.4**	**15.3**	*15.1*	*12.4*	9.8	7.4	5.5	4.1	3.1	2.3	1.7	1.3	WP316	A403
18.0	**17.0**	**16.6**	**16.3**	**16.1**	**15.9**	**15.7**	**15.6**	**15.4**	**15.3**	*15.1*	*12.4*	9.8	7.4	5.5	4.1	3.1	2.3	1.7	1.3	WP317	A403

Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

Nominal Composition	Product Form	Spec. No.	Type/ Grade	UNS No.	Class/ Condition/ Temper	Size, in.	P-No. (5)	Notes	Min. Temp., °F (6)	Specified Min. Strength, ksi: Tensile	Specified Min. Strength, ksi: Yield	Basic Allowable Stress, S, ksi, at Metal Temperature, °F [Notes (1), (4a)]: Min. Temp. to 100	200	300	400
Stainless Steel — Forgings and Fittings (3)(4a)															
18Cr–8Ni	...	A182	F304	S30400	...	...	8	(9) (21) (26) (28)	−425	75	30	20.0	*20.0*	*20.0*	**18.6**
18Cr–8Ni	...	A403	WP304	S30400	...	...	8	(26) (28) (32) (37)	−425	75	30	20.0	*20.0*	*20.0*	**18.6**
18Cr–8Ni	...	A403	WP304H	S30409	...	...	8	(26) (32) (37)	−325	75	30	20.0	*20.0*	*20.0*	**18.6**
18Cr–8Ni	...	A182	F304H	S30409	...	...	8	(9) (21) (26)	−325	75	30	20.0	*20.0*	*20.0*	**18.6**
44Fe–25Ni–21Cr–Mo	...	A182	F904L	N08904	...	...	45	...	−325	71	31	20.7	*20.7*	**20.4**	**18.7**
13Cr	...	A182	F6a	S41000	1	...	6	(35)	−20	70	40	23.3	23.3	22.9	22.5
13Cr	...	A182	F6a	S41000	2	...	6	(35)	−20	85	55	28.3	28.3	27.8	27.3
20Cr–18Ni–6Mo	...	A182	F44	S31254	...	...	8	...	−325	94	44	29.3	*29.3*	**28.9**	**26.7**
20Cr–18Ni–6Mo	...	A403	WPS31254	S31254	...	...	8	...	−325	94	44	29.3	*29.3*	**28.9**	**26.7**
23Cr–4Ni–Mo–Cu–N	...	A182	F68	S32304	...	...	10H	(25)	−60	87	58	29.0	27.9	26.1	24.7
22Cr–5Ni–3Mo–N	...	A182	F51	S31803	...	...	10H	(25)	−60	90	65	30.0	30.0	28.9	27.8
22Cr–5Ni–3Mo–N	...	A815	WPS31803	S31803	...	...	10H	(25)	−60	90	65	30.0	30.0	28.9	27.8
46Fe–24Ni–21Cr–6Mo–Cu–N	Forgings	A182	F62	N08367	...	...	45	(26)	−325	95	45	30.0	*30.0*	*29.9*	*28.6*
46Fe–24Ni–21Cr–6Mo–Cu–N	Fittings	A403	WP6XN	N08367	...	...	45	(26)	−325	95	45	30.0	*30.0*	*29.9*	*28.6*
21Cr–5Mn–1½Ni–Cu–N	...	A815	WP32101	S32101	...	...	10H	(25)	−20	94	65	31.3	31.3	29.8	28.5
22Cr–5Ni–3Mo–N	...	A182	F60	S32205	...	...	10H	(25)	−60	95	65	31.7	31.7	30.6	29.4
22Cr–5Ni–3Mo–N	...	A815	WPS32205	S32205	...	...	10H	(25)	−60	95	65	31.7	31.7	30.6	29.4
25Cr–8Ni–3Mo–W–Cu–N	...	A182	F55	S32760	...	...	10H	(25)	−60	109	80	36.3	36.3	34.8	34.0
25Cr–8Ni–3Mo–W–Cu–N	...	A815	WPS32760	S32760	...	...	10H	(25)	−60	109	80	36.3	36.3	34.8	34.0
25Cr–7Ni–4Mo–N	Forgings	A182	F53	S32750	...	≤2	10H	(25)	−60	116	80	38.7	38.5	36.4	35.1
25Cr–7Ni–4Mo–N	Fittings	A815	WPS32750	S32750	...	...	10H	(25)	−60	116	80	38.7	38.5	36.4	35.1
Stainless Steel — Bar (3)(4a)															
18Cr–8Ni	...	A479	304	S30400	...	...	8	(26) (28)	−425	75	30	20.0	20.0	20.0	18.6
18Cr–8Ni	...	A479	304H	S30409	...	...	8	(26)	−325	75	30	20.0	*20.0*	*20.0*	**18.7**
18Cr–8Ni	...	A479	304L	S30403	...	...	8	...	−425	70	25	16.7	*16.7*	*16.7*	*15.8*
16Cr–12Ni–2Mo	...	A479	316	S31600	...	...	8	(26) (28)	−325	75	30	20.0	*20.0*	*20.0*	**19.3**
16Cr–12Ni–2Mo	...	A479	316H	S31609	...	...	8	(26)	−325	75	30	20.0	*20.0*	*20.0*	**19.3**
16Cr–12Ni–2Mo	...	A479	316L	S31603	...	...	8	...	−425	70	25	16.7	*16.7*	*16.7*	**15.5**
18Cr–10Ni–Ti	Bar	A479	321	S32100	...	...	8	(28)	−325	75	30	20.0	*20.0*	*20.0*	*20.0*
18Cr–10Ni–Ti	Bar	A479	321	S32100	...	...	8	(28) (30)	−325	75	30	20.0	*20.0*	*20.0*	*20.0*
18Cr–10Ni–Ti	Bar	A479	321H	S32109	...	...	8	(30)	−325	75	30	20.0	*20.0*	*20.0*	*20.0*
18Cr–10Ni–Cb	...	A479	347	S34700	...	...	8	...	−425	75	30	20.0	20.0	20.0	20.0
18Cr–10Ni–Cb	...	A479	347	S34700	...	...	8	(28) (30)	−425	75	30	20.0	20.0	20.0	20.0

Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

Basic Allowable Stress, *S*, ksi, at Metal Temperature, °F [Notes (1), (4a)]																					
500	600	650	700	750	800	850	900	950	1,000	1,050	1,100	1,150	1,200	1,250	1,300	1,350	1,400	1,450	1,500	Type/ Grade	Spec. No.
Stainless Steel — Forgings and Fittings (3)(4a) (Cont'd)																					
17.5	**16.6**	16.2	15.8	15.5	15.2	14.9	14.6	14.3	14.0	*12.4*	9.8	7.7	6.1	4.7	3.7	2.9	2.3	1.8	1.4	F304	A182
17.5	**16.6**	16.2	15.8	15.5	15.2	14.9	14.6	14.3	14.0	*12.4*	9.8	7.7	6.1	4.7	3.7	2.9	2.3	1.8	1.4	WP304	A403
17.5	**16.6**	**16.2**	**15.8**	**15.5**	**15.2**	**14.9**	**14.6**	**14.3**	*14.0*	*12.4*	9.8	7.7	6.1	4.7	3.7	2.9	2.3	1.8	1.4	WP304H	A403
17.5	**16.6**	**16.2**	**15.8**	**15.5**	**15.2**	**14.9**	**14.6**	**14.3**	*14.0*	*12.4*	9.8	7.7	6.1	4.7	3.7	2.9	2.3	1.8	1.4	F304H	A182
17.1	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	F904L	A182
22.1	21.6	21.2	20.6	20.0	19.2	17.2	12.3	8.8	6.4	...	...	...	...	...	...	...	...	...	...	F6a Cl. 1	A182
26.9	26.2	25.7	25.1	24.3	23.3	17.2	12.3	8.8	6.4	4.4	2.9	1.8	1.0	...	...	...	...	...	...	F6a Cl. 2	A182
25.2	**24.1**	**23.8**	**23.6**	**23.4**	**23.2**	**23.0**	...	...	...	...	...	...	...	...	...	...	...	...	...	F44	A182
25.2	**24.1**	**23.8**	**23.6**	**23.4**	**23.2**	**23.0**	...	...	...	...	...	...	...	...	...	...	...	...	...	WPS31254	A403
22.9	19.2	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	F68	A182
27.2	26.9	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	F51	A182
27.2	26.9	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	WPS31803	A815
27.7	**26.2**	**25.7**	**25.1**	**24.7**	**24.3**	...	...	...	...	...	...	...	...	...	...	...	...	...	...	F62	A182
27.7	**26.2**	**25.7**	**25.1**	**24.7**	**24.3**	...	...	...	...	...	...	...	...	...	...	...	...	...	...	WP6XN	A403
28.5	28.5	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	WPS32101	A815
28.7	28.4	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	F60	A182
28.7	28.4	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	WPS32205	A815
33.9	33.9	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	F55	A182
33.9	33.9	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	WPS32760	A815
34.5	34.3	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	F53	A182
34.5	34.3	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	WPS32750	A815
Stainless Steel — Bar (3)(4a)																					
17.5	16.6	16.2	15.8	15.5	15.2	14.9	14.6	14.3	14.0	12.4	9.8	7.7	6.1	4.7	3.7	2.9	2.3	1.8	1.4	304	A479
17.5	**16.4**	**16.2**	**16.0**	**15.6**	**15.2**	**14.9**	**14.6**	**14.4**	*13.8*	*12.2*	9.7	7.7	6.0	4.7	3.7	2.9	2.3	1.8	1.4	304H	A479
14.8	*14.0*	**13.7**	**13.5**	**13.3**	**13.0**	**12.8**	*11.9*	*9.9*	7.8	6.3	5.1	4.0	3.2	2.6	2.1	1.7	1.1	1.0	0.9	304L	A479
17.9	**17.0**	**16.7**	**16.3**	**16.1**	**15.9**	**15.7**	**15.5**	**15.4**	**15.3**	*14.5*	*12.4*	9.8	7.4	5.5	4.1	3.1	2.3	1.7	1.3	316	A479
17.9	**17.0**	**16.7**	**16.3**	**16.1**	**15.9**	**15.7**	**15.5**	**15.4**	**15.3**	*14.5*	*12.4*	9.8	7.4	5.5	4.1	3.1	2.3	1.7	1.3	316H	A479
14.4	**13.5**	**13.2**	**12.9**	**12.6**	**12.4**	**12.1**	**11.8**	**11.5**	**11.2**	**10.8**	*10.2*	*8.8*	6.4	4.7	3.5	2.5	1.8	1.3	1.0	316L	A479
19.3	**18.3**	**17.8**	**17.5**	**17.2**	**16.9**	**16.7**	**16.5**	**16.4**	**16.2**	9.6	6.9	5.0	3.6	2.6	1.7	1.1	0.8	0.5	0.3	321	A479
19.3	**18.3**	**17.8**	**17.5**	**17.2**	**16.9**	**16.7**	**16.5**	**16.4**	**16.2**	12.3	9.1	6.9	5.4	4.1	3.2	2.5	1.9	1.5	1.1	321	A479
19.3	**18.3**	**17.8**	**17.5**	**17.2**	**16.9**	**16.7**	**16.5**	**16.4**	**16.2**	12.3	9.1	6.9	5.4	4.1	3.2	2.5	1.9	1.5	1.1	321H	A479
20.0	**19.3**	**19.0**	**18.7**	**18.5**	**18.3**	*18.2*	*18.1*	*18.1*	*16.0*	*12.1*	9.1	6.1	4.4	3.3	2.2	1.5	1.2	0.9	0.8	347	A479
20.0	**19.3**	**19.0**	**18.7**	**18.5**	**18.3**	**18.2**	**18.1**	**18.1**	**18.1**	*17.4*	14.1	10.5	7.9	5.9	4.4	3.2	2.5	1.8	1.3	347	A479

Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

Nominal Composition	Product Form	Spec. No.	Type/ Grade	UNS No.	Class/ Condition/ Temper	Size, in.	P-No. (5)	Notes	Min. Temp., °F (6)	Specified Min. Strength, ksi: Tensile	Specified Min. Strength, ksi: Yield	Basic Allowable Stress, S, ksi, at Metal Temperature, °F [Notes (1), (4a)]: Min. Temp. to 100	200	300	400
Stainless Steel — Bar (3)(4a)															
18Cr–10Ni–Cb	...	A479	347H	S34709	...	...	8	...	–325	75	30	20.0	20.0	20.0	20.0
44Fe–25Ni–21Cr–Mo	...	A479	904L	N08904	...	...	45	...	–325	71	31	20.7	*20.7*	**20.4**	**18.7**
22Cr–5Ni–3Mo–N	...	A479	...	S31803	...	...	10H	(25)	–60	90	65	30.0	30.0	28.9	27.8
20Cr–18Ni–6Mo	...	A479	...	S31254	...	...	8	...	–325	95	45	30.0	*30.0*	**29.5**	**27.3**
46Fe–24Ni–21Cr–6Mo–Cu–N	...	A479	...	N08367	...	...	45	(26)	–325	95	45	30.0	*30.0*	*29.9*	*28.6*
21Cr–5Mn–1.5Ni–Cu–N	...	A479	...	S32101	...	...	10H	(25)	–20	94	65	31.3	31.3	29.8	28.5
22Cr–5Ni–3Mo–N	...	A479	...	S32205	...	...	10H	(25)	–60	95	65	31.7	31.7	30.6	29.4
24Cr–4Ni–3Mn–1.5Mo–N	...	A479	...	S82441	...	$\geq \frac{7}{16}$ thk.	10H	(25)	–60	99	70	32.9	32.9	32.9	32.9
22Cr–13Ni–5Mn	...	A479	XM-19	S20910	Annealed	...	8	...	–325	100	55	33.3	*33.1*	*31.4*	*30.4*
24Cr–4Ni–3Mn–1.5Mo–N	...	A479	...	S82441	...	$< \frac{7}{16}$ thk.	10H	(25)	–60	107	78	35.8	35.8	35.8	35.8
29Cr–6.5Ni–2Mo–N	...	A479	...	S32906	...	...	10H	(25)	–60	109	80	36.3	36.3	34.5	33.5
25Cr–7Ni–4Mo–N	...	A479	...	S32750	...	≤2 thk.	10H	(25)	–60	116	80	38.7	38.5	36.4	35.1
Stainless Steel — Castings (3)(4a)															
29Ni–20Cr–3Cu–2Mo	...	A351	CN7M	N08007	...	...	45	(9) (30)	–325	62	25	16.7	...	...	...
35Ni–15Cr–½Mo	...	A351	HT30	N08603	...	...	45	(36) (39)	–325	65	28	18.7	...	...	...
25Cr–12Ni	...	A351	CH8	J93400	...	...	8	(9) (31)	–325	65	28	18.7	*18.7*	*18.5*	*18.0*
25Cr–20Ni	...	A351	CK20	J94202	...	...	8	(9) (27) (31) (35) (39)	–325	65	28	18.7	*18.7*	*18.5*	*18.0*
16Cr–14Ni–2Mo	...	A351	CF10MC	...	...	...	8	(30)	–325	70	30	20.0	...	...	...
18Cr–8Ni	...	A351	CF3	J92500	...	...	8	(9)	–425	70	30	20.0	*20.0*	**20.0**	**18.6**
18Cr–12Ni–2Mo	...	A351	CF3M	J92800	...	...	8	(9)	–425	70	30	20.0	*20.0*	20.0	19.2
18Cr–8Ni	...	A351	CF8	J92600	...	...	8	(9) (26) (27) (31)	–425	70	30	20.0	*20.0*	**20.0**	**18.6**
25Cr–12Ni	...	A351	CH10	J93401	...	...	8	(27) (31) (35)	–325	70	30	20.0	*20.0*	*19.9*	*19.4*
25Cr–12Ni	...	A351	CH20	J93402	...	...	8	(9) (27) (31) (35) (39)	–325	70	30	20.0	*20.0*	*19.9*	*19.4*
18Cr–10Ni–Cb	...	A351	CF8C	J92710	...	...	8	(9) (28)	–325	70	30	20.0	*20.0*	*20.0*	*19.5*
18Cr–12Ni–2Mo	...	A351	CF8M	J92900	...	...	8	(9) (26) (27) (30)	–425	70	30	20.0	*20.0*	*20.0*	**18.6**
25Cr–20Ni–½Mo	...	A351	HK40	J94204	...	...	8	(35) (36) (39)	–325	62	35	20.7	...	...	...
25Cr–20Ni–½Mo	...	A351	HK30	J94203	...	...	8	(35) (39)	–325	65	35	21.7	...	...	...
18Cr–8Ni	...	A351	CF3A	J92500	...	...	8	(9) (56)	–425	77	35	23.3	23.3	22.7	21.7

Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

Basic Allowable Stress, *S*, ksi, at Metal Temperature, °F [Notes (1), (4a)]																					
500	600	650	700	750	800	850	900	950	1,000	1,050	1,100	1,150	1,200	1,250	1,300	1,350	1,400	1,450	1,500	Type/ Grade	Spec. No.
																				Stainless Steel — Bar (3)(4a)	**(Cont'd)**
20.0	**19.3**	**19.0**	**18.7**	**18.5**	**18.3**	**18.2**	**18.1**	**18.1**	**18.1**	*17.4*	14.1	10.5	7.9	5.9	4.4	3.2	2.5	1.8	1.3	347H	A479
17.1	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	904L	A479
27.2	26.9	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	A479
25.8	**24.7**	**24.3**	**24.1**	**23.9**	**23.7**	**23.6**	...	...	...	...	...	...	...	...	...	...	...	...	...	...	A479
27.7	**26.2**	**25.7**	**25.1**	**24.7**	**24.3**	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	A479
28.5	28.5	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	A479
28.7	28.4	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	A479
32.9	32.8	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	A479
29.7	29.2	*29.0*	*28.8*	*28.6*	*28.3*	*27.9*	*27.5*	*27.0*	*26.3*	*25.5*	20.4	13.0	8.3	...	...	...	...	...	...	XM-19	A479
35.8	35.7	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	A479
33.0	33.0	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	A479
34.5	34.3	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	A479
																				Stainless Steel — Castings (3)(4a)	
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	CN7M	A351
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	HT30	A351
17.7	**17.1**	**16.7**	**16.3**	**15.9**	**15.4**	*14.9*	*14.4*	*13.9*	11.1	8.5	6.5	5.0	3.8	2.9	2.3	1.8	1.3	0.9	0.8	CH8	A351
17.7	**17.1**	**16.7**	**16.3**	**15.9**	**15.4**	*14.9*	*14.4*	*13.9*	11.3	9.8	8.5	7.3	6.0	4.8	3.5	2.4	1.6	1.1	0.8	CK20	A351
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	CF10MC	A351
17.5	**16.6**	**16.2**	**15.8**	**15.5**	**15.2**	...	...	...	...	...	...	...	...	...	...	...	...	...	...	CF3	A351
17.9	17.0	16.6	16.3	16.0	15.8	15.7	...	...	...	...	...	...	...	...	...	...	...	...	...	CF3M	A351
17.5	**16.6**	**16.2**	**15.8**	**15.5**	**15.2**	*14.9*	*14.6*	*14.3*	*12.2*	9.5	7.5	6.0	4.8	3.9	3.3	2.7	2.3	2.0	1.7	CF8	A351
18.9	**18.3**	**17.9**	**17.5**	**17.0**	**16.5**	**15.9**	**15.4**	*14.3*	11.1	8.5	6.5	5.0	3.8	2.9	2.3	1.8	1.3	0.9	0.8	CH10	A351
18.9	**18.3**	**17.9**	**17.5**	**17.0**	**16.5**	**15.9**	**15.4**	*14.3*	11.1	8.5	6.5	5.0	3.8	2.9	2.3	1.8	1.3	0.9	0.8	CH20	A351
18.8	*18.4*	*18.3*	*18.3*	*18.2*	**18.2**	**18.1**	**18.0**	**18.0**	16.0	12.1	9.1	6.1	4.4	3.3	2.2	1.5	1.2	0.9	0.8	CF8C	A351
17.5	**16.6**	**16.2**	**15.8**	**15.5**	**15.2**	*14.9*	*14.6*	*14.3*	*14.0*	12.1	9.1	6.1	4.4	3.3	2.2	1.5	1.2	0.9	0.8	CF8M	A351
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	HK40	A351
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	HK30	A351
20.4	19.3	18.9	18.5	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	CF3A	A351

Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

										Specified Min. Strength, ksi		Basic Allowable Stress, *S*, ksi, at Metal Temperature, °F [Notes (1), (4a)]			
Nominal Composition	Product Form	Spec. No.	Type/ Grade	UNS No.	Class/ Condition/ Temper	Size, in.	P-No. (5)	Notes	Min. Temp., °F (6)	Tensile	Yield	Min. Temp. to 100	200	300	400
Stainless Steel — Castings (3)(4a)															
18Cr–8Ni	...	A351	CF8A	J92600	...	...	8	(9) (26) (56)	−425	77	35	23.3	23.3	22.7	21.7
25Cr–8Ni–N	...	A351	CE20N	J92802	...	...	8	(35) (39)	−325	80	40	26.7	26.7	26.7	26.7
12Cr	...	A217	CA15	J91150	...	...	6	(35)	−20	90	65	30.0	30.0	29.4	28.9
24Cr–10Ni–4Mo–N	...	A995	2A	J93345	...	...	10H	(9)	−60	95	65	31.7	31.6	29.3	28.2
25Cr–8Ni–3Mo–W–Cu–N	...	A995	6A	J93380	...	...	10H	(9) (25)	−60	100	65	33.3	33.2	31.4	30.3
13Cr–4Ni	...	A487	CA6NM	J91540	A	...	6	(9) (35)	−20	110	80	36.7	36.7	35.9	35.3

Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

Basic Allowable Stress, *S*, ksi, at Metal Temperature, °F [Notes (1), (4a)]																					
500	600	650	700	750	800	850	900	950	1,000	1,050	1,100	1,150	1,200	1,250	1,300	1,350	1,400	1,450	1,500	Type/ Grade	Spec. No.
																				Stainless Steel — Castings (3)(4a)	**(Cont'd)**
20.4	19.3	18.9	18.5	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	CF8A	A351
26.7	26.7	26.7	26.7	26.7	26.7	26.7	26.7	...	...	...	...	...	...	...	...	...	...	...	...	CE20N	A351
28.4	27.7	27.2	26.5	17.5	16.8	14.9	11.0	7.6	5.0	3.3	2.3	1.5	1.0	...	...	...	...	...	...	CA15	A217
28.2	28.2	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	2A	A995
29.8	29.6	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	6A	A995
34.8	33.9	33.3	32.4	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	CA6NM Cl. A	A487

Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

Nominal Composition	Product Form	Spec. No.	UNS No.	Class/ Condition/ Temper	Size Range, in.	P-No. (5)(7)	Notes	Min. Temp., °F (6)	Specified Minimum Strength, ksi Tensile	Yield
Copper and Copper Alloy — Pipes and Tubes										
99.95Cu–P	Pipe	B42	C10200	O61	...	31	...	−452	30	9
99.9Cu–P	Pipe	B42	C12000	O61	...	31	...	−452	30	9
99.9Cu–P	Pipe	B42	C12200	O61	...	31	...	−452	30	9
99.95Cu–P	Tube	B75	C10200	O50	...	31	...	−452	30	9
99.95Cu–P	Tube	B75	C10200	O60	...	31	...	−452	30	9
99.9Cu–P	Tube	B75	C12000	O50	...	31	...	−452	30	9
99.9Cu–P	Tube	B75	C12000	O60	...	31	...	−452	30	9
99.9Cu–P	Tube	B75	C12200	O50	...	31	...	−452	30	9
99.9Cu–P	Tube	B75	C12200	O60	...	31	...	−452	30	9
99.9Cu–P	Tube	B68	C12200	O50	...	31	(24)	−452	30	9
99.9Cu–P	Tube	B68	C12200	O60	...	31	(24)	−452	30	9
99.9Cu–P	Tube	B88	C12200	O50	...	31	(24)	−452	30	9
99.9Cu–P	Tube	B88	C12200	O60	...	31	(24)	−452	30	9
99.9Cu–P	Tube	B280	C12200	O60	...	31	(24)	−452	30	9
85Cu–15Zn	Pipe	B43	C23000	O61	...	32	...	−452	40	12
90Cu–10Ni	...	B467	C70600	WO50	>4.5 O.D.	34	(14)	−452	38	13
90Cu–10Ni	...	B467	C70600	WO61	>4.5 O.D.	34	(14)	−452	38	13
90Cu–10Ni	...	B466	C70600	Annealed	...	34	(14)	−452	38	13
90Cu–10Ni	...	B467	C70600	WO50	≤4.5 O.D.	34	(14)	−452	40	15
90Cu–10Ni	...	B467	C70600	WO61	≤4.5 O.D.	34	(14)	−452	40	15
70Cu–30Ni	...	B467	C71500	WO50	>4.5 O.D.	34	(14)	−452	45	15
70Cu–30Ni	...	B467	C71500	WO61	>4.5 O.D.	34	(14)	−452	45	15
80Cu–20Ni	...	B466	C71000	Annealed	≤4.5 O.D.	34	(14)	−452	45	16
99.95Cu–P	Pipe	B42	C10200	H55	NPS 2½ thru 12	31	(14) (34)	−452	36	30
99.9Cu–P	Pipe	B42	C12000	H55	NPS 2½ thru 12	31	(14) (34)	−452	36	30
99.9Cu–P	Pipe	B42	C12200	H55	NPS 2½ thru 12	31	(14) (34)	−452	36	30
99.95Cu–P	Tube	B75	C10200	H58	...	31	(14) (34)	−452	36	30
99.9Cu–P	Tube	B75	C12000	H58	...	31	(14) (34)	−452	36	30
99.9Cu–P	Tube	B75	C12200	H58	...	31	(14) (34)	−452	36	30
99.9Cu–P	Tube	B88	C12200	H58	...	31	(14) (24) (34)	−452	36	30
70Cu–30Ni	...	B466	C71500	O60	...	34	(14)	−452	52	18
70Cu–30Ni	...	B467	C71500	WO50	≤4.5 O.D.	34	(14)	−452	50	20
70Cu–30Ni	...	B467	C71500	WO61	≤4.5 O.D.	34	(14)	−452	50	20
99.95Cu–P	Pipe	B42	C10200	H80	NPS ⅛ thru 2	31	(14) (34)	−452	45	40
99.9Cu–P	Pipe	B42	C12000	H80	NPS ⅛ thru 2	31	(14) (34)	−452	45	40
99.9Cu–P	Pipe	B42	C12200	H80	NPS ⅛ thru 2	31	(14) (34)	−452	45	40

Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

Basic Allowable Stress, *S*, ksi, at Metal Temperature, °F [Notes (1), (4a)]														
Min. Temp. to 100	150	200	250	300	350	400	450	500	550	600	650	700	UNS No.	Spec. No.
										Copper and Copper Alloy — Pipes and Tubes				
6.0	5.1	4.9	4.8	4.7	4.0	3.0	2.3	1.7	...	...	...	...	C10200	B42
6.0	5.1	4.9	4.8	4.7	4.0	3.0	2.3	1.7	...	...	...	...	C12000	B42
6.0	5.1	4.9	4.8	4.7	4.0	3.0	2.3	1.7	...	...	...	...	C12200	B42
6.0	5.1	4.9	4.8	4.7	4.0	3.0	2.3	1.7	...	...	...	...	C10200	B75
6.0	5.1	4.9	4.8	4.7	4.0	3.0	2.3	1.7	...	...	...	...	C10200	B75
6.0	5.1	4.9	4.8	4.7	4.0	3.0	2.3	1.7	...	...	...	...	C12000	B75
6.0	5.1	4.9	4.8	4.7	4.0	3.0	2.3	1.7	...	...	...	...	C12000	B75
6.0	5.1	4.9	4.8	4.7	4.0	3.0	2.3	1.7	...	...	...	...	C12200	B75
6.0	5.1	4.9	4.8	4.7	4.0	3.0	2.3	1.7	...	...	...	...	C12200	B75
6.0	5.1	4.9	4.8	4.7	4.0	3.0	2.3	1.7	...	...	...	...	C12200	B68
6.0	5.1	4.9	4.8	4.7	4.0	3.0	2.3	1.7	...	...	...	...	C12200	B68
6.0	5.1	4.9	4.8	4.7	4.0	3.0	2.3	1.7	...	...	...	...	C12200	B88
6.0	5.1	4.9	4.8	4.7	4.0	3.0	2.3	1.7	...	...	...	...	C12200	B88
6.0	5.1	4.9	4.8	4.7	4.0	3.0	2.3	1.7	...	...	...	...	C12200	B280
8.0	7.9	7.9	7.9	7.9	7.0	5.0	2.0	...	...	...	...	...	C23000	B43
8.7	8.4	8.2	8.0	7.8	7.7	7.5	7.4	7.3	7.0	6.0	...	...	C70600	B467
8.7	8.4	8.2	8.0	7.8	7.7	7.5	7.4	7.3	7.0	6.0	...	...	C70600	B467
8.7	8.4	8.2	8.0	7.8	7.7	7.5	7.4	7.3	7.0	6.0	...	...	C70600	B466
10.0	9.7	9.5	9.3	9.1	8.9	8.7	8.5	8.0	7.0	6.0	...	...	C70600	B467
10.0	9.7	9.5	9.3	9.1	8.9	8.7	8.5	8.0	7.0	6.0	...	...	C70600	B467
10.0	9.6	9.4	9.2	9.0	8.8	8.6	8.4	8.2	8.1	8.0	7.9	7.8	C71500	B467
10.0	9.6	9.4	9.2	9.0	8.8	8.6	8.4	8.2	8.1	8.0	7.9	7.8	C71500	B467
10.7	10.6	10.5	10.4	10.2	10.1	9.9	9.6	9.3	8.9	8.4	7.7	7.0	C71000	B466
12.0	11.6	10.9	10.4	10.0	9.8	9.5	...	...	...	...	...	...	C10200	B42
12.0	11.6	10.9	10.4	10.0	9.8	9.5	...	...	...	...	...	...	C12000	B42
12.0	11.6	10.9	10.4	10.0	9.8	9.5	...	...	...	...	...	...	C12200	B42
12.0	11.6	10.9	10.4	10.0	9.8	9.5	...	...	...	...	...	...	C10200	B75
12.0	11.6	10.9	10.4	10.0	9.8	9.5	...	...	...	...	...	...	C12000	B75
12.0	11.6	10.9	10.4	10.0	9.8	9.5	...	...	...	...	...	...	C12200	B75
12.0	11.6	10.9	10.4	10.0	9.8	9.5	...	...	...	...	...	...	C12200	B88
12.0	11.6	11.3	11.0	10.8	10.6	10.3	10.1	9.9	9.8	9.6	9.5	9.4	C71500	B466
13.3	12.9	12.6	12.3	12.0	11.7	11.5	11.2	11.0	10.8	10.7	10.5	10.4	C71500	B467
13.3	12.9	12.6	12.3	12.0	11.7	11.5	11.2	11.0	10.8	10.7	10.5	10.4	C71500	B467
15.0	14.5	13.6	13.0	12.6	12.2	4.3	...	...	...	...	...	...	C10200	B42
15.0	14.5	13.6	13.0	12.6	12.2	4.3	...	...	...	...	...	...	C12000	B42
15.0	14.5	13.6	13.0	12.6	12.2	4.3	...	...	...	...	...	...	C12200	B42

Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

Nominal Composition	Product Form	Spec. No.	UNS No.	Class/ Condition/ Temper	Size Range, in.	P-No. (5)(7)	Notes	Min. Temp., °F (6)	Specified Minimum Strength, ksi Tensile	Yield
Copper and Copper Alloy — Pipes and Tubes										
99.95Cu–P	Tube	B75	C10200	H80	...	31	(14) (34)	−452	45	40
99.9Cu–P	Tube	B75	C12000	H80	...	31	(14) (34)	−452	45	40
99.9Cu–P	Tube	B75	C12200	H80	...	31	(14) (34)	−452	45	40
Copper and Copper Alloy — Plates and Sheets										
99.95Cu–P	...	B152	C10200	O25	...	31	(14) (24)	−452	30	10
99.95Cu–Ag	...	B152	C10400	O25	...	31	(14) (24)	−452	30	10
99.95Cu–Ag	...	B152	C10500	O25	...	31	(14) (24)	−452	30	10
99.95Cu–Ag	...	B152	C10700	O25	...	31	(14) (24)	−452	30	10
99.9Cu–P	...	B152	C12200	O25	...	31	(14) (24)	−452	30	10
99.9Cu–P	...	B152	C12300	O25	...	31	(14) (24)	−452	30	10
90Cu–10Ni	...	B171	C70600	...	≤2.5 thk.	34	(14)	−452	40	15
97Cu–3Si	...	B96	C65500	O61	...	33	...	−452	50	18
70Cu–30Ni	...	B171	C71500	...	≤2.5 thk.	34	(14)	−452	50	20
90Cu–7Al–3Fe	...	B169	C61400	O25	≤2.0 thk.	35	(13)	−452	70	30
90Cu–7Al–3Fe	...	B169	C61400	O60	≤2.0 thk.	35	(13)	−452	70	30
Copper and Copper Alloy — Forgings										
99.9Cu	...	B283	C11000	...	...	31	(14)	−452	33	11
97Cu–3Si	...	B283	C65500	...	...	33	(14)	−452	52	18
60Cu–38Zn–2Pb	...	B283	C37700	...	...	a	(14)	−325	58	23
60Cu–37Zn–2Pb–Sn	...	B283	C48500	...	...	a	(14)	−325	62	24
60Cu–39Zn–Sn	...	B283	C46400	...	...	32	(14)	−425	64	26
59Cu–39Zn–Fe–Sn	...	B283	C67500	...	...	32	(14)	−325	72	34
Copper and Copper Alloy — Castings										
85Cu–5Sn–5Zn–5Pb	...	B62	C83600	...	...	a	(9)	−325	30	14
57Cu–20Zn–12Ni–9Pb–2Sn	...	B584	C97300	...	...	a	...	−325	30	15
64Cu–20Ni–8Zn–4Sn–4Pb	...	B584	C97600	...	...	a	...	−325	40	17
87Cu–8Sn–4Zn–1Pb	...	B584	C92300	...	...	a	...	−325	36	16
88Cu–Sn–Zn–Pb	...	B584	C92200	...	...	a	...	−325	34	16
88Cu–Sn–Zn–Pb	...	B61	C92200	...	...	a	(9)	−325	34	16
88Cu–8Sn–4Zn	...	B584	C90300	...	...	b	...	−325	40	18
88Cu–10Sn–2Zn	...	B584	C90500	...	...	b	...	−325	40	18
58Cu–38Zn–1Sn–1Pb–1Fe	...	B584	C86400	...	...	a	(9)	−325	60	20
66Cu–25Ni–5Sn–2Pb–2Zn	...	B584	C97800	...	...	a	...	−325	50	22

Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

Basic Allowable Stress, *S*, ksi, at Metal Temperature, °F [Notes (1), (4a)]														
Min. Temp. to 100	150	200	250	300	350	400	450	500	550	600	650	700	UNS No.	Spec. No.
Copper and Copper Alloy — Pipes and Tubes (Cont'd)														
15.0	14.5	13.6	13.0	12.6	12.2	4.3	...	...	...	...	...	...	C10200	B75
15.0	14.5	13.6	13.0	12.6	12.2	4.3	...	...	...	...	...	...	C12000	B75
15.0	14.5	13.6	13.0	12.6	12.2	4.3	...	...	...	...	...	...	C12200	B75
Copper and Copper Alloy — Plates and Sheets														
6.7	5.7	5.4	5.3	5.0	4.0	3.0	2.3	1.7	...	...	...	...	C10200	B152
6.7	5.7	5.4	5.3	5.0	4.0	3.0	2.3	1.7	...	...	...	...	C10400	B152
6.7	5.7	5.4	5.3	5.0	4.0	3.0	2.3	1.7	...	...	...	...	C10500	B152
6.7	5.7	5.4	5.3	5.0	4.0	3.0	2.3	1.7	...	...	...	...	C10700	B152
6.7	5.7	5.4	5.3	5.0	4.0	3.0	2.3	1.7	...	...	...	...	C12200	B152
6.7	5.7	5.4	5.3	5.0	4.0	3.0	2.3	1.7	...	...	...	...	C12300	B152
10.0	9.7	9.5	9.3	9.1	8.9	8.7	8.5	8.0	7.0	6.0	...	...	C70600	B171
12.0	12.0	11.9	11.9	11.9	10.7	6.8	...	...	...	...	...	...	C65500	B96
13.3	12.9	12.6	12.3	12.0	11.7	11.5	11.2	11.0	10.8	10.7	10.5	10.4	C71500	B171
20.0	19.9	19.8	19.7	19.5	19.4	19.2	19.0	18.8	...	...	...	...	C61400	B169
20.0	19.9	19.8	19.7	19.5	19.4	19.2	19.0	18.8	...	...	...	...	C61400	B169
Copper and Copper Alloy — Forgings														
7.3	6.2	6.0	5.8	5.0	4.0	3.0	2.3	1.7	...	...	...	...	C11000	B283
12.0	12.0	11.9	11.9	11.9	10.7	6.8	...	...	...	...	...	...	C65500	B283
15.3	14.5	13.9	13.3	10.5	7.5	2.0	...	...	...	...	...	...	C37700	B283
16.0	16.0	16.0	16.0	16.0	16.0	16.0	...	...	...	...	...	...	C48500	B283
17.3	17.3	17.3	17.3	17.1	6.3	2.5	...	...	...	...	...	...	C46400	B283
22.7	22.7	22.7	22.7	22.7	22.7	22.7	...	...	...	...	...	...	C67500	B283
Copper and Copper Alloy — Castings														
9.3	9.3	9.2	8.6	8.1	7.7	7.4	7.3	...	...	...	...	...	C83600	B62
10.0	...	...	...	...	...	...	...	...	...	...	...	...	C97300	B584
11.3	10.1	9.5	9.1	8.7	...	...	...	...	...	...	...	...	C97600	B584
10.7	10.7	10.7	10.7	10.7	10.7	10.7	...	...	...	...	...	...	C92300	B584
10.7	9.6	9.5	9.4	9.2	8.9	8.6	...	...	...	...	...	...	C92200	B584
10.7	9.6	9.5	9.4	9.2	8.9	8.6	8.4	8.3	8.3	...	...	...	C92200	B61
12.0	12.0	12.0	12.0	12.0	12.0	12.0	...	...	...	...	...	...	C90300	B584
12.0	12.0	12.0	12.0	12.0	12.0	12.0	...	...	...	...	...	...	C90500	B584
13.3	13.3	13.3	13.3	13.3	13.3	...	...	...	...	...	...	...	C86400	B584
14.7	14.7	14.7	14.7	14.7	14.7	...	...	...	...	...	...	...	C97800	B584

Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

Nominal Composition	Product Form	Spec. No.	UNS No.	Class/ Condition/ Temper	Size Range, in.	P-No. (5)(7)	Notes	Min. Temp., °F (6)	Specified Minimum Strength, ksi Tensile	Specified Minimum Strength, ksi Yield
Copper and Copper Alloy — Castings										
58Cu–39Zn–1Fe–1Al–1Mn	...	B584	C86500	...	...	b	...	−325	65	25
88Cu–9Al–3Fe	...	B148	C95200	...	...	35	(9)	−425	65	25
89Cu–10Al–1Fe	...	B148	C95300	...	...	35	(9)	−425	65	25
90Cu–7Al–3Si	...	B148	C95600	...	...	35	...	−325	60	28
85Cu–11Al–4Fe	...	B148	C95400	...	...	35	...	−325	75	30
58Cu–34Zn–2Fe–2Al–2Mn	...	B584	C86700	...	...	a	...	−325	80	32
82Cu–11Al–4Fe–3Mn	...	B148	C95500	...	...	35	...	−452	90	40
63Cu–27Zn–4Al–3Fe–3Mn	...	B584	C86200	...	...	b	...	−325	90	45
61Cu–27Zn–6Al–3Fe–3Mn	...	B584	C86300	...	...	b	...	−325	110	60
Copper and Copper Alloy — Rod										
75Cu–21.5Zn–3Si	...	B371	C69300	H02	≤$\frac{1}{2}$	a	...	−325	85	45
75Cu–21.5Zn–3Si	...	B371	C69300	H02	>$\frac{1}{2}$, ≤1	a	...	−325	75	35
75Cu–21.5Zn–3Si	...	B371	C69300	H02	>1, ≤2	a	...	−325	70	30

Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

Basic Allowable Stress, *S*, ksi, at Metal Temperature, °F [Notes (1), (4a)]														
Min. Temp. to 100	**150**	**200**	**250**	**300**	**350**	**400**	**450**	**500**	**550**	**600**	**650**	**700**	**UNS No.**	**Spec. No.**
										Copper and Copper Alloy — Castings (Cont'd)				
16.7	16.7	16.7	16.7	16.7	16.7	...	...	...	...	...	...	...	C86500	B584
16.7	15.7	15.2	14.8	14.5	14.3	14.2	14.1	14.1	11.7	7.4	...	...	C95200	B148
16.7	16.7	16.7	16.7	16.7	16.7	16.7	16.7	16.7	16.7	16.7	...	...	C95300	B148
18.7	...	...	...	...	...	...	...	...	...	...	...	...	C95600	B148
20.0	19.0	18.7	18.5	18.5	18.5	18.5	16.0	13.9	...	...	...	...	C95400	B148
21.3	21.3	21.3	21.3	21.3	21.3	...	...	...	...	...	...	...	C86700	B584
26.7	26.7	26.7	26.7	26.7	26.7	26.7	26.7	26.7	...	...	...	...	C95500	B148
30.0	30.0	30.0	30.0	30.0	30.0	...	...	...	...	...	...	...	C86200	B584
36.7	36.7	36.7	36.7	36.7	36.7	...	...	...	...	...	...	...	C86300	B584
											Copper and Copper Alloy — Rod			
28.3	25.9	25.4	25.4	25.4	...	...	...	...	...	...	...	...	C69300	B371
23.3	20.2	19.8	19.8	19.8	...	...	...	...	...	...	...	...	C69300	B371
20.0	17.3	17.0	17.0	17.0	...	...	...	...	...	...	...	...	C69300	B371

Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

Nominal Composition	Spec. No.	UNS No.	Class/ Condition/ Temper	Size Range, in.	P-No. (5)	Notes	Min. Temp., °F (6)	Specified Min. Strength, ksi: Tensile	Specified Min. Strength, ksi: Yield	Basic Allowable Stress, S, ksi, at Metal Temperature, °F [Notes (1), (4a)]: Min. Temp. to 100	200	300	400	500	600	650	700
Nickel and Nickel Alloy — Pipes and Tubes (4a)																	
99.0Ni–Low C	B161	N02201	Annealed	>5 O.D.	41	...	−325	50	10	6.7	6.4	6.3	6.3	6.3	6.3	6.2	6.2
99.0Ni–Low C	B725	N02201	Annealed	>5 O.D.	41	...	−325	50	10	6.7	6.4	6.3	6.3	6.3	6.3	6.2	6.2
99.0Ni	B161	N02200	Annealed	>5 O.D.	41	...	−325	55	12	8.0	8.0	8.0	8.0	8.0	8.0	...	...
99.0Ni	B725	N02200	Annealed	>5 O.D.	41	...	−325	55	12	8.0	8.0	8.0	8.0	8.0	8.0	...	...
99.0Ni–Low C	B161	N02201	Annealed	≤5 O.D.	41	...	−325	50	12	8.0	7.7	7.5	7.5	7.5	7.5	7.5	7.4
99.0Ni–Low C	B725	N02201	Annealed	≤5 O.D.	41	...	−325	50	12	8.0	7.7	7.5	7.5	7.5	7.5	7.5	7.4
99.0Ni	B161	N02200	Annealed	≤5 O.D.	41	...	−325	55	15	10.0	10.0	10.0	10.0	10.0	10.0	...	...
99.0Ni	B725	N02200	Annealed	≤5 O.D.	41	...	−325	55	15	10.0	10.0	10.0	10.0	10.0	10.0	...	...
67Ni–30Cu	B165	N04400	Annealed	>5 O.D.	42	...	−325	70	25	16.7	14.6	13.6	13.2	13.1	13.1	13.1	13.0
67Ni–30Cu	B725	N04400	Annealed	>5 O.D.	42	...	−325	70	25	16.7	14.6	13.6	13.2	13.1	13.1	13.1	13.0
33Ni–42Fe–21Cr	B407	N08800	H.F. or H.F. ann.	...	45	...	−325	65	25	16.7	*16.7*	*16.7*	*16.7*	*16.7*	*16.7*	*16.7*	*16.7*
72Ni–15Cr–8Fe	B167	N06600	H.F. or H.F. ann.	>5 O.D.	43	...	−325	75	25	16.7	*16.7*	*16.7*	*16.7*	*16.7*	*16.7*	*16.7*	*16.7*
33Ni–42Fe–21Cr	B407	N08810	C.D. sol. ann. or H.F. ann.	...	45	(62)	−325	65	25	16.7	16.7	16.7	16.7	16.7	16.5	16.1	15.7
33Ni–42Fe–21Cr	B514	N08810	Annealed	...	45	(62)	−325	65	25	16.7	16.7	16.7	16.7	16.7	16.5	16.1	15.7
33Ni–42Fe–21Cr–Al–Ti	B407	N08811	C.D. sol. ann. or H.F. ann.	...	45	(62)	−325	65	25	16.7	16.7	16.7	16.7	16.7	16.5	16.1	15.7
67Ni–30Cu	B165	N04400	Annealed	≤5 O.D.	42	...	−325	70	28	18.7	16.4	15.2	14.7	14.7	14.7	14.7	14.6
67Ni–30Cu	B725	N04400	Annealed	≤5 O.D.	42	...	−325	70	28	18.7	16.4	15.2	14.7	14.7	14.7	14.7	14.6
26Ni–22Cr–5Mo–Ti	B619	N08320	Sol. ann.	...	45	...	−325	75	28	18.7	*18.7*	*18.7*	*18.7*	*18.7*	*18.6*	*18.2*	*17.8*
26Ni–22Cr–5Mo–Ti	B622	N08320	Sol. ann.	...	45	...	−325	75	28	18.7	18.7	*18.7*	*18.7*	*18.7*	*18.6*	*18.2*	*17.8*
99.0Ni–Low C	B161	N02201	Str. rel.	...	41	...	−325	60	30	20.0	20.0	19.8	19.8	19.7	19.0	...	...
99.0Ni–Low C	B725	N02201	Str. rel.	...	41	...	−325	60	30	20.0	20.0	19.8	19.8	19.7	19.0	...	...
33Ni–42Fe–21Cr	B514	N08800	Annealed	...	45	...	−325	75	30	20.0	*20.0*	*20.0*	*20.0*	*20.0*	*20.0*	*20.0*	*20.0*
72Ni–15Cr–8Fe	B167	N06600	H.F. or H.F. ann.	≤5 O.D.	43	...	−325	80	30	20.0	*20.0*	*20.0*	*20.0*	*20.0*	*20.0*	*20.0*	*20.0*
72Ni–15Cr–8Fe	B167	N06600	C.D. ann.	>5 O.D.	43	...	−325	80	30	20.0	*20.0*	*20.0*	*20.0*	*20.0*	*20.0*	*20.0*	*20.0*
33Ni–42Fe–21Cr	B407	N08800	C.D. ann.	...	45	(61)	−325	75	30	20.0	*20.0*	*20.0*	*20.0*	*20.0*	*20.0*	*20.0*	*20.0*
31Ni–31Fe–29Cr–Mo	B668	N08028	Sol. ann.	...	45	...	−325	73	31	20.7	*20.7*	*20.7*	*20.7*	*20.7*	**19.5**	**18.9**	**18.3**
99.0Ni	B161	N02200	Str. rel.	...	41	...	−325	65	40	21.7	21.7	21.6	21.6	21.4	20.6	...	...
99.0Ni	B725	N02200	Str. rel.	...	41	...	−325	65	40	21.7	21.7	21.6	21.6	21.4	20.6	...	...
35Ni–35Fe–20Cr–Cb	B464	N08020	Annealed	...	45	...	−325	80	35	23.3	*23.3*	*23.3*	*23.3*	*23.3*	*23.3*	23.3	23.3
35Ni–35Fe–20Cr–Cb	B474	N08020	Annealed	...	45	...	−325	80	35	23.3	*23.3*	*23.3*	*23.3*	*23.3*	*23.3*	*23.3*	23.3

Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

Basic Allowable Stress, *S*, ksi, at Metal Temperature, °F [Notes (1), (4a)]																				
750	800	850	900	950	1,000	1,050	1,100	1,150	1,200	1,250	1,300	1,350	1,400	1,450	1,500	1,550	1,600	1,650	UNS No.	Spec. No.
Nickel and Nickel Alloy — Pipes and Tubes (4a)																				
6.1	6.0	5.8	4.5	3.7	3.0	2.4	2.0	1.5	1.2	...	...	...	...	...	...	...	...	...	N02201	B161
6.1	6.0	5.8	4.5	3.7	3.0	2.4	2.0	1.5	1.2	...	...	...	...	...	...	...	...	...	N02201	B725
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	N02200	B161
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	N02200	B725
7.3	7.2	5.8	4.5	3.7	3.0	2.4	2.0	1.5	1.2	...	...	...	...	...	...	...	...	...	N02201	B161
7.3	7.2	5.8	4.5	3.7	3.0	2.4	2.0	1.5	1.2	...	...	...	...	...	...	...	...	...	N02201	B725
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	N02200	B161
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	N02200	B725
12.9	12.7	11.0	8.0	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	N04400	B165
12.9	12.7	11.0	8.0	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	N04400	B725
16.7	*16.7*	*16.7*	*16.7*	*16.7*	*16.6*	*16.3*	*13.0*	9.8	6.6	4.2	2.0	1.6	1.1	1.0	0.8	...	...	...	N08800	B407
16.7	*16.7*	*16.7*	*16.0*	*10.6*	7.0	4.5	3.0	2.2	2.0	...	...	...	...	...	...	...	...	...	N06600	B167
15.3	*15.0*	*14.7*	*14.5*	*14.2*	*14.0*	*13.8*	*11.6*	9.3	7.4	5.9	4.7	3.8	3.0	2.4	1.9	1.4	1.1	0.86	N08810	B407
15.3	*15.0*	*14.7*	*14.5*	*14.2*	*14.0*	*13.8*	*11.6*	9.3	7.4	5.9	4.7	3.8	3.0	2.4	1.9	1.4	1.1	0.86	N08810	B514
15.3	*15.0*	*14.7*	*14.5*	*14.2*	*14.0*	*13.8*	12.9	10.4	8.3	6.7	5.4	4.3	3.4	2.7	2.2	1.6	1.2	0.91	N08811	B407
14.5	14.3	11.0	8.0	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	N04400	B165
14.5	14.3	11.0	8.0	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	N04400	B725
17.5	*17.2*	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	N08320	B619
17.5	*17.2*	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	N08320	B622
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	N02201	B161
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	N02201	B725
20.0	*20.0*	20.0	20.0	20.0	19.9	17.0	13.0	9.8	6.6	4.2	2.0	1.6	1.1	1.0	0.8	...	...	...	N08800	B514
20.0	*20.0*	*20.0*	*16.0*	10.6	7.0	4.5	3.0	2.2	2.0	...	...	...	...	...	...	...	...	...	N06600	B167
20.0	*20.0*	*20.0*	*16.0*	10.6	7.0	4.5	3.0	2.2	2.0	...	...	...	...	...	...	...	...	...	N06600	B167
20.0	*20.0*	*20.0*	*20.0*	*20.0*	*19.9*	*17.0*	13.0	9.8	6.6	4.2	2.0	1.6	1.1	1.0	0.8	...	...	...	N08800	B407
17.7	**17.2**	**16.7**	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	N08028	B668
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	N02200	B161
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	N02200	B725
23.2	*22.7*	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	N08020	B464
23.2	*22.7*	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	N08020	B474

Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

								Specified Min. Strength, ksi		Basic Allowable Stress, *S*, ksi, at Metal Temperature, °F [Notes (1), (4a)]							
Nominal Composition	Spec. No.	UNS No.	Class/ Condition/ Temper	Size Range, in.	P-No. (5)	Notes	Min. Temp., °F (6)	Tensile	Yield	Min. Temp. to 100	200	300	400	500	600	650	700
Nickel and Nickel Alloy — Pipes and Tubes (4a)																	
35Ni–35Fe–20Cr–Cb	B729	N08020	Annealed	...	45	...	−325	80	35	23.3	*23.3*	*23.3*	*23.3*	*23.3*	*23.3*	23.3	23.3
42Ni–21.5Cr–3Mo–2.3Cu	B163	N08825	Annealed	...	45	...	−325	85	35	23.3	*23.3*	*23.3*	*23.3*	*23.3*	*23.3*	*23.3*	*23.3*
42Ni–21.5Cr–3Mo–2.3Cu	B423	N08825	C.D. ann.	...	45	...	−325	85	35	23.3	*23.3*	*23.3*	*23.3*	*23.3*	*23.3*	*23.3*	*23.3*
42Ni–21.5Cr–3Mo–2.3Cu	B474	N08825	Annealed	...	45	...	−325	85	35	23.3	*23.3*	*23.3*	*23.3*	*23.3*	*23.3*	*23.3*	*23.3*
42Ni–21.5Cr–3Mo–2.3Cu	B704	N08825	Annealed	...	45	...	−325	85	35	23.3	*23.3*	*23.3*	*23.3*	*23.3*	*23.3*	*23.3*	*23.3*
42Ni–21.5Cr–3Mo–2.3Cu	B705	N08825	...	...	45	...	−325	85	35	23.3	*23.3*	*23.3*	*23.3*	*23.3*	*23.3*	*23.3*	*23.3*
47Ni–22Cr–19Fe–6Mo	B619	N06007	Sol. ann.	...	45	...	−325	90	35	23.3	*23.3*	*23.3*	*23.3*	23.3	**22.7**	**22.4**	**22.2**
47Ni–22Cr–19Fe–6Mo	B622	N06007	Sol. ann.	...	45	...	−325	90	35	23.3	*23.3*	*23.3*	*23.3*	23.3	**22.7**	**22.4**	**22.2**
40Ni–29Cr–15Fe–5Mo	B619	N06030	Sol. ann.	...	45	...	−325	85	35	23.3	*23.3*	*23.3*	**23.2**	**22.1**	**21.3**	**20.9**	**20.5**
40Ni–29Cr–15Fe–5Mo	B622	N06030	Sol. ann.	...	45	...	−325	85	35	23.3	*23.3*	*23.3*	**23.2**	**22.1**	**21.3**	**20.9**	**20.5**
40Ni–29Cr–15Fe–5Mo	B626	N06030	Sol. ann.	...	45	...	−325	85	35	23.3	*23.3*	*23.3*	**23.2**	**22.1**	**21.3**	**20.9**	**20.5**
72Ni–15Cr–8Fe	B167	N06600	C.D. ann.	≤5 O.D.	43	...	−325	80	35	23.3	*23.3*	*23.3*	**23.3**	23.3	*23.3*	*23.3*	*23.3*
72Ni–15Cr–8Fe	B517	N06600	C.D. ann.	...	43	...	−325	80	35	23.3	*23.3*	*23.3*	**23.3**	23.3	*23.3*	*23.3*	*23.3*
58Ni–29Cr–9Fe	B163	N06690	C.D. ann.	≤3 O.D.	43	...	−325	85	35	23.3	*23.3*	*23.3*	*23.3*	*23.3*	*23.3*	*23.3*	*23.3*
58Ni–29Cr–9Fe	B167	N06690	C.D. ann.	≤5 O.D.	43	...	−325	85	35	23.3	*23.3*	*23.3*	*23.3*	*23.3*	*23.3*	*23.3*	*23.3*
37Ni–33Fe–25Cr	B163	N08120	Sol. ann.	...	45	...	−325	90	40	26.7	*26.7*	*26.7*	*26.7*	**25.1**	**24.4**	**23.3**	**22.9**
37Ni–33Fe–25Cr	B407	N08120	Sol. ann.	...	45	...	−325	90	40	26.7	*26.7*	*26.7*	*26.7*	**25.1**	**24.4**	**23.3**	**22.9**
37Ni–33Fe–25Cr	B514	N08120	Sol. ann.	...	45	...	−325	90	40	26.7	*26.7*	*26.7*	*26.7*	**25.1**	**24.4**	**23.3**	**22.9**
37Ni–33Fe–25Cr	B515	N08120	Sol. ann.	...	45	...	−325	90	40	26.7	*26.7*	*26.7*	*26.7*	**25.1**	**24.4**	**23.3**	**22.9**
61Ni–16Mo–16Cr	B619	N06455	Sol. ann.	...	43	...	−325	100	40	26.7	*26.7*	*26.7*	**26.7**	26.7	*26.7*	*26.7*	*26.5*

Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

Basic Allowable Stress, *S*, ksi, at Metal Temperature, °F [Notes (1), (4a)]																				
750	800	850	900	950	1,000	1,050	1,100	1,150	1,200	1,250	1,300	1,350	1,400	1,450	1,500	1,550	1,600	1,650	UNS No.	Spec. No.
Nickel and Nickel Alloy — Pipes and Tubes (4a) (Cont'd)																				
23.2	*22.7*	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	N08020	B729
23.2	**23.0**	**22.9**	**22.8**	**22.6**	**22.3**	...	...	...	...	...	...	...	...	...	...	...	...	...	N08825	B163
23.2	**23.0**	**22.9**	**22.8**	**22.6**	**22.3**	...	...	...	...	...	...	...	...	...	...	...	...	...	N08825	B423
23.2	**23.0**	**22.9**	**22.8**	**22.6**	**22.3**	...	...	...	...	...	...	...	...	...	...	...	...	...	N08825	B474
23.2	**23.0**	**22.9**	**22.8**	**22.6**	**22.3**	...	...	...	...	...	...	...	...	...	...	...	...	...	N08825	B704
23.2	**23.0**	**22.9**	**22.8**	**22.6**	**22.3**	...	...	...	...	...	...	...	...	...	...	...	...	...	N08825	B705
22.0	**21.8**	*21.7*	*20.0*	*19.5*	*18.9*	...	...	...	...	...	...	...	...	...	...	...	...	...	N06007	B619
22.0	**21.8**	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	N06007	B622
20.1	**19.7**	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	N06030	B619
20.1	**19.7**	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	N06030	B622
20.1	**19.7**	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	N06030	B626
23.3	*23.3*	*23.3*	16.0	10.6	7.0	4.5	3.0	2.2	2.0	...	...	...	...	...	...	...	...	...	N06600	B167
23.3	*23.3*	*23.3*	16.0	10.6	7.0	4.5	3.0	2.2	2.0	...	...	...	...	...	...	...	...	...	N06600	B517
23.3	*23.3*	*23.3*	*23.3*	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	N06690	B163
23.3	*23.3*	*23.3*	*23.3*	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	N06690	B167
22.6	**22.4**	**22.2**	**22.1**	**22.0**	**21.9**	**21.9**	17.9	14.2	12.3	9.4	7.6	6.2	5.0	4.0	3.2	2.6	2.0	1.4	N08120	B163
22.6	**22.4**	**22.2**	**22.1**	**22.0**	**21.9**	**21.9**	17.9	14.2	12.3	9.4	7.6	6.2	5.0	4.0	3.2	2.6	2.0	1.4	N08120	B407
22.6	**22.4**	**22.2**	**22.1**	**22.0**	**21.9**	**21.9**	17.9	14.2	12.3	9.4	7.6	6.2	5.0	4.0	3.2	2.6	2.0	1.4	N08120	B514
22.6	**22.4**	**22.2**	**22.1**	**22.0**	**21.9**	**21.9**	17.9	14.2	12.3	9.4	7.6	6.2	5.0	4.0	3.2	2.6	2.0	1.4	N08120	B515
26.2	*25.8*	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	N06455	B619

Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

Nominal Composition	Product Form	Spec. No.	Type/ Grade	UNS No.	Class/ Condition/ Temper	Size Range, in.	P-No. (5)	Notes	Min. Temp., °F (6)	Specified Min. Strength, ksi: Tensile	Yield	Basic Allowable Stress, S, ksi, at Metal Temperature, °F [Notes (1), (4a)]: Min. Temp. to 100	200	300	400	500	600
Nickel and Nickel Alloy — Pipes and Tubes (4a)																	
47Ni–22Cr–9Mo–18Fe	...	B619	...	N06002	Sol. ann.	...	43	...	−325	100	40	26.7	*26.7*	*26.7*	*26.7*	*25.5*	*24.2*
47Ni–22Cr–9Mo–18Fe	...	B622	...	N06002	Sol. ann.	...	43	...	−325	100	40	26.7	*26.7*	*26.7*	*26.7*	*25.5*	*24.2*
31Ni–33Fe–27Cr–6.5Mo–Cu–N	...	B619	...	N08031	Annealed	...	45	...	−325	94	40	26.7	*26.7*	**26.7**	**24.7**	**23.3**	**22.2**
31Ni–33Fe–27Cr–6.5Mo–Cu–N	...	B622	...	N08031	Annealed	...	45	...	−325	94	40	26.7	*26.7*	**26.7**	**24.7**	**23.3**	**22.2**
61Ni–16Mo–16Cr	...	B622	...	N06455	Sol. ann.	...	43	...	−325	100	40	26.7	*26.7*	*26.7*	*26.7*	*26.7*	*26.7*
54Ni–16Mo–15Cr	...	B619	...	N10276	Sol. ann.	...	43	...	−325	100	41	27.3	*27.3*	*27.3*	*27.3*	**26.9**	**25.2**
54Ni–16Mo–15Cr	...	B622	...	N10276	Sol. ann.	...	43	...	−325	100	41	27.3	*27.3*	*27.3*	*27.3*	**26.9**	**25.2**
54Ni–16Mo–15Cr	...	B626	...	N10276	Sol. ann.	...	43	...	−325	100	41	27.3	*27.3*	*27.3*	*27.3*	**26.9**	**25.2**
67Ni–30Cu	...	B165	...	N04400	Str. rel.	...	42	(54)	−325	85	55	28.3	28.3	28.3	28.3	28.3	...
67Ni–30Cu	...	B725	...	N04400	Str. rel.	...	42	(54)	−325	85	55	28.3	28.3	28.3	28.3	28.3	...
46Fe–24Ni–21Cr–6Mo–Cu–N	...	B675	...	N08367	Annealed	$>^3/_{16}$	45	...	−325	95	45	30.0	*30.0*	*29.9*	*28.6*	**27.7**	**26.2**
46Fe–24Ni–21Cr–6Mo–Cu–N	...	B690	...	N08367	Annealed	$>^3/_{16}$	45	...	−325	95	45	30.0	*30.0*	*29.9*	*28.6*	**27.7**	**26.2**
46Fe–24Ni–21Cr–6Mo–Cu–N	...	B804	...	N08367	Annealed	$>^3/_{16}$	45	...	−325	95	45	30.0	*30.0*	*29.9*	*28.6*	**27.7**	**26.2**
46Fe–24Ni–21Cr–6Mo–Cu–N	...	B675	...	N08367	Annealed	$\leq^3/_{16}$	45	...	−325	100	45	30.0	*30.0*	*30.0*	**29.6**	**27.7**	**26.2**
46Fe–24Ni–21Cr–6Mo–Cu–N	...	B690	...	N08367	Annealed	$\leq^3/_{16}$	45	...	−325	100	45	30.0	*30.0*	*30.0*	**29.6**	**27.7**	**26.2**
46Fe–24Ni–21Cr–6Mo–Cu–N	...	B804	...	N08367	Annealed	$\leq^3/_{16}$	45	...	−325	100	45	30.0	*30.0*	*29.9*	**28.6**	**27.7**	**26.2**
55Ni–21Cr–13.5Mo	...	B619	...	N06022	Sol. ann.	...	43	...	−325	100	45	30.0	*30.0*	*30.0*	*30.0*	**29.0**	**27.6**
55Ni–21Cr–13.5Mo	...	B622	...	N06022	Sol. ann.	...	43	...	−325	100	45	30.0	*30.0*	*30.0*	*30.0*	**29.0**	**27.6**
58Ni–33Cr–8Mo	...	B619	...	N06035	Sol. ann.	...	43	...	−325	85	35	23.3	*23.3*	*23.3*	**22.2**	**20.6**	**19.7**
58Ni–33Cr–8Mo	...	B622	...	N06035	Sol. ann.	...	43	...	−325	85	35	23.3	*23.3*	*23.3*	**22.2**	**20.6**	**19.7**
58Ni–33Cr–8Mo	...	B626	...	N06035	Sol. ann.	...	43	...	−325	85	35	23.3	*23.3*	*23.3*	**22.2**	**20.6**	**19.7**
59Ni–23Cr–16Mo	...	B619	...	N06059	Sol. ann.	...	43	...	−325	100	45	30.0	*30.0*	*30.0*	*30.0*	**29.7**	**28.2**
59Ni–23Cr–16Mo	...	B622	...	N06059	Sol. ann.	...	43	...	−325	100	45	30.0	*30.0*	*30.0*	*30.0*	**29.7**	**28.2**
59Ni–23Cr–16Mo	...	B626	...	N06059	Sol. ann.	All	43	...	−325	100	45	30.0	30.0	30.0	30.0	**29.7**	**28.2**
59Ni–23Cr–16Mo–1.6Cu	...	B619	...	N06200	Sol. ann.	All	43	...	−325	100	45	30.0	*30.0*	*30.0*	*30.0*	**28.6**	**26.9**
59Ni–23Cr–16Mo–1.6Cu	...	B622	...	N06200	Sol. ann.	All	43	...	−325	100	45	30.0	*30.0*	*30.0*	*30.0*	**28.6**	**26.9**
59Ni–23Cr–16Mo–1.6Cu	...	B626	...	N06200	Sol. ann.	All	43	...	−325	100	45	30.0	*30.0*	*30.0*	*30.0*	**28.6**	**26.9**
62Ni–22Mo–15Cr	...	B619	...	N10362	Sol. ann.	All	43	...	−325	105	45	30.0	*30.0*	*30.0*	*30.0*	**28.9**	**27.7**
62Ni–22Mo–15Cr	...	B622	...	N10362	Sol. ann.	All	43	...	−325	105	45	30.0	*30.0*	*30.0*	*30.0*	**28.9**	**27.7**
62Ni–22Mo–15Cr	...	B626	...	N10362	Sol. ann.	All	43	...	−325	105	45	30.0	*30.0*	*30.0*	*30.0*	**28.9**	**27.7**
62Ni–28Mo–5Fe	...	B619	...	N10001	Sol. ann.	...	44	...	−325	100	45	30.0	*30.0*	*30.0*	*30.0*	*30.0*	*30.0*
62Ni–28Mo–5Fe	...	B622	...	N10001	Sol. ann.	...	44	...	−325	100	45	30.0	*30.0*	*30.0*	*30.0*	*30.0*	*30.0*
65Ni–28Mo–2Fe	...	B619	...	N10665	Sol. ann.	...	44	...	−325	110	51	34.0	*34.0*	*34.0*	*34.0*	*34.0*	*34.0*
65Ni–28Mo–2Fe	...	B622	...	N10665	Sol. ann.	...	44	...	−325	110	51	34.0	*34.0*	*34.0*	*34.0*	*34.0*	*34.0*
65Ni–29.5Mo–2Fe–2Cr	...	B619	...	N10675	Sol. ann.	...	44	...	−325	110	51	34.0	*34.0*	*34.0*	*34.0*	*34.0*	*34.0*
65Ni–29.5Mo–2Fe–2Cr	...	B622	...	N10675	Sol. ann.	...	44	...	−325	110	51	34.0	*34.0*	*34.0*	*34.0*	*34.0*	*34.0*
65Ni–29.5Mo–2Fe–2Cr	...	B626	...	N10675	Sol. ann.	...	44	...	−325	110	51	34.0	*34.0*	*34.0*	*34.0*	*34.0*	*34.0*
60Ni–22Cr–9Mo–3.5Cb	...	B444	1	N06625	Annealed	...	43	(64) (70)	−325	120	60	40.0	*40.0*	*39.6*	*39.2*	*38.6*	*37.8*
60Ni–22Cr–9Mo–3.5Cb	...	B705	1	N06625	Annealed	...	43	(64) (70)	−325	120	60	40.0	*40.0*	*39.6*	*39.2*	*38.6*	*37.8*

Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

Basic Allowable Stress, S, ksi, at Metal Temperature, °F [Notes (1), (4a)]																						
650	700	750	800	850	900	950	1,000	1,050	1,100	1,150	1,200	1,250	1,300	1,350	1,400	1,450	1,500	1,550	1,600	1,650	UNS No. or Grade	Spec. No.
																					Nickel and Nickel Alloy — Pipes and Tubes (4a)	
23.7	23.3	22.9	22.7	22.5	19.6	19.5	19.3	19.3	17.5	14.1	11.3	9.3	7.7	6.1	4.8	3.8	3.0	...	...	...	N06002	B619
23.7	23.3	22.9	22.7	22.5	19.6	19.5	19.3	19.3	17.5	14.1	11.3	9.3	7.7	6.1	4.8	3.8	3.0	...	...	...	N06002	B622
21.7	11.1	8.9	7.2	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	N08031	B619
21.7	11.1	8.9	7.2	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	N08031	B622
26.7	26.5	26.1	25.8	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	N06455	B622
24.6	24.0	23.5	23.1	22.8	22.6	22.4	22.3	18.5	15.0	12.2	9.8	7.8	...	...	...	...	...	...	...	...	N10276	B619
24.6	24.0	23.5	23.1	22.8	22.6	22.4	22.3	18.5	15.0	12.2	9.8	7.8	...	...	...	...	...	...	...	...	N10276	B622
24.6	24.0	23.5	23.1	22.8	22.6	22.4	22.3	18.5	15.0	12.2	9.8	7.8	...	...	...	...	...	...	...	...	N10276	B626
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	N04400	B165
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	N04400	B725
25.6	25.1	24.7	24.3	23.9	23.6	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	N08367	B675
25.6	25.1	24.7	24.3	23.9	23.6	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	N08367	B690
25.6	25.1	24.7	24.3	23.9	23.6	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	N08367	B804
25.6	25.1	24.7	24.3	23.9	23.6	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	N08367	B675
25.6	25.1	24.7	24.3	23.9	23.6	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	N08367	B690
25.6	25.1	24.7	24.3	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	N08367	B804
27.0	26.5	26.1	25.7	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	N06022	B619
27.0	26.5	26.1	25.7	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	N06022	B622
19.4	19.2	19.0	18.8	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	N06035	B619
19.4	19.2	19.0	18.8	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	N06035	B622
19.4	19.2	19.0	18.8	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	N06035	B626
27.5	26.8	26.1	25.5	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	N06059	B619
27.5	26.8	26.1	25.5	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	N06059	B622
27.5	26.8	26.1	25.5	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	N06059	B626
26.2	25.7	25.4	25.2	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	N06200	B619
26.2	25.7	25.4	25.2	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	N06200	B622
26.2	25.7	25.4	25.2	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	N06200	B626
27.3	27.0	26.7	26.4	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	N10362	B619
27.3	27.0	26.7	26.4	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	N10362	B622
27.3	27.0	26.7	26.4	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	N10362	B626
30.0	30.0	30.0	29.9	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	N10001	B619
30.0	30.0	30.0	29.9	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	N10001	B622
34.0	34.0	34.0	34.0	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	N10665	B619
34.0	34.0	34.0	34.0	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	N10665	B622
34.0	34.0	33.9	33.5	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	N10675	B619
34.0	34.0	33.9	33.5	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	N10675	B622
34.0	34.0	33.9	33.5	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	N10675	B626
37.4	37.0	36.6	36.3	36.1	35.8	35.4	31.2	31.2	23.1	21.0	13.2	...	...	...	...	...	...	...	...	...	N06625	B444
37.4	37.0	36.6	36.3	36.1	35.8	35.4	31.2	31.2	23.1	21.0	13.2	...	...	...	...	...	...	...	...	...	N06625	B705

Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

Nominal Composition	Product Form	Spec. No.	Type/ Grade	UNS No.	Class/ Condition/ Temper	Size Range, in.	P-No. (5)	Notes	Min. Temp., °F (6)	Specified Min. Strength, ksi: Tensile	Yield	Basic Allowable Stress, S, ksi, at Metal Temperature, °F [Notes (1), (4a)]: Min. Temp. to 100	200	300	400	500	600
Nickel and Nickel Alloy — Pipes and Tubes (4a)																	
57Ni–22Cr–14W–2Mo–La	...	B619	...	N06230	Sol. ann.	...	43	...	−325	110	45	30.0	*30.0*	*30.0*	*30.0*	*30.0*	**29.6**
57Ni–22Cr–14W–2Mo–La	...	B622	...	N06230	Sol. ann.	...	43	...	−325	110	45	30.0	*30.0*	*30.0*	*30.0*	*30.0*	**29.6**
57Ni–22Cr–14W–2Mo–La	...	B626	...	N06230	Sol. ann.	...	43	...	−325	110	45	30.0	*30.0*	*30.0*	*30.0*	*30.0*	**29.6**
33Cr–31Ni–32Fe–1.5Mo–0.6Cu–N	...	B619	...	R20033	Sol. ann.	All	45	...	−325	109	55	36.3	30.9	28.1	26.1	24.7	23.8
33Cr–31Ni–32Fe–1.5Mo–0.6Cu–N	...	B622	...	R20033	Sol. ann.	All	45	...	−325	109	55	36.3	30.9	28.1	26.1	24.7	23.8
33Cr–31Ni–32Fe–1.5Mo–0.6Cu–N	...	B626	...	R20033	Sol. ann.	All	45	...	−325	109	55	36.3	30.9	28.1	26.1	24.7	23.8
Nickel and Nickel Alloy — Plates and Sheets (4a)																	
99.0Ni–Low C	Plate	B162	...	N02201	H.R. ann.	...	41	...	−325	50	12	8.0	7.7	7.5	7.5	7.5	7.5
99.0Ni–Low C	Plate	B162	...	N02201	H.R. as R.	...	41	...	−325	50	12	8.0	7.7	7.5	7.5	7.5	7.5
99.0Ni	Plate	B162	...	N02200	H.R. ann.	...	41	...	−325	55	15	10.0	10.0	10.0	10.0	10.0	10.0
99.0Ni	Plate	B162	...	N02200	H.R. as R.	...	41	...	−325	55	20	13.3	13.3	13.3	13.3	13.3	13.3
33Ni–42Fe–21Cr	...	B409	...	N08810	Annealed	All	45	...	−325	65	25	16.7	16.7	16.7	16.7	16.7	16.6
33Ni–42Fe–21Cr–Al–Ti	...	B409	...	N08811	Annealed	All	45	...	−325	65	25	16.7	16.7	16.7	16.7	16.7	16.5
26Ni–22Cr–5Mo–Ti	...	B620	...	N08320	Sol. ann.	All	45	...	−325	75	28	18.7	*18.7*	*18.7*	*18.7*	*18.7*	*18.6*
67Ni–30Cu	Plate	B127	...	N04400	H.R. ann.	...	42	...	−325	70	28	18.7	16.4	*15.2*	14.7	14.7	14.7
47Ni–22Cr–19Fe–6Mo	...	B582	...	N06007	Sol. ann.	>3/4	45	...	−325	85	30	20.0	*20.0*	*20.0*	*20.0*	*20.0*	**19.5**
33Ni–42Fe–21Cr	...	B409	...	N08800	Annealed	All	45	...	−325	75	30	20.0	*20.0*	*20.0*	*20.0*	*20.0*	*20.0*
31Ni–31Fe–29Cr–Mo	...	B709	...	N08028	Sol. ann.	...	45	...	−325	73	31	20.7	*20.7*	*20.7*	*20.7*	*20.7*	**19.5**
42Ni–21.5Cr–3Mo–2.3Cu	...	B424	...	N08825	Annealed	...	45	...	−325	85	35	23.3	*23.3*	*23.3*	*23.3*	*23.3*	*23.3*
35Ni–35Fe–20Cr–Cb	...	B463	...	N08020	Annealed	All	45	...	−325	80	35	23.3	*23.3*	*23.3*	*23.3*	*23.3*	*23.3*
40Ni–29Cr–15Fe–5Mo	...	B582	...	N06030	Sol. ann.	All	45	...	−325	85	35	23.3	*23.3*	*23.3*	**23.2**	**22.1**	**21.3**
47Ni–22Cr–19Fe–6Mo	...	B582	...	N06007	Sol. ann.	≤3/4	45	...	−325	90	35	23.3	*23.3*	*23.3*	*23.3*	*23.3*	*22.7*
47Ni–22Cr–9Mo–18Fe	...	B435	...	N06002	H.R. sol. ann.	All	43	...	−325	95	35	23.3	23.3	23.3	23.3	22.3	21.2
72Ni–15Cr–8Fe	Plate	B168	...	N06600	H.R. ann.	...	43	...	−325	80	35	23.3	*23.3*	*23.3*	*23.3*	*23.3*	*23.3*
72Ni–15Cr–8Fe	Plate	B168	...	N06600	H.R. as R.	...	43	...	−325	85	35	23.3	*23.3*	*23.3*	*23.3*	*23.3*	*23.3*
58Ni–29Cr–9Fe	Plate	B168	...	N06690	Annealed	≥3/16	43	...	−325	85	35	23.3	*23.3*	*23.3*	*23.3*	*23.3*	*23.3*
58Ni–29Cr–9Fe	Sheet	B168	...	N06690	Annealed	0.018–0.250	43	...	−325	85	35	23.3	*23.3*	*23.3*	*23.3*	*23.3*	*23.3*
67Ni–30Cu	Plate	B127	...	N04400	H.R. as R.	...	42	...	−325	75	40	25.0	25.0	24.7	23.9	23.4	23.1
37Ni–33Fe–25Cr	...	B409	...	N08120	Sol. ann.	All	45	...	−325	90	40	26.7	*26.7*	*26.7*	*26.7*	**25.1**	**24.4**
31Ni–33Fe–27Cr–6.5Mo–Cu–N	...	B625	...	N08031	Annealed	All	45	...	−325	94	40	26.7	*26.7*	**26.7**	**24.7**	**23.3**	**22.2**
61Ni–16Mo–16Cr	...	B575	...	N06455	Sol. ann.	All	43	...	−325	100	40	26.7	*26.7*	*26.7*	*26.7*	*26.7*	*26.7*
54Ni–16Mo–15Cr	...	B575	...	N10276	Sol. ann.	All	43	...	−325	100	41	27.3	*27.3*	*27.3*	*27.3*	**26.9**	**25.2**
60Ni–22Cr–9Mo–3.5Cb	Plate	B443	1	N06625	Annealed	All	43	(64) (70)	−325	110	55	36.7	36.7	36.3	35.9	35.4	34.7
57Ni–22Cr–14W–2Mo–La	...	B435	...	N06230	Sol. ann.	All	43	...	−325	110	45	30.0	*30.0*	*30.0*	*30.0*	*30.0*	**29.6**
55Ni–21Cr–13.5Mo	Sheet	B575	...	N06022	Sol. ann.	<3/16	43	...	−325	100	45	30.0	*30.0*	*30.0*	*30.0*	**29.0**	**27.6**
58Ni–33Cr–8Mo	...	B575	...	N06035	Sol. ann.	All	43	...	−325	85	35	23.3	*23.3*	*23.3*	**22.2**	**20.6**	**19.7**

Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

Basic Allowable Stress, *S*, ksi, at Metal Temperature, °F [Notes (1), (4a)]																						
650	700	750	800	850	900	950	1,000	1,050	1,100	1,150	1,200	1,250	1,300	1,350	1,400	1,450	1,500	1,550	1,600	1,650	UNS No. or Grade	Spec. No.
Nickel and Nickel Alloy — Pipes and Tubes (4a) (Cont'd)																						
29.1	**28.7**	**28.4**	**28.2**	**28.2**	**28.2**	**28.2**	**28.2**	**28.2**	23.2	19.0	15.6	12.9	10.6	8.5	6.7	5.3	4.1	2.9	2.1	1.5	N06230	B619
29.1	**28.7**	**28.4**	**28.2**	**28.2**	**28.2**	**28.2**	**28.2**	**28.2**	23.2	19.0	15.6	12.9	10.6	8.5	6.7	5.3	4.1	2.9	2.1	1.5	N06230	B622
29.1	**28.7**	**28.4**	**28.2**	**28.2**	**28.2**	**28.2**	**28.2**	**28.2**	23.2	19.0	15.6	12.9	10.6	8.5	6.7	5.3	4.1	2.9	2.1	1.5	N06230	B626
23.5	23.1	22.9	22.6	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	R20033	B619
23.5	23.1	22.9	22.6	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	R20033	B622
23.5	23.1	22.9	22.6	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	R20033	B626
Nickel and Nickel Alloy — Plates and Sheets (4a)																						
7.5	7.4	7.4	7.2	5.8	4.5	3.7	3.0	2.4	2.0	1.5	1.2	...	...	...	...	...	...	...	...	...	N02201	B162
7.5	7.4	7.4	7.2	5.8	4.5	3.7	3.0	2.4	2.0	1.5	1.2	...	...	...	...	...	...	...	...	...	N02201	B162
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	N02200	B162
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	N02200	B162
16.2	15.8	15.5	15.1	14.9	14.6	14.3	14.0	13.8	11.6	9.3	7.4	5.9	4.7	3.8	3.0	2.4	1.9	1.4	1.1	0.86	N08810	B409
16.1	15.7	15.3	15.0	14.7	14.5	14.2	14.0	13.7	12.9	10.4	8.3	6.7	5.4	4.3	3.4	2.7	2.2	1.6	1.2	0.91	N08811	B409
18.2	*17.8*	**17.5**	**17.2**	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	N08320	B620
14.7	14.6	14.5	14.3	11.0	8.0	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	N04400	B127
19.2	**19.0**	**18.8**	**18.7**	*18.6*	*18.5*	*18.4*	*18.3*	...	...	...	...	...	...	...	...	...	...	...	...	...	N06007	B582
20.0	*20.0*	*20.0*	*20.0*	20.0	20.0	20.0	19.9	17.0	13.0	9.8	6.6	4.2	2.0	1.6	1.1	1.0	0.8	...	...	...	N08800	B409
18.9	**18.3**	**17.7**	**17.2**	**16.7**	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	N08028	B709
23.3	*23.3*	**23.2**	**23.0**	**22.9**	**22.8**	**22.6**	**22.3**	...	...	...	...	...	...	...	...	...	...	...	...	...	N08825	B424
23.3	*23.3*	*23.2*	22.7	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	N08020	B463
20.9	**20.5**	**20.1**	**19.7**	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	N06030	B582
22.4	*22.2*	*22.0*	*21.8*	*21.7*	*20.0*	*19.5*	*18.9*	...	...	...	...	...	...	...	...	...	...	...	...	...	N06007	B582
20.7	20.3	20.1	19.9	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	N06002	B435
23.3	*23.3*	*23.3*	*23.3*	*23.3*	16.0	10.6	7.0	4.5	3.0	2.2	2.0	...	...	...	...	...	...	...	...	...	N06600	B168
23.3	*23.3*	*23.3*	*23.3*	*23.3*	*16.0*	*10.6*	7.0	4.5	3.0	2.2	2.0	...	...	...	...	...	...	...	...	...	N06600	B168
23.3	*23.3*	*23.3*	*23.3*	*23.3*	*23.3*	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	N06690	B168
23.3	*23.3*	*23.3*	*23.3*	*23.3*	*23.3*	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	N06690	B168
22.9	22.7	20.0	14.5	8.5	4.0	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	N04400	B127
23.3	**22.9**	**22.6**	**22.4**	**22.2**	**22.1**	**22.0**	**21.9**	**21.9**	17.9	14.2	12.3	9.4	7.6	6.2	5.0	4.0	3.2	2.6	2.0	1.4	N08120	B409
21.7	**21.3**	**20.9**	**20.5**	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	N08031	B625
26.7	**26.5**	**26.1**	**25.8**	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	N06455	B575
24.6	**24.0**	**23.5**	**23.1**	**22.8**	**22.6**	**22.4**	**22.3**	18.5	15.0	12.2	9.8	7.8	...	...	...	...	...	...	...	...	N10276	B575
34.3	33.9	33.6	33.3	33.1	32.8	32.5	31.2	31.2	23.1	21.0	13.2	...	...	...	...	...	...	...	...	...	N06625	B443
29.1	**28.7**	**28.4**	**28.2**	**28.2**	**28.2**	**28.2**	**28.2**	**28.2**	23.2	19.0	15.6	12.9	10.6	8.5	6.7	5.3	4.1	2.9	2.1	1.5	N06230	B435
27.0	**26.5**	**26.1**	**25.7**	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	N06022	B575
19.4	**19.2**	**19.0**	**18.8**	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	N06035	B575

Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

										Specified Min. Strength, ksi		Basic Allowable Stress, *S*, ksi, at Metal Temperature, °F [Notes (1), (4a)]					
Nominal Composition	Product Form	Spec. No.	Type/ Grade	UNS No.	Class/ Condi-tion/ Temper	Size Range, in.	P-No. (5)	Notes	Min. Tem-p., °F (6)	Tensile	Yield	Min. Temp. to 100	200	300	400	500	600
Nickel and Nickel Alloy — Plates and Sheets (4a)																	
46Fe–24Ni–21Cr–6Mo–Cu–N	...	B688	...	N08367	Annealed	$>\frac{3}{16}$	45	...	−325	95	45	30.0	*30.0*	*29.9*	28.6	**27.7**	**26.2**
46Fe–24Ni–21Cr–6Mo–Cu–N	...	B688	...	N08367	Annealed	$\leq\frac{3}{16}$	45	...	−325	100	45	30.0	*30.0*	*30.0*	**29.6**	**27.7**	**26.2**
59Ni–23Cr–16Mo	...	B575	...	N06059	Sol. ann.	All	43	...	−325	100	45	30.0	*30.0*	*30.0*	*30.0*	29.6	28.1
59Ni–23Cr–16Mo–1.6Cu	...	B575	...	N06200	Sol. ann.	All	43	...	−325	100	45	30.0	*30.0*	*30.0*	*30.0*	**28.6**	**26.9**
62Ni–22Mo–15Cr	...	B575	...	N10362	Sol. ann.	All	43	...	−325	105	45	30.0	*30.0*	*30.0*	*30.0*	**28.9**	**27.7**
62Ni–28Mo–5Fe	Plate	B333	...	N10001	Sol. ann.	$\geq\frac{3}{16}$, $\leq2\frac{1}{2}$	44	...	−325	100	45	30.0	*30.0*	*30.0*	*30.0*	*30.0*	*30.0*
62Ni–28Mo–5Fe	Sheet	B333	...	N10001	Sol. ann.	$<\frac{3}{16}$	44	...	−325	115	50	33.3	*33.3*	*33.3*	*33.3*	*33.3*	*33.3*
65Ni–28Mo–2Fe	...	B333	...	N10665	Sol. ann.	All	44	...	−325	110	51	34.0	*34.0*	*34.0*	*34.0*	*34.0*	*34.0*
65Ni–29.5Mo–2Fe–2Cr	...	B333	...	N10675	Sol. ann.	All	44	...	−325	110	51	34.0	*34.0*	*34.0*	*34.0*	*34.0*	*34.0*
33Cr–31Ni–32Fe–1.5Mo–0.6Cu–N	...	B625	...	R20033	Sol. ann.	All	45	...	−325	109	55	36.3	30.9	28.1	26.1	24.7	23.8
Nickel and Nickel Alloy — Forgings and Fittings (4a)																	
99.0Ni–Low C	...	B160	...	N02201	Annealed	All	41	(9) (9a)	−325	50	10	6.7	6.4	6.3	6.3	6.3	6.3
99.0Ni–Low C	...	B366	...	N02201	Annealed	All	41	(32) (74)	−325	50	10	6.7	6.4	6.3	6.3	6.3	6.3
99.0Ni	...	B366	...	N02200	Annealed	All	41	(32) (74)	−325	55	15	10.0	10.0	10.0	10.0	10.0	10.0
33Ni–42Fe–21Cr	...	B564	...	N08810	Annealed	...	45	(9)	−325	65	25	16.7	16.7	16.7	16.7	16.7	16.5
33Ni–42Fe–21Cr–Al–Ti	...	B564	...	N08811	Annealed	...	45	(9)	−325	65	25	16.7	16.7	16.7	16.7	16.7	16.5
33Ni–42Fe–21Cr	...	B366	...	N08810	Annealed	All	45	(9) (74)	−325	65	25	16.7	16.7	16.7	16.7	16.7	16.5
33Ni–42Fe–21Cr–Al–Ti	...	B366	...	N08811	Annealed	All	45	(9) (74)	−325	65	25	16.7	16.7	16.7	16.7	16.7	16.5
67Ni–30Cu	...	B564	...	N04400	Annealed	...	42	(9)	−325	70	25	16.7	14.6	13.6	13.2	13.1	13.1
67Ni–30Cu	...	B366	...	N04400	Annealed	All	42	(32) (74)	−325	70	25	16.7	14.6	13.6	13.2	13.1	13.1
72Ni–15Cr–8Fe	...	B366	...	N06600	Annealed	All	43	(32) (74)	−325	75	25	16.7	*16.7*	*16.7*	*16.7*	*16.7*	*16.7*
40Ni–29Cr–15Fe–5Mo	...	B366	...	N06030	Sol. ann.	All	45	(74)	−325	85	35	23.3	*23.3*	*23.3*	**23.2**	**22.1**	**21.3**
40Ni–29Cr–15Fe–5Mo	...	B462	...	N06030	Sol. ann.	All	45	...	−325	85	35	23.3	*23.3*	*23.3*	**23.2**	**22.1**	**21.3**
33Ni–42Fe–21Cr	...	B366	...	N08800	C.D. ann.	All	45	(74)	−325	75	30	20.0	*20.0*	*20.0*	*20.0*	*20.0*	*20.0*
33Ni–42Fe–21Cr	...	B564	...	N08800	Annealed	...	45	(9)	−325	75	30	20.0	*20.0*	*20.0*	*20.0*	*20.0*	*20.0*
35Ni–35Fe–20Cr–Cb	...	B366	...	N08020	Annealed	All	45	(74)	−325	80	35	23.3	*23.3*	*23.3*	*23.3*	23.3	*23.3*
35Ni–35Fe–20Cr–Cb	...	B462	...	N08020	Annealed	...	45	(9)	−325	80	35	23.3	*23.3*	*23.3*	*23.3*	23.3	*23.3*
72Ni–15Cr–8Fe	...	B564	...	N06600	Annealed	All	43	(9)	−325	80	35	23.3	*23.3*	*23.3*	*23.3*	*23.3*	*23.3*
42Ni–21.5Cr–3Mo–2.3Cu	...	B366	...	N08825	C.D. ann.	All	45	(74)	−325	85	35	23.3	*23.3*	*23.3*	*23.3*	*23.3*	*23.3*
42Ni–21.5Cr–3Mo–2.3Cu	...	B564	...	N08825	Annealed	...	45	...	−325	85	35	23.3	*23.3*	*23.3*	*23.3*	*23.3*	*23.3*
58Ni–29Cr–9Fe	Forg.	B564	...	N06690	Annealed	All	43	(9)	−325	85	35	23.3	*23.3*	*23.3*	*23.3*	*23.3*	*23.3*
37Ni–33Fe–25Cr	...	B366	...	N08120	Sol. ann.	All	45	...	−325	90	40	26.7	*26.7*	*26.7*	*26.7*	**25.1**	**24.4**

Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

Basic Allowable Stress, *S*, ksi, at Metal Temperature, °F [Notes (1), (4a)]																						
650	700	750	800	850	900	950	1,000	1,050	1,100	1,150	1,200	1,250	1,300	1,350	1,400	1,450	1,500	1,550	1,600	1,650	UNS No. or Grade	Spec. No.
Nickel and Nickel Alloy — Plates and Sheets (4a) (Cont'd)																						
25.6	**25.1**	**24.7**	**24.3**	**23.9**	**23.6**	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	N08367	B688
25.6	**25.1**	**24.7**	**24.3**	**23.9**	**23.6**	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	N08367	B688
27.5	**26.7**	**26.1**	**25.6**	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	N06059	B575
26.2	**25.7**	**25.4**	**25.2**	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	N06200	B575
27.3	**27.0**	**26.7**	**26.4**	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	N10362	B575
30.0	*30.0*	*30.0*	**29.8**	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	N10001	B333
33.3	*33.3*	*33.3*	**33.2**	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	N10001	B333
34.0	*34.0*	34.0	34.0	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	N10665	B333
34.0	*34.0*	**33.9**	**33.5**	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	N10675	B333
23.5	23.1	22.9	22.6	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	R20033	B625
Nickel and Nickel Alloy — Forgings and Fittings (4a)																						
6.2	6.2	6.1	6.0	5.8	4.5	3.7	3.0	2.4	2.0	1.5	1.2	...	...	...	...	...	...	...	...	...	N02201	B160
6.2	6.2	6.1	6.0	5.8	4.5	3.7	3.0	2.4	2.0	1.5	1.2	...	...	...	...	...	...	...	...	...	N02201	B366
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	N02200	B366
16.1	15.7	15.3	15.0	14.7	14.5	14.2	14.0	13.8	11.6	9.3	7.4	5.9	4.7	3.8	3.0	2.4	1.9	1.4	1.1	0.86	N08810	B564
16.1	15.7	15.3	15.0	14.7	14.5	14.2	14.0	13.8	12.9	10.4	8.3	6.7	5.4	4.3	3.4	2.7	2.2	1.6	1.2	0.91	N08811	B564
16.1	15.7	15.3	15.0	14.7	14.5	14.2	14.0	13.8	11.6	9.3	7.4	5.9	4.7	3.8	3.0	2.4	1.9	1.4	1.1	0.86	N08810	B366
16.1	15.7	15.3	15.0	14.7	14.5	14.2	14.0	13.8	12.9	10.4	8.3	6.7	5.4	4.3	3.4	2.7	2.2	1.6	1.2	0.91	N08811	B366
13.1	13.0	12.9	12.7	11.0	8.0	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	N04400	B564
13.1	13.0	12.9	12.7	11.0	8.0	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	N04400	B366
16.7	*16.7*	*16.7*	*16.7*	*16.5*	*15.9*	10.6	7.0	4.5	3.0	2.2	2.0	...	...	...	...	...	...	...	...	...	N06600	B366
20.9	**20.5**	**20.1**	**19.7**	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	N06030	B366
20.9	**20.5**	**20.1**	**19.7**	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	N06030	B462
20.0	*20.0*	*20.0*	*20.0*	20.0	20.0	20.0	19.9	17.0	13.0	9.8	6.6	4.2	2.0	1.6	1.1	1.0	0.8	...	...	...	N08800	B366
20.0	*20.0*	*20.0*	*20.0*	20.0	20.0	20.0	19.9	17.0	13.0	9.8	6.6	4.2	2.0	1.6	1.1	1.0	0.8	...	...	...	N08800	B564
23.3	23.3	23.2	22.7	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	N08020	B366
23.3	23.3	23.2	22.7	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	N08020	B462
23.3	*23.3*	*23.3*	*23.3*	23.3	16.0	10.6	7.0	4.5	3.0	2.2	2.0	...	...	...	...	...	...	...	...	...	N06600	B564
23.3	*23.3*	**23.2**	**23.0**	**22.9**	**22.8**	**22.6**	**22.3**	...	...	...	...	...	...	...	...	...	...	...	...	...	N08825	B366
23.3	*23.3*	**23.2**	**23.0**	**22.9**	**22.8**	**22.6**	**22.3**	...	...	...	...	...	...	...	...	...	...	...	...	...	N08825	B564
23.3	*23.3*	*23.3*	*23.3*	*23.3*	*23.3*	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	N06690	B564
23.3	**22.9**	**22.6**	**22.4**	**22.2**	**22.1**	**22.0**	**21.9**	**21.9**	17.9	14.2	12.3	9.4	7.6	6.2	5.0	4.0	3.2	2.6	2.0	1.4	N08120	B366

Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

Nominal Composition	Product Form	Spec. No.	Type/ Grade	UNS No.	Class/ Condition/ Temper	Size Range, in.	P-No. (5)	Notes	Min. Temp., °F (6)	Specified Min. Strength, ksi: Tensile	Yield	Basic Allowable Stress, S, ksi, at Metal Temperature, °F [Notes (1), (4a)]: Min. Temp. to 100	200	300	400	500	600
Nickel and Nickel Alloy — Forgings and Fittings (4a)																	
37Ni–33Fe–25Cr	...	B564	...	N08120	Sol. ann.	All	45	...	−325	90	40	26.7	*26.7*	*26.7*	*26.7*	**25.1**	**24.4**
47Ni–22Cr–9Mo–18Fe	...	B366	...	N06002	Sol. ann.	All	43	(32)	−325	100	40	26.7	*26.7*	*26.7*	*26.7*	*25.5*	*24.2*
31Ni–33Fe–27Cr–6.5Mo–Cu–N	...	B366	...	N08031	Sol. ann.	All	45	(74)	−325	94	40	26.7	*26.7*	**26.7**	**24.7**	**23.3**	**22.2**
31Ni–33Fe–27Cr–6.5Mo–Cu–N	...	B564	...	N08031	Annealed H.W.	All	45	...	−325	94	40	26.7	*26.7*	**26.7**	**24.7**	**23.3**	**22.2**
54Ni–16Mo–15Cr	...	B366	...	N10276	Sol. ann.	All	43	(74)	−325	100	41	27.3	*27.3*	*27.3*	*27.3*	**26.9**	**25.2**
54Ni–16Mo–15Cr	...	B462	...	N10276	Sol. ann.	All	43	(9)	−325	100	41	27.3	*27.3*	*27.3*	*27.3*	**26.9**	**25.2**
54Ni–16Mo–15Cr	...	B564	...	N10276	Sol. ann.	All	43	(9)	−325	100	41	27.3	*27.3*	*27.3*	*27.3*	**26.9**	**25.2**
62Ni–28Mo–5Fe	...	B366	...	N10001	Sol. ann.	All	44	(32)	−325	100	45	30.0	*30.0*	*30.0*	*30.0*	*30.0*	*30.0*
55Ni–21Cr–13.5Mo	...	B366	...	N06022	Sol. ann.	All	43	(32) (74)	−325	100	45	30.0	*30.0*	*30.0*	*30.0*	**29.0**	**27.6**
55Ni–21Cr–13.5Mo	...	B462	...	N06022	Sol. ann.	All	43	(9)	−325	100	45	30.0	*30.0*	*30.0*	*30.0*	**30.0**	**27.6**
55Ni–21Cr–13.5Mo	...	B564	...	N06022	Sol. ann.	All	43	(9)	−325	100	45	30.0	*30.0*	*30.0*	30.0	**29.0**	**27.6**
58Ni–33Cr–8Mo	...	B366	...	N06035	Sol. ann.	All	43	(32) (74)	−325	85	35	23.3	*23.3*	*23.3*	**22.2**	**20.6**	**19.7**
58Ni–33Cr–8Mo	...	B462	...	N06035	Sol. ann.	All	43	(9)	−325	85	35	23.3	*23.3*	*23.3*	**22.2**	**20.6**	**19.7**
58Ni–33Cr–8Mo	...	B564	...	N06035	Sol. ann.	All	43	(9)	−325	85	35	23.3	*23.3*	*23.3*	**22.2**	**20.6**	**19.7**
59Ni–23Cr–16Mo	...	B366	...	N06059	Sol. ann.	All	43	(74)	−325	100	45	30.0	*30.0*	*30.0*	*30.0*	**29.7**	**28.2**
59Ni–23Cr–16Mo	...	B564	...	N06059	H.W. sol. ann.	All	43	...	−325	100	45	30.0	*30.0*	*30.0*	*30.0*	**29.7**	**28.2**
59Ni–23Cr–16Mo–1.6Cu	...	B366	...	N06200	Sol. ann.	All	43	(74)	−325	100	45	30.0	*30.0*	*30.0*	*30.0*	**28.6**	**26.9**
59Ni–23Cr–16Mo–1.6Cu	...	B462	...	N06200	Sol. ann.	All	43	...	−325	100	45	30.0	*30.0*	*30.0*	*30.0*	**28.6**	**26.9**
59Ni–23Cr–16Mo–1.6Cu	...	B564	...	N06200	Sol. ann.	All	43	...	−325	100	45	30.0	*30.0*	*30.0*	*30.0*	**28.6**	**26.9**
62Ni–22Mo–15Cr	...	B366	...	N10362	Sol. ann.	All	43	(9)	−325	105	45	30.0	*30.0*	*30.0*	*30.0*	**28.9**	**27.7**
62Ni–22Mo–15Cr	...	B462	...	N10362	Sol. ann.	All	43	(9)	−325	105	45	30.0	*30.0*	*30.0*	*30.0*	**28.9**	**27.7**
62Ni–22Mo–15Cr	...	B564	...	N10362	Sol. ann.	All	43	(9)	−325	105	45	30.0	*30.0*	*30.0*	*30.0*	**28.9**	**27.7**
60Ni–22Cr–9Mo–3.5Cb	...	B564	...	N06625	Annealed	≤4	43	(9) (64)	−325	120	60	40.0	*40.0*	*39.6*	*39.2*	**38.6**	**37.8**
65Ni–28Mo–2Fe	...	B366	...	N10665	Sol. ann.	All	44	(74)	−325	110	51	34.0	*34.0*	*34.0*	*34.0*	*34.0*	*34.0*
65Ni–29.5Mo–2Fe–2Cr	...	B366	...	N10675	Sol. ann.	All	44	(74)	−325	110	51	34.0	*34.0*	*34.0*	*34.0*	*34.0*	*34.0*
65Ni–29.5Mo–2Fe–2Cr	...	B462	...	N10675	Sol. ann.	All	44	...	−325	110	51	34.0	*34.0*	*34.0*	*34.0*	*34.0*	*34.0*
65Ni–29.5Mo–2Fe–2Cr	...	B564	...	N10675	Sol. ann.	All	44	...	−325	110	51	34.0	*34.0*	*34.0*	*34.0*	*34.0*	*34.0*
57Ni–22Cr–14W–2Mo–La	...	B564	...	N06230	Sol. ann.	All	43	...	−325	110	45	30.0	*30.0*	*30.0*	*30.0*	*30.0*	**29.6**
57Ni–22Cr–14W–2Mo–La	...	B366	...	N06230	Sol. ann.	All	43	(74)	−325	110	45	30.0	*30.0*	*30.0*	*30.0*	*30.0*	**29.6**
33Cr–31Ni–32Fe–1.5Mo–0.6Cu–N	...	B366	...	R20033	Sol. ann.	All	45	...	−325	109	55	36.3	30.9	28.1	26.1	24.7	23.8
33Cr–31Ni–32Fe–1.5Mo–0.6Cu–N	...	B462	...	R20033	Sol. ann.	All	45	...	−325	109	55	36.3	30.9	28.1	26.1	24.7	23.8
33Cr–31Ni–32Fe–1.5Mo–0.6Cu–N	...	B564	...	R20033	Sol. ann.	All	45	...	−325	109	55	36.3	30.9	28.1	26.1	24.7	23.8
Nickel and Nickel Alloy — Rod and Bar (4a)																	
99.0Ni	...	B160	...	N02200	H.W.	All	41	(9)	−325	60	15	10.0	10.0	10.0	10.0	10.0	10.0

Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

Basic Allowable Stress, *S*, ksi, at Metal Temperature, °F [Notes (1), (4a)]																						
650	700	750	800	850	900	950	1,000	1,050	1,100	1,150	1,200	1,250	1,300	1,350	1,400	1,450	1,500	1,550	1,600	1,650	UNS No. or Grade	Spec. No.
Nickel and Nickel Alloy — Forgings and Fittings (4a) (Cont'd)																						
23.3	22.9	22.6	22.4	22.2	22.1	22.0	21.9	21.9	17.9	14.2	12.3	9.4	7.6	6.2	5.0	4.0	3.2	2.6	2.0	1.4	N08120	B564
23.7	23.3	22.9	22.7	22.5	19.6	19.5	19.3	19.3	17.5	14.1	11.3	9.3	7.7	6.1	4.8	3.8	3.0	...	...	...	N06002	B366
21.7	21.3	20.9	20.5	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	N08031	B366
21.7	21.3	20.9	20.5	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	N08031	B564
24.6	24.0	23.5	23.1	22.8	22.6	22.4	22.3	18.5	15.0	12.2	9.8	7.8	...	...	...	...	...	...	...	...	N10276	B366
24.6	24.0	23.5	23.1	22.8	22.6	22.4	22.3	18.5	15.0	12.2	9.8	7.8	...	...	...	...	...	...	...	...	N10276	B462
24.6	24.0	23.5	23.1	22.8	22.6	22.4	22.3	18.5	15.0	12.2	9.8	7.8	...	...	...	...	...	...	...	...	N10276	B564
30.0	30.0	30.0	29.9	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	N10001	B366
27.0	26.5	26.1	25.7	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	N06022	B366
27.0	26.5	26.1	25.7	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	N06022	B462
27.0	26.5	26.1	25.7	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	N06022	B564
19.4	19.2	19.0	18.8	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	N06035	B366
19.4	19.2	19.0	18.8	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	N06035	B462
19.4	19.2	19.0	18.8	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	N06035	B564
27.5	26.8	26.1	25.5	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	N06059	B366
27.5	26.8	26.1	25.5	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	N06059	B564
26.2	25.7	25.4	25.2	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	N06200	B366
26.2	25.7	25.4	25.2	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	N06200	B462
26.2	25.7	25.4	25.2	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	N06200	B564
27.3	27.0	26.7	26.4	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	N10362	B366
27.3	27.0	26.7	26.4	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	N10362	B462
27.3	27.0	26.7	26.4	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	N10362	B564
37.4	37.0	36.6	36.3	36.1	35.8	35.4	31.2	31.2	23.1	21.0	13.2	...	...	...	...	...	...	...	...	...	N06625	B564
34.0	34.0	34.0	34.0	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	N10665	B366
34.0	34.0	33.9	33.5	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	N10675	B366
34.0	34.0	33.9	33.5	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	N10675	B462
34.0	34.0	33.9	33.5	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	N10675	B564
29.1	28.7	28.4	28.2	28.2	28.2	28.2	28.2	28.2	23.2	19.0	15.6	12.9	10.6	8.5	6.7	5.3	4.1	2.9	2.1	1.5	N06230	B564
29.1	28.7	28.4	28.2	28.2	28.2	28.2	28.2	28.2	23.2	19.0	15.6	12.9	10.6	8.5	6.7	5.3	4.1	2.9	2.1	1.5	N06230	B366
23.5	23.1	22.9	22.6	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	R20033	B366
23.5	23.1	22.9	22.6	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	R20033	B462
23.5	23.1	22.9	22.6	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	R20033	B564
Nickel and Nickel Alloy — Rod and Bar (4a)																						
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	N02200	B160

Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

Nominal Composition	Product Form	Spec. No.	Type/ Grade	UNS No.	Class/ Condition/ Temper	Size Range, in.	P-No. (5)	Notes	Min. Temp., °F (6)	Specified Min. Strength, ksi: Tensile	Yield	Basic Allowable Stress, S, ksi, at Metal Temperature, °F [Notes (1), (4a)]: Min. Temp. to 100	200	300	400	500	600
Nickel and Nickel Alloy — Rod and Bar (4a)																	
99.0Ni	...	B160	...	N02200	Annealed	All	41	(9)	−325	55	15	10.0	10.0	10.0	10.0	10.0	10.0
67Ni–30Cu	...	B164	...	N04400	Ann. forg.	All	42	(13)	−325	70	25	16.7	14.6	13.6	13.2	13.1	13.1
33Ni–42Fe–21Cr	Bar	B408	...	N08810	Sol. tr. or ann.	...	45	...	−325	65	25	16.7	16.7	16.7	16.7	16.7	16.5
33Ni–42Fe–21Cr–Al–Ti	Bar	B408	...	N08811	Sol. tr. or ann.	...	45	...	−325	65	25	16.7	16.7	16.7	16.7	16.7	16.5
33Ni–42Fe–21Cr	Bar	B408	...	N08800	H.F.	...	45	...	−325	75	30	20.0	20.0	20.0	20.0	20.0	20.0
26Ni–22Cr–5Mo–Ti	...	B621	...	N08320	Sol. ann.	All	45	...	−325	75	28	18.7	*18.7*	*18.7*	*18.7*	*18.7*	*18.6*
47Ni–22Cr–19Fe–6Mo	...	B581	...	N06007	Sol. ann.	$>\frac{3}{4}$	45	...	−325	85	30	20.0	*20.0*	*20.0*	*20.0*	*20.0*	**19.5**
42Ni–21.5Cr–3Mo–2.3Cu	...	B425	...	N08825	Annealed	...	45	...	−325	85	35	23.3	*23.3*	*23.3*	*23.3*	*23.3*	*23.3*
58Ni–29Cr–9Fe	Bar	B166	...	N06690	H.R.	>3	43	...	−325	85	35	23.3	*23.3*	*23.3*	*23.3*	*23.3*	*23.3*
58Ni–29Cr–9Fe	Bar	B166	...	N06690	H.R or C.D. ann.	All	43	...	−325	85	35	23.3	*23.3*	*23.3*	*23.3*	*23.3*	*23.3*
47Ni–22Cr–19Fe–6Mo	...	B581	...	N06007	Sol. ann.	$\leq\frac{3}{4}$	45	...	−325	90	35	23.3	*23.3*	*23.3*	*23.3*	*23.3*	**22.7**
40Ni–29Cr–15Fe–5Mo	...	B581	...	N06030	Sol. ann.	All	45	...	−325	85	35	23.3	*23.3*	*23.3*	**23.2**	**22.1**	**21.3**
37Ni–33Fe–25Cr	...	B408	...	N08120	Sol. ann.	All	45	...	−325	90	40	26.7	*26.7*	*26.7*	*26.7*	**25.1**	**24.4**
31Ni–33Fe–27Cr–6.5Mo–Cu–N	...	B649	...	N08031	Annealed	All	45	...	−325	94	40	26.7	*26.7*	*26.7*	*24.7*	**23.3**	**22.2**
67Ni–30Cu	...	B164	...	N04400	H.W.	All except hex. $>2\frac{1}{8}$	42	...	−325	80	40	26.7	25.8	24.8	23.9	23.4	23.1
58Ni–33Cr–8Mo	...	B574	...	N06035	Sol. ann.	All	43	(9)	−325	85	35	23.3	*23.3*	*23.3*	**22.2**	**20.6**	**19.7**
61Ni–16Mo–16Cr	...	B574	...	N06455	Sol. ann.	All	43	(9)	−325	100	40	26.7	*26.7*	*26.7*	*26.7*	*26.7*	*26.7*
54Ni–16Mo–15Cr	...	B574	...	N10276	Sol. ann.	All	43	...	−325	100	41	27.3	*27.3*	*27.3*	*27.3*	**26.9**	**25.2**
62Ni–22Mo–15Cr	...	B574	...	N10362	Sol. ann.	All	43	(9)	−325	105	45	30.0	*30.0*	*30.0*	*30.0*	**28.9**	**27.7**
60Ni–22Cr–9Mo–3.5Cb	...	B446	1	N06625	Annealed	>4 to 10	43	(9) (64) (70)	−325	110	50	33.3	*33.3*	*33.3*	*33.3*	33.3	33.3
60Ni–22Cr–9Mo–3.5Cb	...	B446	1	N06625	Annealed	≤4	43	(9) (64) (70)	−325	120	60	40.0	*40.0*	*40.0*	*40.0*	**38.3**	**38.0**
57Ni–22Cr–14W–2Mo–La	...	B572	...	N06230	Sol. ann.	All	43	...	−325	110	45	30.0	*30.0*	*30.0*	*30.0*	*30.0*	**29.6**
59Ni–23Cr–16Mo	...	B574	...	N06059	Sol. ann.	All	43	...	−325	100	45	30.0	*30.0*	*30.0*	*30.0*	**29.7**	**28.2**
59Ni–23Cr–16Mo–1.6Cu	...	B574	...	N06200	Sol. ann.	All	43	...	−325	100	45	30.0	*30.0*	*30.0*	*30.0*	**28.6**	**26.9**
65Ni–29.5Mo–2Fe–2Cr	...	B335	...	N10675	Sol. ann.	All	44	...	−325	110	51	34.0	*34.0*	*34.0*	*34.0*	*34.0*	*34.0*
33Cr–31Ni–32Fe–1.5Mo–0.6Cu–N	...	B649	...	R20033	Sol. ann.	All	45	...	−325	109	55	36.3	30.9	28.1	26.1	24.7	23.8

Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

Basic Allowable Stress, *S*, ksi, at Metal Temperature, °F [Notes (1), (4a)]																						
650	700	750	800	850	900	950	1,000	1,050	1,100	1,150	1,200	1,250	1,300	1,350	1,400	1,450	1,500	1,550	1,600	1,650	UNS No. or Grade	Spec. No.
Nickel and Nickel Alloy — Rod and Bar (4a) (Cont'd)																						
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	N02200	B160
13.1	13.0	12.9	12.7	11.0	8.0	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	N04400	B164
16.1	15.7	15.3	15.0	14.7	14.5	14.2	14.0	13.8	11.6	9.3	7.4	5.9	4.7	3.8	3.0	2.4	1.9	1.4	1.1	0.86	N08810	B408
16.1	15.7	15.3	15.0	14.7	14.5	14.2	14.0	13.7	12.9	10.4	8.3	6.7	5.4	4.3	3.4	2.7	2.2	1.6	1.2	0.91	N08811	B408
20.0	20.0	20.0	20.0	20.0	20.0	20.0	19.9	17.0	13.0	9.8	6.6	4.2	2.0	1.6	1.1	1.0	0.8	...	...	...	N08800	B408
18.2	*17.8*	*17.5*	*17.2*	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	N08320	B621
19.2	**19.0**	18.8	**18.7**	18.6	18.5	18.4	18.3	...	...	...	...	...	...	...	...	...	...	...	...	...	N06007	B581
23.3	*23.3*	**23.2**	**23.0**	**22.9**	**22.8**	**22.6**	**22.3**	...	...	...	...	...	...	...	...	...	...	...	...	...	N08825	B425
23.3	*23.3*	*23.3*	*23.3*	*23.3*	*23.3*	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	N06690	B166
23.3	*23.3*	*23.3*	*23.3*	*23.3*	*23.3*	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	N06690	B166
22.4	*22.2*	*22.0*	*21.8*	*21.7*	*20.0*	*19.5*	*18.9*	...	...	...	...	...	...	...	...	...	...	...	...	...	N06007	B581
20.9	**20.5**	**20.1**	**19.7**	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	N06030	B581
23.3	**22.9**	**22.6**	**22.4**	**22.2**	**22.1**	**22.0**	**21.9**	**21.9**	17.9	14.2	12.3	9.4	7.6	6.2	5.0	4.0	3.2	2.6	2.0	1.4	N08120	B408
21.7	**21.3**	**20.9**	**20.5**	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	N08031	B649
22.9	22.7	20.0	14.5	8.5	4.0	1.9	...	...	...	...	...	...	...	...	...	...	...	...	...	...	N04400	B164
19.4	**19.2**	**19.0**	**18.8**	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	N06035	B574
26.7	*26.5*	*26.1*	*25.8*	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	N06455	B574
24.6	**24.0**	**23.5**	**23.1**	**22.8**	**22.6**	**22.4**	**22.3**	18.5	15.0	12.2	9.8	7.8	...	...	...	...	...	...	...	...	N10276	B574
27.3	**27.0**	**26.7**	**26.4**	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	N10362	B574
33.3	33.3	33.3	33.3	33.1	32.8	32.5	31.2	31.2	23.1	21.0	13.2	...	...	...	...	...	...	...	...	...	N06625	B446
37.7	37.4	37.4	37.4	37.4	37.4	37.4	37.4	37.4	37.4	27.7	21.0	13.2	...	...	...	...	...	...	...	...	N06625	B446
29.1	**28.7**	**28.4**	**28.2**	**28.2**	**28.2**	**28.2**	**28.2**	**28.2**	23.2	19.0	15.6	12.9	10.6	8.5	6.7	5.3	4.1	2.9	2.1	1.5	N06230	B572
27.5	**26.8**	**26.1**	**25.5**	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	N06059	B574
26.2	**25.7**	**25.4**	**25.2**	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	N06200	B574
34.0	*34.0*	**33.9**	**33.5**	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	N10675	B335
23.5	23.1	22.9	22.6	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	R20033	B649

Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

Nominal Composition	Product Form	Spec. No.	Type/ Grade	UNS No.	Class/ Condi- tion/ Temper	Size Range, in.	P- No. (5)	Notes	Min. Tem- p., °F (6)	Specified Min. Strength, ksi Tensile	Yield	Basic Allowable Stress, S, ksi, at Metal Temperature, °F [Notes (1), (4a)] Min. Temp. to 100	200	300	400	500	600
Nickel and Nickel Alloy — Castings (4a)																	
59Ni–22Cr–14Mo–4Fe–3W	...	A494	CX2MW	N26022	...	...	43	(9)	−325	80	45	26.7	26.7	26.7	26.7	26.7	...
53Ni–17Mo–16Cr–6Fe–5W	...	A494	CW12-MW	N30002	...	...	a	(7) (9)	−325	72	40	24.0	24.0	24.0	24.0	24.0	24.0
56Ni–19Mo–18Cr–2Fe	...	A494	CW6M	N30107	...	...	44	(9)	−325	72	40	24.0	24.0	24.0	24.0	24.0	24.0

Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

Basic Allowable Stress, *S*, ksi, at Metal Temperature, °F [Notes (1), (4a)]																						
650	700	750	800	850	900	950	1,000	1,050	1,100	1,150	1,200	1,250	1,300	1,350	1,400	1,450	1,500	1,550	1,600	1,650	UNS No. or Grade	Spec. No.
Nickel and Nickel Alloy — Castings (4a)																						
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	CX2MW	A494
24.0	24.0	24.0	24.0	24.0	24.0	24.0	22.8	...	...	...	...	...	...	...	...	...	...	...	...	...	CW12M-W	A494
24.0	24.0	24.0	24.0	24.0	24.0	24.0	22.8	...	...	...	...	...	...	...	...	...	...	...	...	...	CW6M	A494

Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

Nominal Composition	Product Form	Spec. No.	Type/ Grade	UNS No.	Class/ Condition/ Temper	P-No. (5)	Notes	Min. Temp., °F (6)	Specified Min. Strength, ksi: Tensile	Specified Min. Strength, ksi: Yield
Titanium and Titanium Alloy — Pipes and Tubes										
Ti	Smls. & wld. tube	B338	1	R50250	Annealed	51	...	−75	35	20
Ti	Smls. pipe	B861	1	R50250	Annealed	51	...	−75	35	20
Ti	Wld. pipe	B862	1	R50250	Annealed	51	...	−75	35	20
Ti	Smls. & wld. tube	B338	2	R50400	Annealed	51	...	−75	50	40
Ti	Smls. pipe	B861	2	R50400	Annealed	51	...	−75	50	40
Ti	Wld. pipe	B862	2	R50400	Annealed	51	...	−75	50	40
Ti	Smls. & wld. tube	B338	3	R50550	Annealed	52	...	−75	65	55
Ti	Smls. pipe	B861	3	R50550	Annealed	52	...	−75	65	55
Ti	Wld. pipe	B862	3	R50550	Annealed	52	...	−75	65	55
Ti–Pd	Smls. & wld. tube	B338	7	R52400	Annealed	51	...	−75	50	40
Ti–Pd	Smls. pipe	B861	7	R52400	Annealed	51	...	−75	50	40
Ti–Pd	Wld. pipe	B862	7	R52400	Annealed	51	...	−75	50	40
Ti–0.3Mo–0.8Ni	Smls. & wld. tube	B338	12	R53400	Annealed	52	...	−75	70	50
Ti–0.3Mo–0.8Ni	Smls. pipe	B861	12	R53400	Annealed	52	...	−75	70	50
Ti–0.3Mo–0.8Ni	Wld. pipe	B862	12	R53400	Annealed	52	...	−75	70	50
Titanium and Titanium Alloy — Plates, Sheets, and Strips										
Ti	...	B265	1	R50250	Annealed	51	...	−75	35	20
Ti	...	B265	2	R50400	Annealed	51	...	−75	50	40
Ti	...	B265	3	R50550	Annealed	52	...	−75	65	55
Ti–Pd	...	B265	7	R52400	Annealed	51	...	−75	50	40
Ti–0.3Mo–0.8Ni	...	B265	12	R53400	Annealed	52	...	−75	70	50
Titanium and Titanium Alloy — Forgings and Fittings										
Ti	Fittings	B363	WPT1	R50250	Annealed	51	...	−75	35	20
Ti	Forgings	B381	F-1	R50250	Annealed	51	...	−75	35	20
Ti	Fittings	B363	WPT2	R50400	Annealed	51	...	−75	50	40
Ti	Forgings	B381	F-2	R50400	Annealed	51	...	−75	50	40
Ti	Fittings	B363	WPT3	R50550	Annealed	52	...	−75	65	55
Ti	Forgings	B381	F-3	R50550	Annealed	52	...	−75	65	55
Ti–Pd	Fittings	B363	WPT7	R52400	Annealed	51	...	−75	50	40
Ti–Pd	Forgings	B381	F-7	R52400	Annealed	51	...	−75	50	40
Ti–0.3Mo–0.8Ni	Fittings	B363	WPT12	R53400	Annealed	52	...	−75	70	50
Ti–0.3Mo–0.8Ni	Forgings	B381	F-12	R53400	Annealed	52	...	−75	70	50
Titanium and Titanium Alloy — Bars										
Ti	...	B348	1	R50250	Annealed	51	...	−75	35	20
Ti	...	B348	2	R50400	Annealed	51	...	−75	50	40
Ti	...	B348	3	R50550	Annealed	52	...	−75	65	55

Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

Basic Allowable Stress, *S*, ksi, at Metal Temperature, °F [Notes (1), (4a)]														
Min. Temp. to 100	150	200	250	300	350	400	450	500	550	600	650	700	UNS No.	Spec. No.
Titanium and Titanium Alloy — Pipes and Tubes														
11.7	10.7	9.3	8.2	7.2	6.3	5.5	4.7	4.2	3.8	3.5	...	...	R50250	B338
11.7	10.7	9.3	8.2	7.2	6.3	5.5	4.7	4.2	3.8	3.5	...	...	R50250	B861
11.7	10.7	9.3	8.2	7.2	6.3	5.5	4.7	4.2	3.8	3.5	...	...	R50250	B862
16.7	15.6	14.5	13.3	12.1	11.2	10.3	9.6	8.9	8.2	7.6	...	...	R50400	B338
16.7	15.6	14.5	13.3	12.1	11.2	10.3	9.6	8.9	8.2	7.6	...	...	R50400	B861
16.7	15.6	14.5	13.3	12.1	11.2	10.3	9.6	8.9	8.2	7.6	...	...	R50400	B862
21.7	20.0	18.4	16.6	14.9	13.5	12.1	11.0	9.9	9.3	8.6	...	...	R50550	B338
21.7	20.0	18.4	16.6	14.9	13.5	12.1	11.0	9.9	9.3	8.6	...	...	R50550	B861
21.7	20.0	18.4	16.6	14.9	13.5	12.1	11.0	9.9	9.3	8.6	...	...	R50550	B862
16.7	15.6	14.5	13.3	12.1	11.2	10.3	9.6	8.9	8.2	7.6	...	...	R52400	B338
16.7	15.6	14.5	13.3	12.1	11.2	10.3	9.6	8.9	8.2	7.6	...	...	R52400	B861
16.7	15.6	14.5	13.3	12.1	11.2	10.3	9.6	8.9	8.2	7.6	...	...	R52400	B862
23.3	22.6	21.8	20.4	18.9	17.8	16.7	16.0	15.2	14.8	14.4	...	...	R53400	B338
23.3	22.6	21.8	20.4	18.9	17.8	16.7	16.0	15.2	14.8	14.4	...	...	R53400	B861
23.3	22.6	21.8	20.4	18.9	17.8	16.7	16.0	15.2	14.8	14.4	...	...	R53400	B862
Titanium and Titanium Alloy — Plates, Sheets, and Strips														
11.7	10.7	9.3	8.2	7.2	6.3	5.5	4.7	4.2	3.8	3.5	...	...	R50250	B265
16.7	15.6	14.5	13.3	12.1	11.2	10.3	9.6	8.9	8.2	7.6	...	...	R50400	B265
21.7	20.0	18.4	16.6	14.9	13.5	12.1	11.0	9.9	9.3	8.6	...	...	R50550	B265
16.7	15.6	14.5	13.3	12.1	11.2	10.3	9.6	8.9	8.2	7.6	...	...	R52400	B265
23.3	22.6	21.8	20.4	18.9	17.8	16.7	16.0	15.2	14.8	14.4	...	...	R53400	B265
Titanium and Titanium Alloy — Forgings and Fittings														
11.7	10.7	9.3	8.2	7.2	6.3	5.5	4.7	4.2	3.8	3.5	...	...	R50250	B363
11.7	10.7	9.3	8.2	7.2	6.3	5.5	4.7	4.2	3.8	3.5	...	...	R50250	B381
16.7	15.6	14.5	13.3	12.1	11.2	10.3	9.6	8.9	8.2	7.6	...	...	R50400	B363
16.7	15.6	14.5	13.3	12.1	11.2	10.3	9.6	8.9	8.2	7.6	...	...	R50400	B381
21.7	20.0	18.4	16.6	14.9	13.5	12.1	11.0	9.9	9.3	8.6	...	...	R50550	B363
21.7	20.0	18.4	16.6	14.9	13.5	12.1	11.0	9.9	9.3	8.6	...	...	R50550	B381
16.7	15.6	14.5	13.3	12.1	11.2	10.3	9.6	8.9	8.2	7.6	...	...	R52400	B363
16.7	15.6	14.5	13.3	12.1	11.2	10.3	9.6	8.9	8.2	7.6	...	...	R52400	B381
23.3	22.6	21.8	20.4	18.9	17.8	16.7	16.0	15.2	14.8	14.4	...	...	R53400	B363
23.3	22.6	21.8	20.4	18.9	17.8	16.7	16.0	15.2	14.8	14.4	...	...	R53400	B381
Titanium and Titanium Alloy — Bars														
11.7	10.7	9.3	8.2	7.2	6.3	5.5	4.7	4.2	3.8	3.5	...	...	R50250	B348
16.7	15.6	14.5	13.3	12.1	11.2	10.3	9.6	8.9	8.2	7.6	...	...	R50400	B348
21.7	20.0	18.4	16.6	14.9	13.5	12.1	11.0	9.9	9.3	8.6	...	...	R50550	B348

Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

Nominal Composition	Product Form	Spec. No.	Type/ Grade	UNS No.	Class/ Condition/ Temper	P-No. (5)	Notes	Min. Temp., °F (6)	Specified Min. Strength, ksi Tensile	Specified Min. Strength, ksi Yield
Titanium and Titanium Alloy — Bars										
Ti–Pd	...	B348	7	R52400	Annealed	51	...	−75	50	40
Ti–0.3Mo–0.8Ni	...	B348	12	R53400	Annealed	52	...	−75	70	50
Titanium and Titanium Alloy — Castings										
Ti	...	B367	C-2	R52550	...	51	(14) (44)	−75	50	40
Ti	...	B367	C-3	R52550	...	52	(14) (44)	−75	65	55
Ti–Pd	...	B367	C-7	R52700	...	51	(14) (44)	−75	50	40
Zirconium and Zirconium Alloy — Pipes and Tubes										
99.2Zr	Smls. & wld. tube	B523	...	R60702		61	...	−75	55	30
99.2Zr	Smls. & wld. tube	B658	...	R60702		61	...	−75	55	30
95.5Zr + 2.5Nb	Smls. & wld. pipe	B658	...	R60705		62	(73)	−75	80	55
Zirconium and Zirconium Alloy — Plates and Sheets										
99.2Zr	Plate, sheet, strip	B551	...	R60702		61	...	−75	55	30
95.5Zr + 2.5Nb	Plate, sheet, strip	B551	...	R60705		62	(73)	−75	80	55
Zirconium and Zirconium Alloy — Forgings and Bar										
99.2Zr	Forgings	B493	...	R60702		61	...	−75	55	30
99.2Zr	Bar, wire	B550	...	R60702		61	...	−75	55	30
95.5Zr + 2.5Nb	Forgings	B493	...	R60705		62	(73)	−75	70	55
95.5Zr + 2.5Nb	Bar, wire	B550	...	R60705		62	(73)	−75	80	55

Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

Basic Allowable Stress, *S*, ksi, at Metal Temperature, °F [Notes (1), (4a)]														
Min. Temp. to 100	**150**	**200**	**250**	**300**	**350**	**400**	**450**	**500**	**550**	**600**	**650**	**700**	**UNS No.**	**Spec. No.**
Titanium and Titanium Alloy — Bars (Cont'd)														
16.7	15.6	14.5	13.3	12.1	11.2	10.3	9.6	8.9	8.2	7.6	...	...	R52400	B348
23.3	22.6	21.8	20.4	18.9	17.8	16.7	16.0	15.2	14.8	14.4	...	...	R53400	B348
Titanium and Titanium Alloy — Castings														
16.7	15.2	13.8	12.6	11.4	10.4	9.5	8.7	7.9	...	...	...	...	R52550	B367
21.7	20.0	18.4	16.6	14.9	13.5	12.1	11.0	9.9	...	...	...	...	R52550	B367
16.7	15.2	13.8	12.6	11.4	10.4	9.5	8.7	7.9	...	...	...	...	R52700	B367
Zirconium and Zirconium Alloy — Pipes and Tubes														
18.3	17.2	15.4	13.6	12.0	10.6	9.3	8.3	7.4	6.6	6.0	5.6	5.2	R60702	B523
18.3	17.2	15.4	13.6	12.0	10.6	9.3	8.3	7.4	6.6	6.0	5.6	5.2	R60702	B658
26.7	24.4	22.1	20.4	18.9	17.7	16.7	15.8	15.0	14.4	13.9	13.5	13.2	R60705	B658
Zirconium and Zirconium Alloy — Plates and Sheets														
18.3	17.2	15.4	13.6	12.0	10.6	9.3	8.3	7.4	6.6	6.0	5.6	5.2	R60702	B551
26.7	24.4	22.1	20.4	18.9	17.7	16.7	15.8	15.0	14.4	13.9	13.5	13.2	R60705	B551
Zirconium and Zirconium Alloy — Forgings and Bar														
18.3	17.2	15.4	13.6	12.0	10.6	9.3	8.3	7.4	6.6	6.0	5.6	5.2	R60702	B493
18.3	17.2	15.4	13.6	12.0	10.6	9.3	8.3	7.4	6.6	6.0	5.6	5.2	R60702	B550
23.3	21.3	19.3	17.8	16.5	15.5	14.6	13.8	13.1	12.6	12.2	11.8	11.5	R60705	B493
26.7	24.4	22.1	20.4	18.9	17.7	16.7	15.8	15.0	14.4	13.9	13.5	13.2	R60705	B550

Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

Nominal Composition	Spec. No.	Type/ Grade	UNS No.	Class/ Condition/ Temper	Size or Thickness Range, in.	P-No. (5)	Notes	Min. Temp., °F (6)	Specified Min. Strength, ksi: Tensile	Yield	Basic Allowable Stress, S, ksi, at Metal Temperature, °F [Notes (1), (4a)]: Min. Temp. to 100	150	200	250	300	350	400
Aluminum Alloy — Seamless Pipes and Tubes																	
Al–Mn–Cu	B210	Alclad 3003	A83003	O	...	21	(14) (33)	−452	13	4.5	3.0	2.9	2.8	2.7	2.5	1.9	1.5
Al–Mn–Cu	B210	Alclad 3003	A83003	H112	...	21	(14) (33)	−452	13	4.5	3.0	2.9	2.8	2.7	2.5	1.9	1.5
Al–Mn–Cu	B241	Alclad 3003	A83003	O	...	21	(14) (33)	−452	13	4.5	3.0	2.9	2.8	2.7	2.5	1.9	1.5
Al–Mn–Cu	B241	Alclad 3003	A83003	H112	...	21	(14) (33)	−452	13	4.5	3.0	2.9	2.8	2.7	2.5	1.9	1.5
Al–Mn–Cu	B210	Alclad 3003	A83003	H14	...	21	(14) (33)	−452	19	16	6.3	6.3	6.3	6.1	4.3	3.0	2.3
Al–Mn–Cu	B210	Alclad 3003	A83003	H18	...	21	(14) (33)	−452	26	23	8.7	8.7	8.7	8.4	4.3	3.0	2.3
99.60Al	B210	1060	A91060	O	...	21	(14) (33)	−452	8.5	2.5	1.7	1.7	1.6	1.4	1.2	1.1	0.8
99.60Al	B210	1060	A91060	H112	...	21	(14) (33)	−452	8.5	2.5	1.7	1.7	1.6	1.4	1.2	1.1	0.8
99.60Al	B210	1060	A91060	H113	...	21	(14) (33)	−452	8.5	2.5	1.7	1.7	1.6	1.4	1.2	1.1	0.8
99.60Al	B241	1060	A91060	O	...	21	(14) (33)	−452	8.5	2.5	1.7	1.7	1.6	1.4	1.2	1.1	0.8
99.60Al	B241	1060	A91060	H112	...	21	(14) (33)	−452	8.5	2.5	1.7	1.7	1.6	1.4	1.2	1.1	0.8
99.60Al	B241	1060	A91060	H113	...	21	(14) (33)	−452	8.5	2.5	1.7	1.7	1.6	1.4	1.2	1.1	0.8
99.60Al	B210	1060	A91060	H14	...	21	(14) (33)	−452	12	10	4.0	4.0	4.0	4.0	2.7	1.8	1.1
99.0Al–Cu	B241	1100	A91100	O	...	21	(14) (33)	−452	11	3	2.0	2.0	2.0	1.9	1.7	1.3	1.0
99.0Al–Cu	B241	1100	A91100	H112	...	21	(14) (33)	−452	11	3	2.0	2.0	2.0	1.9	1.7	1.3	1.0
99.0Al–Cu	B210	1100	A91100	H113	...	21	(14) (33)	−452	11	3.5	2.3	2.3	2.3	2.3	1.7	1.3	1.0
99.0Al–Cu	B210	1100	A91100	H14	...	21	(14) (33)	−452	16	14	5.3	5.3	5.3	4.9	2.8	1.9	1.1
Al–Mn–Cu	B210	3003	A93003	O	...	21	(14) (33)	−452	14	5	3.3	3.2	3.1	3.0	2.7	1.9	1.5
Al–Mn–Cu	B210	3003	A93003	H112	...	21	(14) (33)	−452	14	5	3.3	3.2	3.1	3.0	2.7	1.9	1.5
Al–Mn–Cu	B241	3003	A93003	O	...	21	(14) (33)	−452	14	5	3.3	3.2	3.1	3.0	2.7	1.9	1.5
Al–Mn–Cu	B241	3003	A93003	H112	...	21	(14) (33)	−452	14	5	3.3	3.2	3.1	3.0	2.7	1.9	1.5
Al–Mn–Cu	B491	3003	A93003	O	...	21	(14) (33)	−452	14	5	3.3	3.2	3.1	3.0	2.7	1.9	1.5
Al–Mn–Cu	B491	3003	A93003	H112	...	21	(14) (33)	−452	14	5	3.3	3.2	3.1	3.0	2.7	1.9	1.5
Al–Mn–Cu	B210	3003	A93003	H14	...	21	(14) (33)	−452	20	17	6.7	6.7	6.5	4.8	4.3	3.0	2.3
Al–Mn–Cu	B210	3003	A93003	H18	...	21	(14) (33)	−452	27	24	9.0	9.0	8.7	8.0	5.3	3.5	2.5
Al–Mn–Cu	B241	3003	A93003	H18	...	21	(14) (33)	−452	27	24	9.0	9.0	8.7	8.0	5.3	3.5	2.5
Al–2.5Mg	B210	5052	A95052	O	...	22	(14)	−452	25	10	6.7	6.7	6.7	6.6	6.1	4.1	2.3
Al–2.5Mg	B241	5052	A95052	O	...	22	(14)	−452	25	10	6.7	6.7	6.7	6.6	6.1	4.1	2.3
Al–2.5Mg	B210	5052	A95052	H32	...	22	(14) (33)	−452	31	23	10.3	10.3	10.3	10.3	6.1	4.1	2.3
Al–2.5Mg	B210	5052	A95052	H34	...	22	(14) (33)	−452	34	26	11.3	11.3	11.3	11.3	6.1	4.1	2.3
Al–4.4Mg–Mn	B210	5083	A95083	O	...	25	(33)	−452	39	16	10.7	10.7	...	...	...	...	...
Al–4.4Mg–Mn	B210	5083	A95083	H112	...	25	(33)	−452	39	16	10.7	10.7	...	...	...	...	...
Al–4.4Mg–Mn	B241	5083	A95083	O	...	25	(33)	−452	39	16	10.7	10.7	...	...	...	...	...
Al–4.4Mg–Mn	B241	5083	A95083	H112	...	25	(33)	−452	39	16	10.7	10.7	...	...	...	...	...
Al–4.0Mg–Mn	B210	5086	A95086	O	...	25	(33)	−452	35	14	9.3	9.3	...	...	...	...	...
Al–4.0Mg–Mn	B210	5086	A95086	H112	...	25	(33)	−452	35	14	9.3	9.3	...	...	...	...	...
Al–4.0Mg–Mn	B241	5086	A95086	O	...	25	(33)	−452	35	14	9.3	9.3	...	...	...	...	...
Al–4.0Mg–Mn	B241	5086	A95086	H112	...	25	(33)	−452	35	14	9.3	9.3	...	...	...	...	...
Al–4.0Mg–Mn	B210	5086	A95086	H32	...	25	(33)	−452	40	28	13.3	13.3	...	...	...	...	...

Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

Nominal Composition	Spec. No.	Type/ Grade	UNS No.	Class/ Condition/ Temper	Size or Thickness Range, in.	P-No. (5)	Notes	Min. Temp., °F (6)	Specified Min. Strength, ksi: Tensile	Yield	Basic Allowable Stress, S, ksi, at Metal Temperature, °F [Notes (1), (4a)]: Min. Temp. to 100	150	200	250	300	350	400
Aluminum Alloy — Seamless Pipes and Tubes (Cont'd)																	
Al–4.0Mg–Mn	B210	5086	A95086	H34	...	25	(33)	−452	44	34	14.7	14.7	...	...	...	...	...
Al–3.5Mg	B210	5154	A95154	O	...	22	...	−452	30	11	7.3	7.3	...	...	...	...	...
Al–3.5Mg	B210	5154	A95154	H34	...	22	(33)	−452	39	29	13.3	13.0	...	...	...	...	...
Al–2.7Mg–Mn	B241	5454	A95454	O	...	22	(33)	−452	31	12	8.0	8.0	8.0	7.4	5.5	4.1	3.0
Al–2.7Mg–Mn	B241	5454	A95454	H112	...	22	(33)	−452	31	12	8.0	8.0	8.0	7.4	5.5	4.1	3.0
Al–5.1Mg–Mn	B210	5456	A95456	O	...	25	(33)	−452	41	19	12.7	12.7	...	...	...	...	...
Al–5.1Mg–Mn	B210	5456	A95456	H112	...	25	(33)	−452	41	19	12.7	12.7	...	...	...	...	...
Al–5.1Mg–Mn	B241	5456	A95456	O	...	25	(33)	−452	41	19	12.7	12.7	...	...	...	...	...
Al–5.1Mg–Mn	B241	5456	A95456	H112	...	25	(33)	−452	41	19	12.7	12.7	...	...	...	...	...
Al–Mg–Si–Cu	B210	6061	A96061	T4 wld.	...	23	(22) (63)	−452	24	...	8.0	8.0	8.0	8.0	7.7	6.9	5.1
Al–Mg–Si–Cu	B210	6061	A96061	T6 wld.	...	23	(22) (63)	−452	24	...	8.0	8.0	8.0	8.0	7.7	6.9	5.1
Al–Mg–Si–Cu	B241	6061	A96061	T4 wld.	...	23	(22) (63)	−452	24	...	8.0	8.0	8.0	8.0	7.7	6.9	5.1
Al–Mg–Si–Cu	B241	6061	A96061	T6 wld.	...	23	(22) (63)	−452	24	...	8.0	8.0	8.0	8.0	7.7	6.9	5.1
Al–Mg–Si–Cu	B241	6061	A96061	T4	...	23	(33) (63)	−452	26	16	8.7	8.7	8.7	8.7	8.3	7.4	5.2
Al–Mg–Si–Cu	B210	6061	A96061	T4	...	23	(33)	−452	30	16	10.0	10.0	10.0	9.9	9.5	8.4	5.2
Al–Mg–Si–Cu	B241	6061	A96061	T6	...	23	(33) (63)	−452	38	35	12.7	12.7	12.7	12.3	10.5	8.1	5.2
Al–Mg–Si–Cu	B210	6061	A96061	T6	...	23	(33)	−452	42	35	14.0	14.0	14.0	13.6	11.7	8.9	5.2
Al–Mg–Si	B210	6063	A96063	T4 wld.	...	23	...	−452	17	...	5.7	5.7	5.6	5.3	4.8	3.8	2.0
Al–Mg–Si	B210	6063	A96063	T5 wld.	...	23	...	−452	17	...	5.7	5.7	5.6	5.3	4.8	3.8	2.0
Al–Mg–Si	B210	6063	A96063	T6 wld.	...	23	...	−452	17	...	5.7	5.7	5.6	5.3	4.8	3.8	2.0
Al–Mg–Si	B241	6063	A96063	T4 wld.	...	23	...	−452	17	...	5.7	5.7	5.6	5.3	4.8	3.8	2.0
Al–Mg–Si	B241	6063	A96063	T5 wld.	...	23	...	−452	17	...	5.7	5.7	5.6	5.3	4.8	3.8	2.0
Al–Mg–Si	B241	6063	A96063	T6 wld.	...	23	...	−452	17	...	5.7	5.7	5.6	5.3	4.8	3.8	2.0
Al–Mg–Si	B241	6063	A96063	T4	≤0.500	23	(33)	−452	19	10	6.3	6.3	6.3	6.3	5.8	3.9	1.5
Al–Mg–Si	B210	6063	A96063	T4	...	23	(33)	−452	22	10	6.7	6.5	6.5	6.3	6.3	4.5	1.7
Al–Mg–Si	B241	6063	A96063	T5	≤0.500	23	(33)	−452	22	16	7.3	7.3	7.3	7.3	7.1	3.8	2.0
Al–Mg–Si	B241	6063	A96063	T6	...	23	(33)	−452	30	25	10.0	10.0	10.0	9.1	7.2	3.4	2.0
Al–Mg–Si	B210	6063	A96063	T6	...	23	(33)	−452	33	28	11.0	11.0	11.0	9.6	7.3	3.8	2.0
Aluminum Alloy — Structural Tubes																	
Al–Mn–Cu	B221	Alclad 3003	A83003	O	...	21	(33) (69)	−452	13	4.5	3.0	2.9	2.8	2.7	2.5	1.9	1.5
Al–Mn–Cu	B221	Alclad 3003	A83003	H112	...	21	(33) (69)	−452	13	4.5	3.0	2.9	2.8	2.7	2.5	1.9	1.5
99.0Al	B221	1060	A91060	O	...	21	(33) (69)	−452	8.5	2.5	1.7	1.7	1.6	1.4	1.2	1.1	0.8
99.0Al	B221	1060	A91060	H112	...	21	(33) (69)	−452	8.5	2.5	1.7	1.7	1.6	1.4	1.2	1.1	0.8
99.0Al–Cu	B221	1100	A91100	O	...	21	(33) (69)	−452	11	3	2.0	2.0	2.0	1.9	1.7	1.3	1.0
99.0Al–Cu	B221	1100	A91100	H112	...	21	(33) (69)	−452	11	3	2.0	2.0	2.0	1.9	1.7	1.3	1.0
Al–Mn–Cu	B221	3003	A93003	O	...	21	(33) (69)	−452	14	5	3.3	3.2	3.1	3.0	2.7	1.9	1.5
Al–Mn–Cu	B221	3003	A93003	H112	...	21	(33) (69)	−452	14	5	3.3	3.2	3.1	3.0	2.7	1.9	1.5

Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

									Specified Min. Strength, ksi		Basic Allowable Stress, *S*, ksi, at Metal Temperature, °F [Notes (1), (4a)]						
Nominal Composition	Spec. No.	Type/ Grade	UNS No.	Class/ Condition/ Temper	Size or Thickness Range, in.	P-No. (5)	Notes	Min. Temp., °F (6)	Tensile	Yield	Min. Temp. to 100	150	200	250	300	350	400
Aluminum Alloy — Structural Tubes (Cont'd)																	
Al–2.5Mg	B221	5052	A95052	O	...	22	(69)	−452	25	10	6.7	6.7	6.7	6.6	6.1	4.1	2.3
Al–4.4Mg–Mn	B221	5083	A95083	O	...	25	(69)	−452	39	16	10.7	10.7	...	...	...	...	...
Al–4.0Mg–Mn	B221	5086	A95086	O	...	25	(69)	−452	35	14	9.3	9.3	...	...	...	...	...
Al–3.5Mg	B221	5154	A95154	O	...	22	(69)	−452	30	11	7.3	7.3	...	...	...	...	...
Al–2.7Mg–Mn	B221	5454	A95454	O	...	22	(69)	−452	31	12	8.0	8.0	8.0	7.4	5.5	4.1	3.0
Al–5.1Mg–Mn	B221	5456	A95456	O	...	25	(69)	−452	41	19	12.7	12.7	...	...	...	...	...
Al–Mg–Si–Cu	B221	6061	A96061	T4 wld.	...	23	(22) (63) (69)	−452	24	...	8.0	8.0	8.0	8.0	7.7	6.9	5.1
Al–Mg–Si–Cu	B221	6061	A96061	T6 wld.	...	23	(22) (63) (69)	−452	24	...	8.0	8.0	8.0	8.0	7.7	6.9	5.1
Al–Mg–Si–Cu	B221	6061	A96061	T4	...	23	(33) (63) (69)	−452	26	16	8.7	8.7	8.7	8.7	8.3	7.4	5.2
Al–Mg–Si–Cu	B221	6061	A96061	T6	...	23	(33) (63) (69)	−452	38	35	12.7	12.7	12.7	12.3	10.5	8.1	5.2
Al–Mg–Si	B221	6063	A96063	T4 wld.	...	23	(69)	−452	17	...	5.7	5.7	5.6	5.3	4.8	3.8	2.0
Al–Mg–Si	B221	6063	A96063	T5 wld.	...	23	(69)	−452	17	...	5.7	5.7	5.6	5.3	4.8	3.8	2.0
Al–Mg–Si	B221	6063	A96063	T6 wld.	...	23	(69)	−452	17	...	5.7	5.7	5.6	5.3	4.8	3.8	2.0
Al–Mg–Si	B221	6063	A96063	T4	≤0.500	23	(13) (33) (69)	−452	19	10	6.3	6.3	6.3	6.3	5.8	3.9	1.5
Al–Mg–Si	B221	6063	A96063	T5	≤0.500	23	(13) (33) (69)	−452	22	16	7.3	7.3	7.3	7.3	7.1	3.8	2.0
Al–Mg–Si	B221	6063	A96063	T6	...	23	(33) (69)	−452	30	25	10.0	10.0	10.0	9.1	7.2	3.4	2.0
Aluminum Alloy — Plates and Sheets																	
Al–Mn–Cu	B209	Alclad 3003	A83003	O	0.006–0.499	21	(66)	−452	13	4.5	3.0	2.9	2.8	2.7	2.5	1.9	1.5
Al–Mn–Cu	B209	Alclad 3003	A83003	O	0.500–3.000	21	(68)	−452	14	5	3.3	3.2	3.1	3.0	2.7	1.9	1.5
Al–Mn–Cu	B209	Alclad 3003	A83003	H112	0.500–2.000	21	(33) (66)	−452	15	6	4.0	3.9	3.7	3.6	2.7	1.9	1.5
Al–Mn–Cu	B209	Alclad 3003	A83003	H12	0.017–0.499	21	(33) (66)	−452	16	11	5.3	5.3	5.2	4.9	4.3	3.0	2.3
Al–Mn–Cu	B209	Alclad 3003	A83003	H12	0.500–2.000	21	(33) (68)	−452	17	12	5.7	5.7	5.7	5.7	4.3	3.0	2.3
Al–Mn–Cu	B209	Alclad 3003	A83003	H14	0.009–0.499	21	(33) (66)	−452	19	16	6.3	6.3	6.3	6.1	4.3	3.0	2.3
Al–Mn–Cu	B209	Alclad 3003	A83003	H14	0.500–1.000	21	(33) (68)	−452	20	17	6.7	6.7	6.7	6.5	4.3	3.0	2.3
Al–Mn–Mg	B209	Alclad 3004	A83004	O	0.006–0.499	22	(66)	−452	21	8	5.3	5.3	5.3	5.3	5.3	3.8	2.3
Al–Mn–Mg	B209	Alclad 3004	A83004	O	0.500–3.000	22	(68)	−452	22	8.5	5.7	5.6	5.6	5.6	5.6	3.8	2.3
Al–Mn–Mg	B209	Alclad 3004	A83004	H112	0.250–0.499	22	(33) (66)	−452	22	8.5	5.7	5.6	5.6	5.6	5.6	3.8	2.3
Al–Mn–Mg	B209	Alclad 3004	A83004	H112	0.500–3.000	22	(33) (68)	−452	23	9	6.0	6.0	6.0	6.0	5.7	3.8	2.3
Al–Mn–Mg	B209	Alclad 3004	A83004	H32	0.017–0.499	22	(33) (66)	−452	27	20	9.0	9.0	9.0	9.0	5.7	3.8	2.3
Al–Mn–Mg	B209	Alclad 3004	A83004	H32	0.500–2.000	22	(33) (68)	−452	28	21	9.3	9.3	9.3	9.3	5.7	3.8	2.3
Al–Mn–Mg	B209	Alclad 3004	A83004	H34	0.009–0.499	22	(33) (66)	−452	31	24	10.3	10.3	10.3	10.3	5.7	3.8	2.3
Al–Mn–Mg	B209	Alclad 3004	A83004	H34	0.500–1.000	22	(33) (68)	−452	32	25	10.7	10.7	10.7	10.7	5.7	3.8	2.3
Al–Mg–Si–Cu	B209	Alclad 6061	A86061	T4 wld.	...	23	(22) (63)	−452	24	...	8.0	8.0	8.0	8.0	7.7	6.9	5.1
Al–Mg–Si–Cu	B209	Alclad 6061	A86061	T6 wld.	...	23	(22) (63)	−452	24	...	8.0	8.0	8.0	8.0	7.7	6.9	5.1
Al–Mg–Si–Cu	B209	Alclad 6061	A86061	T4	...	23	(33) (66)	−452	27	14	9.0	9.0	9.0	8.9	8.6	7.6	5.2
Al–Mg–Si–Cu	B209	Alclad 6061	A86061	T451	0.250–0.499	23	(33) (66)	−452	27	14	9.0	9.0	9.0	8.9	8.6	7.6	5.2
Al–Mg–Si–Cu	B209	Alclad 6061	A86061	T451	0.500–3.000	23	(33) (68)	−452	30	16	9.0	9.0	9.0	8.9	8.5	8.4	5.2

Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

									Specified Min. Strength, ksi		Basic Allowable Stress, *S*, ksi, at Metal Temperature, °F [Notes (1), (4a)]						
Nominal Composition	Spec. No.	Type/ Grade	UNS No.	Class/ Condition/ Temper	Size or Thickness Range, in.	P-No. (5)	Notes	Min. Temp., °F (6)	Tensile	Yield	Min. Temp. to 100	150	200	250	300	350	400
Aluminum Alloy — Plates and Sheets (Cont'd)																	
Al–Mg–Si–Cu	B209	Alclad 6061	A86061	T6	...	23	(33) (66)	−452	38	32	12.7	12.7	12.7	12.3	10.6	8.1	5.2
Al–Mg–Si–Cu	B209	Alclad 6061	A86061	T651	0.250–0.499	23	(33) (66)	−452	38	32	12.7	12.7	12.7	12.3	10.6	8.1	5.2
Al–Mg–Si–Cu	B209	Alclad 6061	A86061	T651	0.500–4.000	23	(33) (68)	−452	42	35	14.0	14.0	14.0	13.6	11.7	8.9	5.2
99.60Al	B209	1060	A91060	O	...	21	...	−452	8	2.5	1.7	1.6	1.6	1.4	1.2	1.1	0.8
99.60Al	B209	1060	A91060	H112	0.500–1.000	21	(13) (33)	−452	10	5	3.3	3.2	2.9	2.5	2.0	1.5	0.9
99.60Al	B209	1060	A91060	H12	...	21	(33)	−452	11	9	3.7	3.7	3.4	3.1	2.7	1.8	1.1
99.60Al	B209	1060	A91060	H14	...	21	(33)	−452	12	10	4.0	4.0	4.0	4.0	2.7	1.8	1.1
99.0Al–Cu	B209	1100	A91100	O	...	21	...	−452	11	3.5	2.3	2.3	2.3	2.3	1.7	1.3	1.0
99.0Al–Cu	B209	1100	A91100	H112	0.500–2.000	21	(13) (33)	−452	12	5	3.3	3.3	3.3	3.2	2.4	1.7	1.0
99.0Al–Cu	B209	1100	A91100	H12	...	21	(33)	−452	14	11	4.7	4.7	4.6	3.8	2.8	1.9	1.1
99.0Al–Cu	B209	1100	A91100	H14	...	21	(33)	−452	16	14	5.3	5.3	5.3	4.9	2.8	1.9	1.1
Al–Mn–Cu	B209	3003	A93003	O	...	21	...	−452	14	5	3.3	3.2	3.1	3.0	2.7	1.9	1.5
Al–Mn–Cu	B209	3003	A93003	H112	0.500–2.000	21	(13) (33)	−452	15	6	4.0	3.9	3.7	3.6	2.7	1.9	1.5
Al–Mn–Cu	B209	3003	A93003	H12	...	21	(33)	−452	17	12	5.7	5.7	5.6	5.2	4.3	3.0	2.3
Al–Mn–Cu	B209	3003	A93003	H14	...	21	(33)	−452	20	17	6.7	6.7	6.7	6.5	4.3	3.0	2.3
Al–Mn–Mg	B209	3004	A93004	O	...	22	...	−452	22	8.5	5.7	5.7	5.7	5.7	5.7	3.8	2.3
Al–Mn–Mg	B209	3004	A93004	H112	...	22	(33)	−452	23	9	6.0	6.0	6.0	6.0	5.8	3.8	2.3
Al–Mn–Mg	B209	3004	A93004	H32	...	22	(33)	−452	28	21	9.3	9.3	9.3	9.3	5.7	3.8	2.3
Al–Mn–Mg	B209	3004	A93004	H34	...	22	(33)	−452	32	25	10.7	10.7	10.7	10.7	5.7	3.8	2.3
Al–1.5Mg	B209	5050	A95050	O	...	21	...	−452	18	6	4.0	4.0	4.0	4.0	4.0	2.8	1.4
Al–1.5Mg	B209	5050	A95050	H112	...	21	(33)	−452	20	8	5.3	5.3	5.3	5.2	5.2	2.8	1.4
Al–1.5Mg	B209	5050	A95050	H32	...	21	(33)	−452	22	16	7.3	7.3	7.3	7.3	5.3	2.8	1.4
Al–1.5Mg	B209	5050	A95050	H34	...	21	(33)	−452	25	20	8.3	8.3	8.3	7.8	5.3	2.8	1.4
Al–2.5Mg	B209	5052	A95052	O	...	22	...	−452	25	9.5	6.3	6.3	6.3	6.2	6.1	4.1	2.3
Al–2.5Mg	B209	5052	A95052	H112	0.500–3.000	22	(13) (33)	−452	25	9.5	6.3	6.3	6.3	6.3	6.1	4.1	2.3
Al–2.5Mg	B209	5052	A95052	H32	...	22	(33)	−452	31	23	10.3	10.3	10.3	10.3	6.1	4.1	2.3
Al–2.5Mg	B209	5052	A95052	H34	...	22	(33)	−452	34	26	11.3	11.3	11.3	11.3	6.1	4.1	2.3
Al–4.4Mg–Mn	B209	5083	A95083	O	0.051–1.500	25	(13)	−452	40	18	12.0	12.0	...	...	...	...	...
Al–4.4Mg–Mn	B209	5083	A95083	H32	0.188–1.500	25	(13) (33)	−452	44	31	14.7	14.7	...	...	...	...	...
Al–4.0Mg–Mn	B209	5086	A95086	O	...	25	...	−452	35	14	9.3	9.3	...	...	...	...	...
Al–4.0Mg–Mn	B209	5086	A95086	H112	0.500–1.000	25	(13) (33)	−452	35	16	9.3	9.3	...	...	...	...	...
Al–4.0Mg–Mn	B209	5086	A95086	H32	...	25	(33)	−452	40	28	13.3	13.3	...	...	...	...	...
Al–4.0Mg–Mn	B209	5086	A95086	H34	...	25	(33)	−452	44	34	14.7	14.7	...	...	...	...	...
Al–3.5Mg	B209	5154	A95154	O	...	22	...	−452	30	11	7.3	7.3	...	...	...	...	...
Al–3.5Mg	B209	5154	A95154	H112	0.500–3.000	22	(13) (33)	−452	30	11	7.3	7.3	...	...	...	...	...
Al–3.5Mg	B209	5154	A95154	H32	...	22	(33)	−452	36	26	12.0	12.0	...	...	...	...	...
Al–3.5Mg	B209	5154	A95154	H34	...	22	(33)	−452	39	29	13.0	13.0	...	...	...	...	...

Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

Nominal Composition	Spec. No.	Type/ Grade	UNS No.	Class/ Condition/ Temper	Size or Thickness Range, in.	P-No. (5)	Notes	Min. Temp., °F (6)	Specified Min. Strength, ksi: Tensile	Specified Min. Strength, ksi: Yield	Basic Allowable Stress, S, ksi, at Metal Temperature, °F [Notes (1), (4a)]: Min. Temp. to 100	150	200	250	300	350	400
Aluminum Alloy — Plates and Sheets (Cont'd)																	
Al–3.5Mg	B209	5254	A95254	O	...	22	...	−452	30	11	7.3	7.3	...	...	...	...	...
Al–3.5Mg	B209	5254	A95254	H112	0.500–3.000	22	(13) (33)	−452	30	11	7.3	7.3	...	...	...	...	...
Al–3.5Mg	B209	5254	A95254	H32	...	22	(33)	−452	36	26	12.0	12.0	...	...	...	...	...
Al–3.5Mg	B209	5254	A95254	H34	...	22	(33)	−452	39	29	13.0	13.0	...	...	...	...	...
Al–2.7Mg–Mn	B209	5454	A95454	O	...	22	...	−452	31	12	8.0	8.0	8.0	7.4	5.5	4.1	3.0
Al–2.7Mg–Mn	B209	5454	A95454	H112	0.500–3.000	22	(13) (33)	−452	31	12	8.0	8.0	8.0	7.4	5.5	4.1	3.0
Al–2.7Mg–Mn	B209	5454	A95454	H32	...	22	(33)	−452	36	26	12.0	12.0	12.0	7.5	5.5	4.1	3.0
Al–2.7Mg–Mn	B209	5454	A95454	H34	...	22	(33)	−452	39	29	13.0	13.0	13.0	7.5	5.5	4.1	3.0
Al–5.1Mg–Mn	B209	5456	A95456	O	0.051–1.500	25	(13)	−452	42	19	12.7	12.7	...	...	...	...	...
Al–5.1Mg–Mn	B209	5456	A95456	H32	0.188–0.499	25	(13) (33)	−452	46	33	15.3	15.3	...	...	...	...	...
Al–2.5Mg	B209	5652	A95652	O	...	22	...	−452	25	9.5	6.3	6.3	6.3	6.2	6.1	4.1	2.3
Al–2.5Mg	B209	5652	A95652	H112	0.500–3.000	22	(13) (33)	−452	25	9.5	6.3	6.3	6.3	6.3	6.1	4.1	2.3
Al–2.5Mg	B209	5652	A95652	H32	...	22	(33)	−452	31	23	10.3	10.3	10.3	10.3	6.1	4.1	2.3
Al–2.5Mg	B209	5652	A95652	H34	...	22	(33)	−452	34	26	11.3	11.3	11.3	11.3	6.1	4.1	2.3
Al–Mg–Si–Cu	B209	6061	A96061	T4 wld.	...	23	(22) (63)	−452	24	...	8.0	8.0	8.0	8.0	7.7	6.9	5.1
Al–Mg–Si–Cu	B209	6061	A96061	T6 wld.	...	23	(22) (63)	−452	24	...	8.0	8.0	8.0	8.0	7.7	6.9	5.1
Al–Mg–Si–Cu	B209	6061	A96061	T4	...	23	(33) (63)	−452	30	16	10.0	10.0	10.0	9.9	9.5	8.4	5.2
Al–Mg–Si–Cu	B209	6061	A96061	T6	...	23	(33)	−452	42	35	14.0	14.0	14.0	13.6	11.7	8.9	5.2
Al–Mg–Si–Cu	B209	6061	A96061	T651	0.250–4.000	23	(13) (33)	−452	42	35	14.0	14.0	14.0	13.6	11.7	8.9	5.2
Aluminum Alloy — Forgings and Fittings																	
Al–Mn–Cu	B361	WP Alclad 3003	A83003	O	...	21	(13) (14) (32) (33) (66)	−452	13	4.5	3.0	2.9	2.8	2.7	2.5	1.9	1.5
Al–Mn–Cu	B361	WP Alclad 3003	A83003	H112	...	21	(13) (14) (32) (33) (66)	−452	13	4.5	3.0	2.9	2.8	2.7	2.5	1.9	1.5
99.60Al	B361	WP1060	A91060	O	...	21	(13) (14) (32) (33)	−452	8	2.5	1.7	1.6	1.6	1.4	1.2	1.1	0.8
99.60Al	B361	WP1060	A91060	H112	...	21	(13) (14) (32) (33)	−452	8	2.5	1.7	1.6	1.6	1.4	1.2	1.1	0.8
99.0Al–Cu	B361	WP1100	A91100	O	...	21	(13) (14) (32) (33)	−452	11	3	2.0	2.0	2.0	1.9	1.7	1.3	1.0
99.0Al–Cu	B361	WP1100	A91100	H112	...	21	(13) (14) (32) (33)	−452	11	3	2.0	2.0	2.0	1.9	1.7	1.3	1.0
Al–Mn–Cu	B247	3003	A93003	H112	...	21	(9) (45)	−452	14	5	3.3	3.2	3.1	3.0	2.7	1.9	1.5
Al–Mn–Cu	B247	3003	A93003	H112 wld.	...	21	(9) (45)	−452	14	5	3.3	3.2	3.1	3.0	2.7	1.9	1.5
Al–Mn–Cu	B361	WP3003	A93003	O	...	21	(13) (14) (32) (33)	−452	14	5	3.3	3.2	3.1	3.0	2.7	1.9	1.5
Al–Mn–Cu	B361	WP3003	A93003	H112	...	21	(13) (14) (32) (33)	−452	14	5	3.3	3.2	3.1	3.0	2.7	1.9	1.5
Al–Mn–Cu	B247	5083	A95083	O	...	25	(9) (32) (33)	−452	39	16	10.7	10.7	...	...	...	...	...
Al–Mn–Cu	B247	5083	A95083	H112	...	25	(9) (32) (33)	−452	39	16	10.7	10.7	...	...	...	...	...
Al–Mn–Cu	B247	5083	A95083	H112 wld.	...	25	(9) (32) (33)	−452	39	16	10.7	10.7	...	...	...	...	...

Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

Nominal Composition	Spec. No.	Type/ Grade	UNS No.	Class/ Condition/ Temper	Size or Thickness Range, in.	P-No. (5)	Notes	Min. Temp., °F (6)	Specified Min. Strength, ksi: Tensile	Yield	Basic Allowable Stress, S, ksi, at Metal Temperature, °F [Notes (1), (4a)]: Min. Temp. to 100	150	200	250	300	350	400
Aluminum Alloy — Forgings and Fittings (Cont'd)																	
Al–4.4Mg–Mn	B361	WP5083	A95083	O	...	25	(13) (32) (33)	−452	39	16	10.7	10.7	...	...	...	...	...
Al–4.4Mg–Mn	B361	WP5083	A95083	H112	...	25	(13) (32) (33)	−452	39	16	10.7	10.7	...	...	...	...	...
Al–3.5Mg	B361	WP5154	A95154	O	...	22	(32) (33)	−452	30	11	7.3	7.3	...	...	...	...	...
Al–3.5Mg	B361	WP5154	A95154	H112	...	22	(32) (33)	−452	30	11	7.3	7.3	...	...	...	...	...
Al–Mg–Si–Cu	B247	6061	A96061	T6 wld.	...	23	(9) (22)	−452	24	...	8.0	8.0	8.0	8.0	7.7	6.9	5.1
Al–Mg–Si–Cu	B361	WP6061	A96061	T4 wld.	...	23	(22) (32) (63)	−452	24	...	8.0	8.0	8.0	8.0	7.7	6.9	5.1
Al–Mg–Si–Cu	B361	WP6061	A96061	T6 wld.	...	23	(22) (32) (63)	−452	24	...	8.0	8.0	8.0	8.0	7.7	6.9	5.1
Al–Mg–Si–Cu	B361	WP6061	A96061	T4	...	23	(13) (32) (33) (63)	−452	26	16	8.7	8.7	8.7	8.7	8.3	7.4	5.2
Al–Mg–Si–Cu	B247	6061	A96061	T6	...	23	(9) (33)	−452	38	35	12.7	12.7	12.7	12.3	10.5	8.1	5.2
Al–Mg–Si–Cu	B361	WP6061	A96061	T6	...	23	(13) (32) (33) (63)	−452	38	35	12.7	12.7	12.7	12.3	10.5	8.1	5.2
Al–Mg–Si	B361	WP6063	A96063	T4 wld.	...	23	(32)	−452	17	...	5.7	5.7	5.7	5.7	5.5	3.8	2.0
Al–Mg–Si	B361	WP6063	A96063	T6 wld.	...	23	(32)	−452	17	...	5.7	5.7	5.7	5.7	5.5	3.8	2.0
Al–Mg–Si	B361	WP6063	A96063	T4	...	23	(13) (32) (33)	−452	18	9	6.0	5.9	5.8	5.7	5.5	3.7	1.4
Al–Mg–Si	B361	WP6063	A96063	T6	...	23	(13) (32) (33)	−452	30	25	10.0	10.0	10.0	9.1	7.2	3.4	2.0
Aluminum Alloy — Castings																	
Al–Si–Mg	B26	356.0	A03560	T71	...	26	(9) (43)	−452	25	18	8.3	8.3	8.3	8.1	7.3	5.5	2.4
Al–Si–Mg	B26	356.0	A03560	T6	...	26	(9) (43)	−452	30	20	10.0	10.0	10.0	8.4	...	...	...
Al–Si	B26	443.0	A04430	F	...	...	(9) (43)	−452	17	7	4.7	4.7	4.7	4.7	4.7	4.7	3.5

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Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

Line No.	Nominal Composition	Product Form	Spec. No.	Type/ Grade	UNS No.	Class/ Condition/ Temper	Notes	Min. Temp., °C (6)	Min. Tensile Strgth., MPa	Min. Yield Strgth., MPa	Max. Use Temp., °C
1	Fe	Castings	A126	A	F11501	...	(8e) (9) (48)	−29	145	...	204
2	Fe	Castings	A48	150	F11401	...	(8e) (48)	−29	150	...	204
3	Fe	Castings	A278	150	F11401	...	(8e) (48)	−29	150	...	204
4	Fe	Castings	A48	175	F11701	...	(8e) (48)	−29	175	...	204
5	Fe	Castings	A278	175	F11701	...	(8e) (48)	−29	175	...	204
6	Fe	Castings	A48	200	F12101	...	(8e) (48)	−29	200	...	204
7	Fe	Castings	A278	200	F12101	...	(8e) (48)	−29	200	...	204
8	Fe	Castings	A126	B	F12102	...	(8e) (9) (48)	−29	214	...	204
9	Fe	Castings	A48	225	...	...	(8e) (48)	−29	225	...	204
10	Fe	Castings	A278	225	...	...	(8e) (48)	−29	225	...	204
11	Fe	Castings	A48	250	F12401	...	(8e) (9) (48)	−29	250	...	204
12	Fe	Castings	A278	250	F12401	...	(8e) (53)	−29	250	...	343
13	Fe	Castings	A48	275	F12801	...	(8e) (48)	−29	275	...	204
14	Fe	Castings	A278	275	F12803	...	(8e) (53)	−29	275	...	204
15	Fe	Castings	A48	375	...	...	(8e) (48)	−29	375	...	204
16	Fe	Castings	A278	380	F13801	...	(8e) (53)	−29	380	...	204
17	Fe	Castings	A197	...	F22000	...	(8e) (9)	−29	275	200	343
18	Fe	Castings	A126	C	F12802	...	(8e) (9) (48)	−29	283	...	204
19	Fe	Castings	A48	300	F13101	...	(8e) (48)	−29	300	...	204
20	Fe	Castings	A278	300	F13101	...	(8e) (53)	−29	300	...	343
21	Fe	Castings	A48	325	...	...	(8e) (48)	−29	325	...	204
22	Fe	Castings	A278	325	...	...	(8e) (53)	−29	325	...	204
23	Fe	Castings	A47	22010	F22200	...	(8e) (9)	−29	340	220	343
24	Fe	Castings	A48	350	F13501	...	(8e) (48)	−29	350	...	204
25	Fe	Castings	A278	350	F13502	...	(8e) (53)	−29	350	...	343
26	Fe	Castings	A48	400	F14101	...	(8e) (48)	−29	400	...	204
27	Fe	Castings	A278	415	F14102	...	(8e) (53)	−29	415	...	204
28	Fe	Castings	A395	60-40-18	F32800	...	(8d) (9)	−29	415	275	343
29	Fe	Castings	A536	65-45-12	F33100	...	(8d) (9)	−29	448	310	260
30	Fe	Castings	A571	D-2M	F43010	3	(8d)	−29	450	205	40

Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

Line No.	Basic Allowable Stress, *S*, MPa, at Metal Temperature, °C [Notes (1) and (4b)]												
	Min. Temp. to 40	65	100	125	150	175	200	225	250	275	300	325	350
1	13.8	13.8	13.8	13.8	13.8	13.8	13.8	13.8	...	...	...	...	...
2	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	...	...	...	...	...
3	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	...	...	...	...	...
4	17.5	17.5	17.5	17.5	17.5	17.5	17.5	17.5	...	...	...	...	...
5	17.5	17.5	17.5	17.5	17.5	17.5	17.5	17.5	...	...	...	...	...
6	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	...	...	...	...	...
7	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	...	...	...	...	...
8	20.7	20.7	20.7	20.7	20.7	20.7	20.7	20.7	...	...	...	...	...
9	22.5	22.5	22.5	22.5	22.5	22.5	22.5	22.5	...	...	...	...	...
10	22.5	22.5	22.5	22.5	22.5	22.5	22.5	22.5	...	...	...	...	...
11	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	...	...	...	...	...
12	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	27.6	27.6	27.6	27.6	27.6
13	27.5	27.5	27.5	27.5	27.5	27.5	27.5	27.5	...	...	...	...	...
14	27.5	27.5	27.5	27.5	27.5	27.5	27.5	27.5	...	...	...	...	...
15	37.5	37.5	37.5	37.5	37.5	37.5	37.5	37.5	...	...	...	...	...
16	38.0	38.0	38.0	38.0	38.0	38.0	38.0	38.0	...	...	...	...	...
17	55.2	55.2	55.2	55.2	55.2	55.2	55.2	55.2	55.2	55.2	55.2	55.2	55.2
18	27.6	27.6	27.6	27.6	27.6	27.6	27.6	27.6	...	...	...	...	...
19	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	...	...	...	...	...
20	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	34.5	34.5	34.5	34.5	34.5
21	32.5	32.5	32.5	32.5	32.5	32.5	32.5	32.5	...	...	...	...	...
22	32.5	32.5	32.5	32.5	32.5	32.5	32.5	32.5	...	...	...	...	...
23	68.0	68.0	68.0	68.0	68.0	68.0	68.0	68.0	68.0	68.0	68.0	68.0	68.0
24	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	...	...	...	...	...
25	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	41.4	41.4	41.4	41.4	41.4
26	37.5	37.5	40.0	40.0	40.0	40.0	40.0	40.0	...	...	...	...	...
27	41.5	41.5	41.5	41.5	41.5	41.5	41.5	41.5	...	...	...	...	...
28	137	133	128	125	122	119	116	112	109	106	103	98.0	93.5
29	149	149	149	149	149	149	148	148	148	147	...	...	...
30	137	...	...	...	...	...	...	...	...	...	...	...	...

Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

Line No.	Nominal Composition	Product Form	Spec. No.	Type/ Grade	UNS No.	Class/ Cond./ Temper	Size, mm	P-No. (5)	Notes	Min. Temp., °C (6)	Min. Tensile Str., MPa	Min. Yield Str., MPa	Max. Use Temp., °C
1	Carbon steel	Pipe & tube	A134	A285A	K01700	...	...	1	(8b) (57)	B	310	165	482
2	Carbon steel	Pipe & tube	A672	A45	K01700	...	...	1	(57) (59) (67)	B	310	165	593
3	Carbon steel	Pipe & tube	API 5L	A25	...	...	...	1	(8a) (77)	−29	310	172	204
4	Carbon steel	Pipe & tube	API 5L	A25	...	...	...	1	(57) (59) (77)	B	310	172	204
5	Carbon steel	Pipe & tube	A179	...	K01200	...	...	1	(57) (59)	−29	324	179	593
6	Carbon steel	Pipe & tube	A53	A	K02504	...	...	1	(8a)	−7	331	207	204
7	Carbon steel	Pipe & tube	A139	A	...	...	...	1	(8b)	A	331	207	149
8	Carbon steel	Pipe & tube	A587	...	K11500	...	...	1	(57) (59)	−29	331	207	454
9	Carbon steel	Pipe & tube	A53	A	K02504	...	...	1	(57) (59)	B	331	207	593
10	Carbon steel	Pipe & tube	A106	A	K02501	...	...	1	(57)	B	331	207	593
11	Carbon steel	Pipe & tube	A135	A	...	...	...	1	(57) (59)	B	331	207	593
12	Carbon steel	Pipe & tube	A369	FPA	K02501	...	...	1	(57)	B	331	207	593
13	Carbon steel	Pipe & tube	API 5L	A	...	...	...	1	(57) (59)	B	331	207	593
14	Carbon steel	Pipe & tube	A134	A285B	K02200	...	...	1	(8b) (57)	B	345	186	482
15	Carbon steel	Pipe & tube	A672	A50	K02200	...	...	1	(57) (59) (67)	B	345	186	593
16	Carbon steel	Pipe & tube	A134	A285C	K02801	...	...	1	(8b) (57)	A	379	207	482
17	Carbon steel	Pipe & tube	A524	II	K02104	...	...	1	(57)	−29	379	207	538
18	Carbon steel	Pipe & tube	A333	1	K03008	...	...	1	(57) (59)	−46	379	207	593
19	Carbon steel	Pipe & tube	A334	1	K03008	...	...	1	(57) (59)	−46	379	207	593
20	Carbon steel	Pipe & tube	A671	CA55	K02801	...	...	1	(59) (67)	A	379	207	593
21	Carbon steel	Pipe & tube	A672	A55	K02801	...	...	1	(57) (59) (67)	A	379	207	593
22	Carbon steel	Pipe & tube	A672	C55	K01800	...	...	1	(57) (67)	C	379	207	593
23	Carbon steel	Pipe & tube	A671	CC60	K02100	...	...	1	(57) (67)	C	414	221	538
24	Carbon steel	Pipe & tube	A671	CB60	K02401	...	...	1	(57) (67)	B	414	221	593
25	Carbon steel	Pipe & tube	A672	B60	K02401	...	...	1	(57) (67)	B	414	221	593
26	Carbon steel	Pipe & tube	A672	C60	K02100	...	...	1	(57) (67)	C	414	221	593
27	Carbon steel	Pipe & tube	A139	B	K03003	...	...	1	(8b)	A	414	241	149
28	Carbon steel	Pipe & tube	A135	B	K03018	...	...	1	(57) (59)	B	414	241	538
29	Carbon steel	Pipe & tube	A524	I	K02104	...	...	1	(57)	−29	414	241	538
30	Carbon steel	Pipe & tube	A53	B	K03005	...	...	1	(57) (59)	B	414	241	593
31	Carbon steel	Pipe & tube	A106	B	K03006	...	...	1	(57)	B	414	241	593
32	Carbon steel	Pipe & tube	A333	6	K03006	...	...	1	(57)	−46	414	241	593
33	Carbon steel	Pipe & tube	A334	6	K03006	...	...	1	(57)	−46	414	241	593

Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

	Basic Allowable Stress, *S*, MPa, at Metal Temperature, °C [Notes (1) and (4b)]																		
Line No.	Min. Temp. to 40	65	100	150	200	250	300	325	350	375	400	425	450	475	500	525	550	575	600
1	103	103	101	97.5	94.6	90.8	86.1	83.6	81.1	78.6	73.3	64.0	55.8	43.9	40.7	...	...	...	...
2	103	103	101	97.5	94.6	90.8	86.1	83.6	81.1	78.6	73.3	64.0	55.8	43.9	31.7	21.4	14.2	9.40	6.89
3	103	103	103	102	98.5	...	...	...	...	...	...	...	...	...	...	...	...	...	...
4	103	103	103	102	98.5	...	...	...	...	...	...	...	...	...	...	...	...	...	...
5	108	108	108	106	102	98.3	93.3	90.6	87.8	84.3	73.3	64.0	55.8	43.9	31.7	21.4	14.2	9.40	6.89
6	110	110	110	110	110	...	...	...	...	...	...	...	...	...	...	...	...	...	...
7	110	110	110	110	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
8	110	110	110	110	110	110	108	105	97.0	84.3	73.3	64.0	55.8	54.5	...	...	...	...	...
9	110	110	110	110	110	110	108	105	97.0	84.3	73.3	64.0	55.8	43.9	31.7	21.4	14.2	9.40	6.89
10	110	110	110	110	110	110	108	105	97.0	84.3	73.3	64.0	55.8	43.9	31.7	21.4	14.2	9.40	6.89
11	110	110	110	110	110	110	108	105	97.0	84.3	73.3	64.0	55.8	43.9	31.7	21.4	14.2	9.40	6.89
12	110	110	110	110	110	110	108	105	97.0	84.3	73.3	64.0	55.8	43.9	31.7	21.4	14.2	9.40	6.89
13	110	110	110	110	110	110	108	105	97.0	84.3	73.3	64.0	55.8	43.9	31.7	21.4	14.2	9.40	6.89
14	115	115	113	110	106	102	96.9	94.1	91.2	84.3	73.3	64.0	55.8	43.9	40.7	...	...	...	...
15	115	115	113	110	106	102	96.9	94.1	91.2	84.3	73.3	64.0	55.8	43.9	31.7	21.4	14.2	9.40	6.89
16	126	126	126	122	118	113	108	105	101	98.3	89.1	75.4	62.6	45.5	31.6	...	...	...	...
17	126	126	126	122	118	113	108	105	101	98.3	89.1	75.4	62.6	45.5	31.6	21.9	12.7	...	...
18	126	126	126	122	118	113	108	105	101	98.3	89.1	75.4	62.6	45.5	31.6	21.9	12.7	9.40	6.89
19	126	126	126	122	118	113	108	105	101	98.3	89.1	75.4	62.6	45.5	31.6	21.9	12.7	9.40	6.89
20	126	126	126	122	118	113	108	105	101	98.3	89.1	75.4	62.6	45.5	31.6	21.9	12.7	9.40	6.89
21	126	126	126	122	118	113	108	105	101	98.3	89.1	75.4	62.6	45.5	31.6	21.9	12.7	9.40	6.89
22	126	126	126	122	118	113	108	105	101	98.3	89.1	75.4	62.6	45.5	31.6	21.9	12.7	9.40	6.89
23	138	138	134	130	126	121	115	111	108	105	88.9	75.3	62.7	45.5	31.6	21.9	12.7	...	...
24	138	138	134	130	126	121	115	111	108	105	88.9	75.3	62.7	45.5	31.6	21.9	12.7	9.40	6.89
25	138	138	134	130	126	121	115	111	108	105	88.9	75.3	62.7	45.5	31.6	21.9	12.7	9.40	6.89
26	138	138	134	130	126	121	115	111	108	105	88.9	75.3	62.7	45.5	31.6	21.9	12.7	9.40	6.89
27	138	138	138	138	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
28	138	138	138	138	138	132	126	122	118	113	95.1	79.5	62.6	45.0	31.7	21.4	17.2	...	...
29	138	138	138	138	138	132	126	122	118	113	95.1	79.5	62.6	45.0	31.7	21.4	17.2	...	...
30	138	138	138	138	138	132	126	122	118	113	95.1	79.5	62.6	45.0	31.7	21.4	14.2	9.40	6.89
31	138	138	138	138	138	132	126	122	118	113	95.1	79.5	62.6	45.0	31.7	21.4	14.2	9.40	6.89
32	138	138	138	138	138	132	126	122	118	113	95.1	79.5	62.6	45.0	31.7	21.4	14.2	9.40	6.89
33	138	138	138	138	138	132	126	122	118	113	95.1	79.5	62.6	45.0	31.7	21.4	14.2	9.40	6.89

Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

Line No.	Nominal Composition	Product Form	Spec. No.	Type/ Grade	UNS No.	Class/ Cond./ Temper	Size, mm	P-No. (5)	Notes	Min. Temp., °C (6)	Min. Tensile Str., MPa	Min. Yield Str., MPa	Max. Use Temp., °C
34	Carbon steel	Pipe & tube	A369	FPB	K03006	...	...	1	(57)	−29	414	241	593
35	Carbon steel	Pipe & tube	A381	Y35	...	...	...	1	...	A	414	241	593
36	Carbon steel	Pipe & tube	API 5L	B	...	...	...	1	(57) (59) (77)	B	414	241	593
37	Carbon steel	Pipe & tube	A139	C	K03004	...	...	1	(8b)	A	414	290	149
38	Carbon steel	Pipe & tube	A139	D	K03010	...	...	1	(8b)	A	414	317	149
39	Carbon steel	Pipe & tube	API 5L	X42	...	...	...	1	(55) (77)	A	414	290	204
40	Carbon steel	Pipe & tube	A381	Y42	...	...	...	1	...	A	414	290	204
41	Carbon steel	Pipe & tube	A381	Y48	...	...	...	1	...	A	427	331	343
42	Carbon steel	Pipe & tube	API 5L	X46	...	...	...	1	(55) (77)	A	434	317	204
43	Carbon steel	Pipe & tube	A381	Y46	...	...	...	1	...	A	434	317	204
44	Carbon steel	Pipe & tube	A381	Y50	...	...	...	1	...	A	441	345	343
45	Carbon steel	Pipe & tube	A671	CC65	K02403	...	...	1	(57) (67)	B	448	241	538
46	Carbon steel	Pipe & tube	A671	CB65	K02800	...	...	1	(57) (67)	A	448	241	593
47	Carbon steel	Pipe & tube	A672	B65	K02800	...	...	1	(57) (67)	A	448	241	593
48	Carbon steel	Pipe & tube	A672	C65	K02403	...	...	1	(57) (67)	B	448	241	593
49	Carbon steel	Pipe & tube	A139	E	K03012	...	...	1	(8b)	A	455	359	149
50	Carbon steel	Pipe & tube	API 5L	X52	...	...	...	1	(55) (77)	A	455	359	204
51	Carbon steel	Pipe & tube	A381	Y52	...	...	...	1	...	A	455	359	204
52	Carbon steel	Pipe & tube	A671	CC70	K02700	...	...	1	(57) (67)	B	483	262	538
53	Carbon steel	Pipe & tube	A671	CB70	K03101	...	...	1	(57) (67)	A	483	262	593
54	Carbon steel	Pipe & tube	A672	B70	K03101	...	...	1	(57) (67)	A	483	262	593
55	Carbon steel	Pipe & tube	A672	C70	K02700	...	...	1	(57) (67)	B	483	262	593
56	Carbon steel	Pipe & tube	A106	C	K03501	...	...	1	(57)	B	483	276	427
57	Carbon steel	Pipe & tube	A671	CD70	K12437	...	≤64	1	(67)	D	483	345	371
58	Carbon steel	Pipe & tube	A672	D70	K12437	...	≤64	1	(67)	D	483	345	371
59	Carbon steel	Pipe & tube	A691	CMSH-70	K12437	...	≤64	1	(67)	D	483	345	371
60	Carbon steel	Pipe & tube	API 5L	X56	...	...	...	1	(51) (55) (71) (77)	A	490	386	204
61	Carbon steel	Pipe & tube	A381	Y56	...	...	...	1	(51) (55) (71)	A	490	386	204
62	Carbon steel	Pipe & tube	A671	CK75	K02803	...	>25	1	(57) (67)	A	517	276	593
63	Carbon steel	Pipe & tube	A672	N75	K02803	...	>25	1	(57) (67)	A	517	276	593
64	Carbon steel	Pipe & tube	A691	CMS-75	K02803	...	>25	1	(57) (67)	A	517	276	593
65	Carbon steel	Pipe & tube	A671	CK75	K02803	...	≤25	1	(57) (67)	A	517	290	371
66	Carbon steel	Pipe & tube	A672	N75	K02803	...	≤25	1	(57) (67)	A	517	290	371

Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

Line No.	Basic Allowable Stress, *S*, MPa, at Metal Temperature, °C [Notes (1) and (4b)] Min. Temp. to 40	65	100	150	200	250	300	325	350	375	400	425	450	475	500	525	550	575	600
34	138	138	138	138	138	132	126	122	118	113	95.1	79.5	62.6	45.0	31.7	21.4	14.2	9.40	6.89
35	138	138	138	138	138	132	126	122	118	113	95.1	79.5	62.6	45.0	31.7	21.4	14.2	9.40	6.89
36	138	138	138	138	138	132	126	122	118	113	95.1	79.5	62.6	45.0	31.7	21.4	14.2	9.40	6.89
37	138	138	138	138	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
38	138	138	138	138	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
39	138	138	138	138	138	...	...	...	...	...	...	...	...	...	...	...	...	...	...
40	138	138	138	138	138	...	...	...	...	...	...	...	...	...	...	...	...	...	...
41	142	142	142	142	142	142	142	142	129	...	...	...	...	...	...	...	...	...	...
42	145	145	145	145	145	...	...	...	...	...	...	...	...	...	...	...	...	...	...
43	145	145	145	145	145	...	...	...	...	...	...	...	...	...	...	...	...	...	...
44	147	147	147	147	147	147	147	147	129	...	...	...	...	...	...	...	...	...	...
45	149	149	147	142	138	132	126	122	118	113	95.0	79.6	63.2	45.3	31.7	21.9	12.7	...	...
46	149	149	147	142	138	132	126	122	118	113	95.0	79.6	63.2	45.3	31.7	21.9	12.7	9.40	6.89
47	149	149	147	142	138	132	126	122	118	113	95.0	79.6	63.2	45.3	31.7	21.9	12.7	9.40	6.89
48	149	149	147	142	138	132	126	122	118	113	95.0	79.6	63.2	45.3	31.7	21.9	12.7	9.40	6.89
49	152	152	152	152	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
50	152	152	152	152	152	...	...	...	...	...	...	...	...	...	...	...	...	...	...
51	152	152	152	152	152	...	...	...	...	...	...	...	...	...	...	...	...	...	...
52	161	161	159	154	150	144	136	132	128	122	101	83.8	67.1	51.0	33.6	21.3	12.9	...	...
53	161	161	159	154	150	144	136	132	128	122	101	83.8	67.1	51.0	33.6	21.3	12.9	9.40	6.89
54	161	161	159	154	150	144	136	132	128	122	101	83.8	67.1	51.0	33.6	21.3	12.9	9.40	6.89
55	161	161	159	154	150	144	136	132	128	122	101	83.8	67.1	51.0	33.6	21.3	12.9	9.40	6.89
56	161	161	161	161	158	151	144	139	135	122	101	83.8	82.7	...	...	...	...	...	...
57	161	161	161	157	156	156	156	154	148	126	...	...	...	...	...	...	...	...	...
58	161	161	161	157	156	156	156	154	148	126	...	...	...	...	...	...	...	...	...
59	161	161	161	157	156	156	156	154	148	126	...	...	...	...	...	...	...	...	...
60	163	163	163	163	163	...	...	...	...	...	...	...	...	...	...	...	...	...	...
61	163	163	163	163	163	...	...	...	...	...	...	...	...	...	...	...	...	...	...
62	172	172	168	163	158	151	144	139	135	131	107	88.0	67.3	50.3	33.2	21.4	14.2	9.40	6.89
63	172	172	168	163	158	151	144	139	135	131	107	88.0	67.3	50.3	33.2	21.4	14.2	9.40	6.89
64	172	172	168	163	158	151	144	139	135	131	107	88.0	67.3	50.3	33.2	21.4	14.2	9.40	6.89
65	172	172	172	171	165	159	151	146	142	131	...	...	...	...	...	...	...	...	...
66	172	172	172	171	165	159	151	146	142	131	...	...	...	...	...	...	...	...	...

Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

Line No.	Nominal Composition	Product Form	Spec. No.	Type/ Grade	UNS No.	Class/ Cond./ Temper	Size, mm	P-No. (5)	Notes	Min. Temp., °C (6)	Min. Tensile Str., MPa	Min. Yield Str., MPa	Max. Use Temp., °C
67	Carbon steel	Pipe & tube	A691	CMS-75	K02803	...	≤25	1	(57) (67)	A	517	290	371
68	Carbon steel	Pipe & tube	API 5L	X60	...	...	...	1	(51) (55) (71) (77)	A	517	414	204
69	Carbon steel	Pipe & tube	API 5L	X65	...	...	...	1	(51) (55) (71) (77)	A	531	448	204
70	Carbon steel	Pipe & tube	API 5L	X70	...	...	...	1	(51) (55) (71) (77)	A	565	483	204
71	Carbon steel	Pipe & tube	API 5L	X80	...	...	...	1	(51) (55) (71) (77)	A	621	552	204
72	Carbon steel	Pipe & tube	A381	Y60	...	...	...	1	(51) (71)	A	517	414	204
73	Carbon steel	Structural pipe	A134	A1011SS30	K02502	...	...	1	(8a) (8c)	−29	338	207	204
74	Carbon steel	Structural pipe	A134	A1011SS33	K02502	...	...	1	(8a) (8c)	−29	359	228	204
75	Carbon steel	Structural pipe	A134	A1011SS36-T1	K02502	...	...	1	(8a) (8c)	−29	365	248	204
76	Carbon steel	Structural pipe	A134	A1011SS40	K02502	...	...	1	(8a) (8c)	−29	379	276	204
77	Carbon steel	Structural pipe	A134	A36	K02600	...	...	1	(8a) (8c)	−29	400	248	204
78	Carbon steel	Structural pipe	A134	A283D	K02702	...	...	1	(8a) (8c)	−29	414	228	149
79	Carbon steel	Structural pipe	A134	A1011SS45	K02507	...	...	1	(8a) (8c)	−29	414	310	204
80	Carbon steel	Structural pipe	A134	A1011SS50	K02507	...	...	1	(8a) (8c)	−29	448	345	204
81	Carbon steel	Plate, bar, shps., sheet	A285	A	K01700	...	...	1	(57) (59)	B	310	165	593
82	Carbon steel	Plate, bar, shps., sheet	A285	B	K02200	...	...	1	(57) (59)	B	345	186	593
83	Carbon steel	Plate, bar, shps., sheet	A516	55	K01800	...	...	1	(57)	C	379	207	454
84	Carbon steel	Plate, bar, shps., sheet	A285	C	K02801	...	...	1	(57) (59)	A	379	207	593
85	Carbon steel	Plate, bar, shps., sheet	A516	60	K02100	...	...	1	(57)	C	414	221	454
86	Carbon steel	Plate, bar, shps., sheet	A515	60	K02401	...	...	1	(57)	B	414	221	538
87	Carbon steel	Plate, bar, shps., sheet	A696	B	K03200	...	...	1	(57)	A	415	240	371
88	Carbon steel	Plate, bar, shps., sheet	A516	65	K02403	...	...	1	(57)	B	448	241	454
89	Carbon steel	Plate, bar, shps., sheet	A515	65	K02800	...	...	1	(57)	A	448	241	538
90	Carbon steel	Plate, bar, shps., sheet	A516	70	K02700	...	...	1	(57)	B	483	262	454
91	Carbon steel	Plate, bar, shps., sheet	A515	70	K03101	...	...	1	(57)	A	483	262	538
92	Carbon steel	Plate, bar, shps., sheet	A696	C	K03200	...	...	1	(57)	A	485	275	371
93	Carbon steel	Plate, bar, shps., sheet	A537	...	K12437	1	≤64	1	...	D	483	345	371
94	Carbon steel	Plate, bar, shps., sheet	A299	A	K02803	...	>25	1	(57)	A	517	276	593
95	Carbon steel	Plate, bar, shps., sheet	A299	A	K02803	...	≤25	1	(57)	A	517	290	593

Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

Line No.	Basic Allowable Stress, *S*, MPa, at Metal Temperature, °C [Notes (1) and (4b)]																		
	Min. Temp. to 40	65	100	150	200	250	300	325	350	375	400	425	450	475	500	525	550	575	600
67	*172*	*172*	*172*	171	165	159	151	146	142	**131**	...	...	...	...	...	...	...	...	...
68	*172*	*172*	*172*	*172*	*172*	...	...	...	...	...	...	...	...	...	...	...	...	...	...
69	*177*	*177*	*177*	*177*	*177*	...	...	...	...	...	...	...	...	...	...	...	...	...	...
70	*188*	*188*	*188*	*188*	*188*	...	...	...	...	...	...	...	...	...	...	...	...	...	...
71	*207*	*207*	*207*	*207*	*207*	...	...	...	...	...	...	...	...	...	...	...	...	...	...
72	*172*	*172*	*172*	*172*	*172*	...	...	...	...	...	...	...	...	...	...	...	...	...	...
73	*104*	*104*	*104*	*104*	*104*	...	...	...	...	...	...	...	...	...	...	...	...	...	...
74	*110*	*110*	*110*	*110*	*110*	...	...	...	...	...	...	...	...	...	...	...	...	...	...
75	*112*	*112*	*112*	*112*	*112*	...	...	...	...	...	...	...	...	...	...	...	...	...	...
76	*116*	*116*	*116*	*116*	*116*	...	...	...	...	...	...	...	...	...	...	...	...	...	...
77	*123*	*123*	*123*	*123*	*123*	...	...	...	...	...	...	...	...	...	...	...	...	...	...
78	*127*	*127*	*127*	123	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
79	*127*	*127*	*127*	*127*	*127*	...	...	...	...	...	...	...	...	...	...	...	...	...	...
80	*137*	*137*	*137*	*137*	*137*	...	...	...	...	...	...	...	...	...	...	...	...	...	...
81	*103*	*103*	101	97.5	94.6	90.8	86.1	83.6	81.1	78.6	**73.3**	**64.0**	**55.8**	**43.9**	**31.7**	**21.4**	**14.2**	**9.40**	**6.89**
82	*115*	*115*	113	110	106	102	96.9	94.1	91.2	**84.3**	**73.3**	**64.0**	**55.8**	**43.9**	**31.7**	**21.4**	**14.2**	**9.40**	**6.89**
83	*126*	*126*	126	122	118	113	108	105	101	98.3	**89.1**	**75.4**	**62.6**	**45.5**	**31.6**	**21.9**	**12.7**	...	...
84	*126*	*126*	126	122	118	113	108	105	101	98.3	**89.0**	**75.3**	**62.1**	**45.0**	**31.7**	**21.4**	**14.2**	**9.40**	**6.89**
85	*138*	*138*	134	130	126	121	115	111	108	105	**88.9**	**75.3**	**62.7**	**45.5**	**31.6**	**21.9**	**12.7**	...	...
86	*138*	*138*	134	130	126	121	115	111	108	105	**88.9**	**75.3**	**62.7**	**45.5**	**31.6**	**21.9**	**12.7**	...	...
87	*138*	*138*	*138*	*138*	138	132	125	122	118	115	...	...	...	...	...	...	...	...	...
88	*149*	*149*	147	142	138	132	126	122	118	113	**95.0**	**79.6**	**63.2**	**45.3**	**31.7**	**21.9**	**12.7**	...	...
89	*149*	*149*	147	142	138	132	126	122	118	113	**95.0**	**79.6**	**63.2**	**45.3**	**31.7**	**21.9**	**12.7**	...	...
90	*161*	*161*	159	154	150	144	136	132	128	122	**101**	**83.8**	**67.1**	**51.0**	**33.6**	**21.3**	**12.9**	...	...
91	*161*	*161*	159	154	150	144	136	132	128	122	**101**	**83.8**	**67.1**	**51.0**	**33.6**	**21.3**	**12.9**	...	...
92	*161*	*161*	*161*	*161*	158	151	144	139	135	131	...	...	...	...	...	...	...	...	...
93	*161*	*161*	*161*	*157*	*156*	*156*	156	154	**148**	**126**	...	...	...	...	...	...	...	...	...
94	*172*	*172*	168	163	158	151	144	139	135	**131**	**107**	**88.0**	**67.3**	**50.3**	**33.2**	**21.4**	**14.2**	**9.40**	**6.89**
95	*172*	*172*	*172*	171	165	159	151	146	142	**131**	**107**	**88.0**	**67.3**	**50.3**	**33.2**	**21.4**	**14.2**	**9.40**	**6.89**

Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

Line No.	Nominal Composition	Product Form	Spec. No.	Type/ Grade	UNS No.	Class/ Cond./ Temper	Size, mm	P-No. (5)	Notes	Min. Temp., °C (6)	Min. Tensile Str., MPa	Min. Yield Str., MPa	Max. Use Temp., °C
96	Carbon steel	Struct. sht., strip	A10-11	SS30	K02502	...	...	1	(8c) (57)	A	338	207	399
97	Carbon steel	Struct. sht., strip	A10-11	SS33	K02502	...	...	1	(8c) (57)	A	359	228	399
98	Carbon steel	Struct. sht., strip	A10-11	SS36-T1	K02502	...	...	1	(8c) (57)	A	365	248	399
99	Carbon steel	Structural plate	A283	C	K02401	...	...	1	(8c) (57)	A	379	207	399
100	Carbon steel	Stuct. sht., strip	A10-11	SS40	K02502	...	...	1	(8c) (57)	A	379	276	399
101	Carbon steel	Structural steel	A36	...	K02600	...	...	1	(8c)	A	400	248	371
102	Carbon steel	Structural plate	A283	D	K02702	...	...	1	(8c) (57)	A	414	228	399
103	Carbon steel	Struct. sht., strip	A10-11	SS45	K02507	...	...	1	(8c) (57)	A	414	310	399
104	Carbon steel	Struct. sht., strip	A10-11	SS50	K02507	...	...	1	(8c) (57)	A	448	344	399
105	Carbon steel	Structural shapes	A992	...	...	...	...	1	(8c) (57)	A	448	344	427
106	Carbon steel	Forgings & fittings	A350	LF1	K03009	...	...	1	(9) (57) (59)	−29	414	207	538
107	Carbon steel	Forgings & fittings	A181	...	K03502	60	...	1	(9) (57) (59)	A	414	207	593
108	Carbon steel	Forgings & fittings	A420	WPL6	K03006	...	...	1	(57)	−46	414	241	538
109	Carbon steel	Forgings & fittings	A234	WPB	K03006	...	...	1	(57) (59)	B	414	241	593
110	Carbon steel	Forgings & fittings	A694	F42	K03014	...	...	1	(9)	−29	415	290	260
111	Carbon steel	Forgings & fittings	A707	L1	K02302	1	...	1	(9)	−29	415	290	260
112	Carbon steel	Forgings & fittings	A707	L2	K03301	1	...	1	(9)	−46	415	290	260
113	Carbon steel	Forgings & fittings	A707	L3	K12510	1	...	1	(9)	−46	415	290	260
114	Carbon steel	Forgings & fittings	A860	WPHY 42	...	...	...	1	...	−46	415	290	260
115	Carbon steel	Forgings & fittings	A694	F46	K03014	...	...	1	(9)	−29	435	317	260
116	Carbon steel	Forgings & fittings	A860	WPHY 46	...	...	...	1	...	−46	435	317	260
117	Carbon steel	Forgings & fittings	A694	F52	K03014	...	...	1	(9)	−29	455	360	260
118	Carbon steel	Forgings & fittings	A707	L1	K02302	2	...	1	(9)	−29	455	360	260
119	Carbon steel	Forgings & fittings	A707	L2	K03301	2	...	1	(9)	−46	455	360	260
120	Carbon steel	Forgings & fittings	A707	L3	K12510	2	...	1	(9)	−46	455	360	260
121	Carbon steel	Forgings & fittings	A860	WPHY 52	...	...	...	1	...	−46	455	360	260
122	Carbon steel	Forgings & fittings	A350	LF2	K03011	1	...	1	(9) (57)	−46	483	248	538
123	Carbon steel	Forgings & fittings	A350	LF2	K03011	2	...	1	(9) (57)	−18	483	248	538

Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

Line No.	Basic Allowable Stress, *S*, MPa, at Metal Temperature, °C [Notes (1) and (4b)] Min. Temp. to 40	65	100	150	200	250	300	325	350	375	400	425	450	475	500	525	550	575	600
96	*104*	*104*	*104*	*104*	*104*	*104*	99.4	96.6	**89.2**	**77.6**	**67.9**	...	...	...	...	...	...	...	...
97	*110*	*110*	*110*	*110*	*110*	*110*	109	106	**89.2**	**77.6**	**67.9**	...	...	...	...	...	...	...	...
98	*112*	*112*	*112*	*112*	*112*	*112*	*112*	*112*	**89.2**	**77.6**	**67.9**	...	...	...	...	...	...	...	...
99	*116*	*116*	116	112	109	104	99.4	96.6	92.9	90.4	82.4	...	...	...	...	...	...	...	...
100	*116*	*116*	*116*	*116*	*116*	*116*	*116*	*116*	**114**	**96.6**	**82.4**	...	...	...	...	...	...	...	...
101	*123*	*123*	*123*	*123*	*123*	*123*	119	115	112	99.4	...	...	...	...	...	...	...	...	...
102	*127*	*127*	*127*	123	120	115	109	106	102	99.4	88.1	...	...	...	...	...	...	...	...
103	*127*	*127*	*127*	*127*	*127*	*127*	*127*	*127*	**124**	**104**	**88.1**	...	...	...	...	...	...	...	...
104	*137*	*137*	*137*	*137*	*137*	*137*	*137*	*137*	**124**	**104**	**88.1**	...	...	...	...	...	...	...	...
105	137	137	137	137	137	137	137	137	**117**	**105**	**87.5**	**73.2**	**58.1**	...	...	...	...	...	...
106	*138*	130	126	122	118	113	108	105	101	98.3	**95.1**	**79.5**	**62.6**	**45.0**	**31.7**	**21.4**	**17.2**	...	...
107	*138*	130	126	122	118	113	108	105	101	98.3	**95.1**	**79.5**	**62.6**	**45.0**	**31.7**	**21.4**	**14.2**	**9.40**	**6.89**
108	*138*	*138*	*138*	*138*	*138*	132	126	122	118	**113**	**95.1**	**79.5**	**62.6**	**45.0**	**31.7**	**21.4**	**17.2**	...	...
109	*138*	*138*	*138*	*138*	*138*	132	126	122	118	**113**	**95.1**	**79.5**	**62.6**	**45.0**	**31.7**	**21.4**	**14.2**	**9.40**	**6.89**
110	*138*	*138*	*138*	*138*	*138*	137	132	...	...	...	...	...	...	...	...	...	...	...	...
111	*138*	*138*	*138*	*138*	*138*	137	132	...	...	...	...	...	...	...	...	...	...	...	...
112	*138*	*138*	*138*	*138*	*138*	137	132	...	...	...	...	...	...	...	...	...	...	...	...
113	*138*	*138*	*138*	*138*	*138*	137	132	...	...	...	...	...	...	...	...	...	...	...	...
114	*138*	*138*	*138*	*138*	*138*	137	132	...	...	...	...	...	...	...	...	...	...	...	...
115	*145*	*145*	*145*	*145*	*145*	*145*	144	...	...	...	...	...	...	...	...	...	...	...	...
116	*145*	*145*	*145*	*145*	*145*	*145*	144	...	...	...	...	...	...	...	...	...	...	...	...
117	*150*	*150*	*150*	*150*	*150*	*150*	*150*	...	...	...	...	...	...	...	...	...	...	...	...
118	*150*	*150*	*150*	*150*	*150*	*150*	*150*	...	...	...	...	...	...	...	...	...	...	...	...
119	*150*	*150*	*150*	*150*	*150*	*150*	*150*	...	...	...	...	...	...	...	...	...	...	...	...
120	*150*	*150*	*150*	*150*	*150*	*150*	*150*	...	...	...	...	...	...	...	...	...	...	...	...
121	*150*	*150*	*150*	*150*	*150*	*150*	*150*	...	...	...	...	...	...	...	...	...	...	...	...
122	*161*	156	151	146	142	136	129	125	122	118	**101**	**83.8**	**66.8**	**50.3**	**33.2**	**21.4**	**17.2**	...	...
123	*161*	156	151	146	142	136	129	125	122	118	**101**	**83.8**	**66.8**	**50.3**	**33.2**	**21.4**	**17.2**	...	...

Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

Line No.	Nominal Composition	Product Form	Spec. No.	Type/ Grade	UNS No.	Class/ Cond./ Temper	Size, mm	P-No. (5)	Notes	Min. Temp., °C (6)	Min. Tensile Str., MPa	Min. Yield Str., MPa	Max. Use Temp., °C
124	Carbon steel	Forgings & fittings	A105	...	K03504	...	...	1	(9) (57) (59)	−29	483	248	593
125	Carbon steel	Forgings & fittings	A181	...	K03502	70	...	1	(9) (57) (59)	A	483	248	593
126	Carbon steel	Forgings & fittings	A234	WPC	K03501	...	...	1	(57) (59)	B	483	276	427
127	Carbon steel	Forgings & fittings	A694	F56	K03014	...	...	1	(9)	−29	490	385	260
128	Carbon steel	Forgings & fittings	A694	F60	K03014	...	...	1	(9)	−29	515	415	260
129	Carbon steel	Forgings & fittings	A707	L2	K03301	3	...	1	(9)	−46	515	415	260
130	Carbon steel	Forgings & fittings	A707	L3	K12510	3	...	1	(9)	−46	515	415	260
131	Carbon steel	Forgings & fittings	A860	WPHY 60	...	...	...	1	...	−46	515	415	260
132	Carbon steel	Forgings & fittings	A694	F65	K03014	...	...	1	(9)	−29	530	450	260
133	Carbon steel	Forgings & fittings	A860	WPHY 65	...	...	...	1	...	−46	530	450	260
134	Carbon steel	Forgings & fittings	A694	F70	K03014	...	...	1	(9) (79)	...	565	485	204
135	Carbon steel	Forgings & fittings	A860	WPHY 70	...	...	...	1	...	−46	565	485	204
136	Carbon steel	Castings	A216	WCA	J02502	...	...	1	(57)	−29	414	207	593
137	Carbon steel	Castings	A352	LCB	J03003	...	...	1	(9) (57)	−46	448	241	593
138	Carbon steel	Castings	A352	LCC	J02505	...	...	1	(9)	−46	483	276	371
139	Carbon steel	Castings	A216	WCB	J03002	...	...	1	(9) (57)	−29	483	248	593
140	Carbon steel	Castings	A216	WCC	J02503	...	...	1	(9) (57)	−29	483	276	538

Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

	Basic Allowable Stress, *S*, MPa, at Metal Temperature, °C [Notes (1) and (4b)]																		
Line No.	**Min. Temp. to 40**	**65**	**100**	**150**	**200**	**250**	**300**	**325**	**350**	**375**	**400**	**425**	**450**	**475**	**500**	**525**	**550**	**575**	**600**
124	*161*	156	151	146	142	136	129	125	122	118	**101**	**83.8**	**66.8**	**50.3**	**33.2**	**21.4**	**14.2**	**9.40**	**6.89**
125	*161*	156	151	146	142	136	129	125	122	118	**101**	**83.8**	**66.8**	**50.3**	**33.2**	**21.4**	**14.2**	**9.40**	**6.89**
126	*161*	*161*	*161*	*161*	158	151	144	139	135	**122**	**101**	**83.8**	**82.7**	...	...	...	...	...	...
127	*163*	*163*	*163*	*163*	*163*	*163*	*163*	...	...	...	...	...	...	...	...	...	...	...	...
128	*172*	*172*	*172*	*172*	*172*	*172*	*172*	...	...	...	...	...	...	...	...	...	...	...	...
129	*172*	*172*	*172*	*172*	*172*	*172*	*172*	...	...	...	...	...	...	...	...	...	...	...	...
130	*172*	*172*	*172*	*172*	*172*	*172*	*172*	...	...	...	...	...	...	...	...	...	...	...	...
131	*172*	*172*	*172*	*172*	*172*	*172*	*172*	...	...	...	...	...	...	...	...	...	...	...	...
132	*177*	*177*	*177*	*177*	*177*	*177*	*177*	...	...	...	...	...	...	...	...	...	...	...	...
133	*177*	*177*	*177*	*177*	*177*	*177*	*177*	...	...	...	...	...	...	...	...	...	...	...	...
134	*188*	*188*	*188*	*188*	*188*	*188*	...	...	...	...	...	...	...	...	...	...	...	...	...
135	*188*	*188*	*188*	*188*	*188*	*188*	...	...	...	...	...	...	...	...	...	...	...	...	...
136	*138*	130	126	122	118	113	108	105	101	98.3	**95.1**	**79.5**	**62.6**	**45.0**	**31.7**	**21.4**	**14.2**	**9.40**	**6.89**
137	*149*	*149*	147	142	138	132	126	122	118	**113**	**95.1**	**79.5**	**64.4**	**47.7**	**32.5**	**21.4**	**14.2**	**9.40**	**6.89**
138	*161*	*161*	161	161	158	151	139	137	136	132	...	...	...	...	...	...	...	...	...
139	*161*	156	151	146	142	136	129	125	122	118	**101**	**83.8**	**66.8**	**50.3**	**33.2**	**21.4**	**14.2**	**9.40**	**6.89**
140	*161*	*161*	*161*	*161*	158	151	144	139	135	**122**	**101**	**83.8**	**66.8**	**50.3**	**33.2**	**21.4**	**17.2**	...	...

Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

Line No.	Nominal Composition	Product Form	Spec. No.	Type/ Grade	UNS No.	Class/ Condition/ Temper	Size, mm	P-No. (5)	Notes	Min. Temp., °C (6)	Min. Tensile Str., MPa	Min. Yield Str., MPa	Max. Use Temp., °C
1	½Cr–½Mo	Pipe	A335	P2	K11547	...	...	3	...	−29	379	207	538
2	½Cr–½Mo	Pipe	A691	½CR	K12143	...	...	3	(11) (67)	−29	379	228	538
3	C–½Mo	Pipe	A335	P1	K11522	...	...	3	(58)	−29	379	207	593
4	C–½Mo	Pipe	A369	FP1	K11522	...	...	3	(58)	−29	379	207	593
5	½Cr–½Mo	Pipe	A369	FP2	K11547	...	...	3	...	−29	379	207	593
6	1Cr–½Mo	Pipe	A691	1CR	K11757	...	...	4	(11) (67)	−29	379	228	649
7	½Cr–½Mo	Pipe	A426	CP2	J11547	...	...	3	(10)	−29	414	207	593
8	1½Si–½Mo	Pipe	A335	P15	K11578	...	...	3	...	−29	414	207	593
9	C–½Mo–Si	Pipe	A426	CP15	J11522	...	...	3	(10)	−29	414	207	593
10	1Cr–½Mo	Pipe	A426	CP12	J11562	...	...	4	(10)	−29	414	207	649
11	5Cr–1½Si–½Mo	Pipe	A426	CP5b	J51545	...	...	5B	(10)	−29	414	207	649
12	3Cr–Mo	Pipe	A426	CP21	J31545	...	...	5A	(10)	−29	414	207	649
13	¾Cr–¾Ni–Cu–Al	Pipe	A333	4	K11267	...	...	4	...	−101	414	241	40
14	2Cr–½Mo	Pipe	A369	FP3b	K21509	...	...	4	...	−29	414	207	649
15	1Cr–½Mo	Pipe	A335	P12	K11562	...	...	4	...	−29	414	221	649
16	1Cr–½Mo	Pipe	A369	FP12	K11562	...	...	4	...	−29	414	221	649
17	1¼Cr–½Mo–Si	Pipe	A335	P11	K11597	...	...	4	...	−29	414	207	649
18	1¼Cr–½Mo–Si	Pipe	A369	FP11	K11597	...	...	4	...	−29	414	207	649
19	1¼Cr–½Mo–Si	Pipe	A691	1¼CR	K11789	...	...	4	(11) (67)	−29	414	241	649
20	5Cr–½Mo	Pipe	A691	5CR	K41545	...	...	5B	(11) (67)	−29	414	207	649
21	5Cr–½Mo	Pipe	A335	P5	K41545	...	...	5B	...	−29	414	207	649
22	5Cr–½Mo–Si	Pipe	A335	P5b	K51545	...	...	5B	...	−29	414	207	649
23	5Cr–½Mo–Ti	Pipe	A335	P5c	K41245	...	...	5B	...	−29	414	207	649
24	5Cr–½Mo	Pipe	A369	FP5	K41545	...	...	5B	...	−29	414	207	649
25	9Cr–1Mo	Pipe	A335	P9	K90941	...	...	5B	...	−29	414	207	649
26	9Cr–1Mo	Pipe	A369	FP9	K90941	...	...	5B	...	−29	414	207	649
27	9Cr–1Mo	Pipe	A691	9CR	K90941	...	...	5B	(11) (67)	−29	414	207	649
28	3Cr–1Mo	Pipe	A335	P21	K31545	...	...	5A	...	−29	414	207	649
29	3Cr–1Mo	Pipe	A369	FP21	K31545	...	...	5A	...	−29	414	207	649
30	3Cr–1Mo	Pipe	A691	3CR	K31545	...	...	5A	(11) (67)	−29	414	207	649
31	2¼Cr–1Mo	Pipe	A691	2¼CR	K21590	...	...	5A	(11) (67) (72) (75)	−29	414	207	649
32	2¼Cr–1Mo	Pipe	A369	FP22	K21590	...	...	5A	(72) (75)	−29	414	207	649
33	2¼Cr–1Mo	Pipe	A335	P22	K21590	...	...	5A	(72) (75)	−29	414	207	649
34	2Ni–1Cu	Pipe	A333	9	K22035	...	...	9A	...	−73	434	317	40
35	2Ni–1Cu	Pipe	A334	9	K22035	...	...	9A	...	−73	434	317	40

Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

Line No.	Basic Allowable Stress, *S*, MPa, at Metal Temperature, °C [Notes (1) and (4b)]																								
	Min. Temp. to 40	65	100	125	150	175	200	225	250	275	300	325	350	375	400	425	450	475	500	525	550	575	600	625	650
1	*126*	*126*	*126*	*126*	124	122	120	119	117	115	114	112	110	108	106	103	100	97.1	**74.4**	**49.9**	**40.7**	...	...	...	...
2	*126*	*126*	*126*	*126*	*126*	*126*	*126*	*126*	*126*	*126*	125	123	121	119	116	114	110	107	**74.4**	**49.9**	**40.7**	...	...	...	...
3	*126*	*126*	*126*	*126*	124	122	120	119	117	115	114	112	110	108	106	103	100	97.1	**68.0**	**42.3**	**30.5**	**23.2**	**16.5**	...	...
4	*126*	*126*	*126*	*126*	124	122	120	119	117	115	114	112	110	108	106	103	100	97.1	**68.0**	**42.3**	**30.5**	**23.2**	**16.5**	...	...
5	*126*	*126*	*126*	*126*	124	122	120	119	117	115	114	112	110	108	106	103	100	97.1	**93.5**	**49.9**	**34.7**	**23.9**	**17.2**	...	...
6	*126*	*126*	*123*	*122*	*122*	*122*	*122*	121	120	118	116	115	114	112	110	109	106	104	**92.1**	**61.1**	**40.4**	**26.4**	**17.4**	**11.6**	**7.58**
7	*138*	133	129	126	124	122	120	119	117	115	114	112	110	108	106	103	100	97.1	**74.4**	**49.9**	**34.3**	**23.2**	**16.5**	...	...
8	*138*	133	129	127	125	124	122	121	120	118	117	115	114	112	110	107	103	**88.4**	**74.7**	**53.7**	**35.6**	**23.2**	**16.5**	...	...
9	*138*	133	129	127	125	124	122	121	120	118	117	115	114	112	110	107	103	**88.4**	**74.7**	**53.7**	**35.6**	**23.2**	**16.5**	...	...
10	*138*	129	124	120	117	115	112	110	109	107	106	105	103	102	100	98.7	96.8	94.6	92.0	**61.1**	**40.4**	**26.4**	**17.4**	**11.6**	**7.58**
11	*138*	129	124	122	120	119	119	118	118	117	117	116	114	112	110	106	103	**80.6**	**61.7**	**46.4**	**34.7**	**25.5**	**17.8**	**11.4**	**6.89**
12	*138*	132	128	126	125	124	124	124	124	124	124	124	124	124	123	122	121	**89.2**	**68.8**	**54.2**	**43.4**	**34.0**	**25.1**	**17.1**	**10.3**
13	*138*	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
14	*138*	132	128	126	125	124	124	124	124	124	124	124	124	124	123	122	121	118	**74.7**	**53.3**	**36.0**	**24.6**	**15.5**	**9.21**	**6.89**
15	*138*	*138*	132	128	125	122	120	118	116	114	113	112	110	109	107	105	103	101	**92.1**	**61.1**	**40.4**	**26.4**	**17.4**	**11.6**	**7.58**
16	*138*	*138*	132	128	125	122	120	118	116	114	113	112	110	109	107	105	103	101	**92.1**	**61.1**	**40.4**	**26.4**	**17.4**	**11.6**	**7.58**
17	*138*	131	126	124	121	119	116	115	113	111	109	107	106	104	102	99.6	97.2	94.5	**73.7**	**52.0**	**36.3**	**25.2**	**17.6**	**12.3**	**8.27**
18	*138*	131	126	124	121	119	116	115	113	111	109	107	106	104	102	99.6	97.2	94.5	**73.7**	**52.0**	**36.3**	**25.2**	**17.6**	**12.3**	**8.27**
19	*138*	*138*	*138*	*138*	*138*	*138*	136	134	131	129	127	125	123	121	119	116	113	**104**	**73.7**	**52.0**	**36.3**	**25.2**	**17.6**	**12.3**	**8.27**
20	*138*	129	124	122	120	119	119	118	118	117	117	116	114	112	110	106	103	**80.6**	**61.7**	**46.4**	**34.7**	**25.5**	**17.8**	**11.4**	**6.89**
21	*138*	129	124	122	120	119	119	118	118	117	117	116	114	112	110	106	103	**80.6**	**61.7**	**46.4**	**34.7**	**25.5**	**17.8**	**11.4**	**6.89**
22	*138*	129	124	122	120	119	119	118	118	117	117	116	114	112	110	106	103	**80.6**	**61.7**	**46.4**	**34.7**	**25.5**	**17.8**	**11.4**	**6.89**
23	*138*	129	124	122	120	119	119	118	118	117	117	116	114	112	110	106	103	**80.6**	**61.7**	**46.4**	**34.7**	**25.5**	**17.8**	**11.4**	**6.89**
24	*138*	129	124	122	120	119	119	118	118	117	117	116	114	112	110	106	103	**80.6**	**61.7**	**46.4**	**34.7**	**25.5**	**17.8**	**11.4**	**6.89**
25	*138*	129	124	122	120	119	119	118	118	117	117	116	114	112	110	106	103	98.3	**83.2**	**60.2**	**42.9**	**29.9**	**20.6**	**14.4**	**10.3**
26	*138*	129	124	122	120	119	119	118	118	117	117	116	114	112	110	106	103	98.3	**83.2**	**60.2**	**42.9**	**29.9**	**20.6**	**14.4**	**10.3**
27	*138*	129	124	122	120	119	119	118	118	117	117	116	114	112	110	106	103	98.3	**83.2**	**60.2**	**42.9**	**29.9**	**20.6**	**14.4**	**10.3**
28	*138*	132	128	126	125	124	124	124	124	124	124	124	124	124	123	122	121	**89.2**	**68.8**	**54.2**	**43.4**	**34.0**	**25.1**	**17.1**	**10.3**
29	*138*	132	128	126	125	124	124	124	124	124	124	124	124	124	123	122	121	**89.2**	**68.8**	**54.2**	**43.4**	**34.0**	**25.1**	**17.1**	**10.3**
30	*138*	132	128	126	125	124	124	124	124	124	124	124	124	124	123	122	121	**89.2**	**68.8**	**54.2**	**43.4**	**34.0**	**25.1**	**17.1**	**10.3**
31	*138*	132	128	126	125	124	124	124	124	124	124	124	124	124	123	122	121	**99.6**	**80.9**	**63.3**	**47.5**	**34.2**	**23.5**	**15.3**	**9.65**
32	*138*	132	128	126	125	124	124	124	124	124	124	124	124	124	123	122	121	**99.6**	**80.9**	**63.3**	**47.5**	**34.2**	**23.5**	**15.3**	**9.65**
33	*138*	132	128	126	125	124	124	124	124	124	124	124	124	124	123	122	121	**99.6**	**80.9**	**63.3**	**47.5**	**34.2**	**23.5**	**15.3**	**9.65**
34	*145*	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
35	*145*	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...

Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

Line No.	Nominal Composition	Product Form	Spec. No.	Type/ Grade	UNS No.	Class/ Condition/ Temper	Size, mm	P-No. (5)	Notes	Min. Temp., °C (6)	Min. Tensile Str., MPa	Min. Yield Str., MPa	Max. Use Temp., °C
36	2¼Ni	Pipe	A333	7	K21903	...	...	9A	...	−73	448	241	593
37	2¼Ni	Pipe	A334	7	K21903	...	...	9A	...	−73	448	241	593
38	3½Ni	Pipe	A333	3	K31918	...	...	9B	...	−101	448	241	593
39	3½Ni	Pipe	A334	3	K31918	...	...	9B	...	−101	448	241	593
40	C–½Mo	Pipe	A426	CP1	J12521	...	...	3	(10) (58)	−29	448	241	593
41	C–½Mo	Pipe	A672	L65	K11820	...	...	3	(11) (58) (67)	−29	448	255	593
42	C–½Mo	Pipe	A691	CM-65	K11820	...	...	3	(11) (58) (67)	−29	448	255	593
43	2¼Ni	Pipe	A671	CFB70	K22103	...	...	9A	(11) (65) (67)	−29	483	276	40
44	3½Ni	Pipe	A671	CFE70	K32018	...	...	9B	(11) (65) (67)	−29	483	276	40
45	C–½Mo	Pipe	A672	L70	K12020	...	...	3	(11) (58) (67)	−29	483	276	593
46	C–½Mo	Pipe	A691	CM-70	K12020	...	...	3	(11) (58) (67)	−29	483	276	593
47	1¼Cr–½Mo	Pipe	A426	CP11	J12072	...	...	4	(10)	−29	483	276	649
48	2¼Cr–1Mo	Pipe	A426	CP22	J21890	...	...	5A	(10) (72)	−29	483	276	649
49	C–½Mo	Pipe	A672	L75	K12320	...	...	3	(11) (58) (67)	−29	517	296	593
50	C–½Mo	Pipe	A691	CM-75	K12320	...	...	3	(11) (58) (67)	−29	517	296	593
51	9Cr–1Mo–V	Pipe	A335	P91	K90901	...	≤75	15E	...	−29	586	414	649
52	9Cr–1Mo–V	Pipe	A691	91	K90901	...	≤75	15E	(11) (67)	−29	586	414	649
53	5Cr–½Mo	Pipe	A426	CP5	J42045	...	...	5B	(10)	−29	621	414	649
54	9Cr–1Mo	Pipe	A426	CP9	J82090	...	...	5B	(10)	−29	621	414	649
55	9Ni	Pipe	A333	8	K81340	...	...	11A	(47)	−196	689	517	93
56	9Ni	Pipe	A334	8	K81340	...	...	11A	...	−196	689	517	93
57	½Cr–½Mo	Plate	A387	2	K12143	1	...	3	...	−29	379	228	538
58	1Cr–½Mo	Plate	A387	12	K11757	1	...	4	...	−29	379	228	649
59	9Cr–1Mo	Plate	A387	9	K90941	1	...	5B	...	−29	414	207	649
60	1¼Cr–½Mo–Si	Plate	A387	11	K11789	1	...	4	...	−29	414	241	649
61	5Cr–½Mo	Plate	A387	5	K41545	1	...	5B	...	−29	414	207	649
62	3Cr–1Mo	Plate	A387	21	K31545	1	...	5A	...	−29	414	207	649
63	2¼Cr–1Mo	Plate	A387	22	K21590	1	...	5A	(72)	−29	414	207	649
64	2¼Ni	Plate	A203	A	K21703	...	...	9A	(12) (65)	−29	448	255	538
65	3½Ni	Plate	A203	D	K31718	...	...	9B	(12) (65)	−29	448	255	538
66	C–½Mo	Plate	A204	A	K11820	...	...	3	(58)	−29	448	255	593
67	1Cr–½Mo	Plate	A387	12	K11757	2	...	4	...	−29	448	276	649
68	2¼Ni	Plate	A203	B	K22103	...	...	9A	(12) (65)	−29	483	276	538
69	3½Ni	Plate	A203	E	K32018	...	...	9B	(12) (65)	−29	483	276	538

Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

	Basic Allowable Stress, *S*, MPa, at Metal Temperature, °C [Notes (1) and (4b)]																								
Line No.	Min. Temp. to 40	65	100	125	150	175	200	225	250	275	300	325	350	375	400	425	450	475	500	525	550	575	600	625	650
36	149	149	147	144	142	140	138	135	132	128	124	119	113	107	95.1	79.5	64.4	48.8	35.4	22.6	14.2	9.40	6.89	...	...
37	149	149	147	144	142	140	138	135	132	128	124	119	113	107	95.1	79.5	64.4	48.8	35.4	22.6	14.2	9.40	6.89	...	...
38	149	149	147	144	142	140	138	135	132	128	124	119	113	107	95.1	79.5	64.4	48.8	35.4	22.6	14.2	9.48	7.06	...	...
39	149	149	147	144	142	140	138	135	132	128	124	119	113	107	95.1	79.5	64.4	48.8	35.4	22.6	14.2	9.48	7.06	...	...
40	149	149	149	148	145	143	140	138	137	135	133	131	129	126	123	120	117	109	68.0	42.3	30.5	23.2	16.5	...	...
41	149	149	149	149	149	149	148	146	144	142	140	138	136	133	131	127	124	109	68.0	42.3	30.5	23.2	16.5	...	...
42	149	149	149	149	149	149	148	146	144	142	140	138	136	133	131	127	124	109	68.0	42.3	30.5	23.2	16.5	...	...
43	161	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
44	161	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
45	161	161	161	161	161	161	161	158	156	154	152	149	147	144	141	138	134	109	68.0	42.3	30.5	23.2	16.5	...	...
46	161	161	161	161	161	161	161	158	156	154	152	149	147	144	141	138	134	109	68.0	42.3	30.5	23.2	16.5	...	...
47	161	161	161	161	161	158	155	153	150	148	146	143	141	138	136	133	130	104	73.7	52.0	36.3	25.2	17.6	12.3	8.27
48	161	161	160	157	156	156	156	156	156	156	156	156	156	156	156	156	156	119	88.4	64.0	44.6	30.0	19.7	12.8	8.27
49	172	172	172	172	172	172	172	170	168	165	163	161	158	155	152	148	144	109	68.0	42.3	30.5	23.2	16.5	...	...
50	172	172	172	172	172	172	172	170	168	165	163	161	158	155	152	148	144	109	68.0	42.3	30.5	23.2	16.5	...	...
51	195	195	195	195	195	195	195	195	194	193	192	190	187	183	178	172	165	156	147	137	115	87.0	64.7	45.1	29.6
52	195	195	195	195	195	195	195	195	194	193	192	190	187	183	178	172	165	156	147	137	115	87.0	64.7	45.1	29.6
53	207	207	205	202	200	199	199	199	198	198	196	194	191	187	182	176	169	80.6	61.7	46.4	34.7	25.5	17.8	11.4	6.89
54	207	207	205	202	200	199	199	199	198	198	196	194	191	187	182	176	169	160	87.5	61.2	42.9	29.9	20.6	14.4	10.3
55	230	230	230	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
56	230	230	230	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
57	126	126	126	126	126	126	126	126	126	126	125	123	121	119	116	114	110	107	74.4	49.9	40.7	...	...	...	...
58	126	126	123	122	122	122	122	121	120	118	116	115	114	112	110	109	106	104	92.1	61.1	40.4	26.4	17.4	11.6	7.58
59	138	129	124	122	120	119	119	118	118	117	117	116	114	112	110	106	103	98.3	83.2	60.2	42.9	29.9	20.6	14.4	10.3
60	138	138	138	138	138	138	136	134	131	129	127	125	123	121	119	116	113	104	73.7	52.0	36.3	25.2	17.6	12.3	8.27
61	138	129	124	122	120	119	119	118	118	117	117	116	114	112	110	106	103	80.6	61.7	46.4	34.7	25.5	17.8	11.4	6.89
62	138	130	126	123	121	119	117	116	115	114	112	111	110	109	107	105	103	89.2	68.8	54.2	43.4	34.0	25.1	17.1	10.3
63	138	132	128	126	125	124	124	124	124	124	124	124	124	124	123	122	121	99.6	80.9	63.3	47.5	34.2	23.5	15.3	9.65
64	149	149	149	149	149	148	146	143	140	136	131	126	120	113	95.1	79.5	64.4	48.8	35.4	22.6	17.2	...	...	...	...
65	149	149	149	149	149	148	146	143	140	136	131	126	120	113	95.1	79.5	64.4	48.8	35.4	22.6	17.2	...	...	...	...
66	149	149	149	149	149	149	148	146	144	142	140	138	136	133	131	127	124	109	68.0	42.3	30.5	23.2	16.5	...	...
67	149	149	146	144	144	144	144	144	144	143	141	139	138	136	134	132	129	126	92.1	61.1	40.4	26.4	17.4	11.6	7.58
68	161	161	161	161	161	160	158	155	151	147	142	136	130	113	95.1	79.5	64.4	48.8	35.4	22.6	17.2	...	...	...	...
69	161	161	161	161	161	160	158	155	151	147	142	136	130	122	101	83.8	66.8	49.2	35.4	22.6	17.2	...	...	...	...

Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

Line No.	Nominal Composition	Product Form	Spec. No.	Type/ Grade	UNS No.	Class/ Condition/ Temper	Size, mm	P-No. (5)	Notes	Min. Temp., °C (6)	Min. Tensile Str., MPa	Min. Yield Str., MPa	Max. Use Temp., °C
70	½Cr–½Mo	Plate	A387	2	K12143	2	...	3	...	−29	483	310	538
71	C–½Mo	Plate	A204	B	K12020	...	...	3	(58)	−29	483	276	593
72	Mn–½Mo	Plate	A302	A	K12021	...	...	3	...	−29	517	310	538
73	C–½Mo	Plate	A204	C	K12320	...	...	3	(58)	−29	517	296	593
74	1¼Cr–½Mo–Si	Plate	A387	11	K11789	2	...	4	...	−29	517	310	649
75	5Cr–½Mo	Plate	A387	5	K41545	2	...	5B	...	−29	517	310	649
76	3Cr–1Mo	Plate	A387	21	K31545	2	...	5A	...	−29	517	310	649
77	2¼Cr–1Mo	Plate	A387	22	K21590	2	...	5A	(72)	−29	517	310	649
78	Mn–½Mo	Plate	A302	B	K12022	...	...	3	...	−29	552	345	538
79	Mn–½Mo–½Ni	Plate	A302	C	K12039	...	...	3	...	−29	552	345	538
80	Mn–½Mo–¾Ni	Plate	A302	D	K12054	...	...	3	...	−29	552	345	538
81	9Cr–1Mo–V	Plate	A387	91	K90901	2	≤75	15E	...	−29	586	414	649
82	8Ni	Plate	A553	II	K71340	...	...	11A	(47)	−171	689	586	40
83	5Ni–¼Mo	Plate	A645	A	K41583	...	...	11A	...	−171	655	448	93
84	9Ni	Plate	A553	I	K81340	...	...	11A	(47)	−196	689	586	93
85	9Ni	Plate	A353	...	K81340	...	...	11A	(47)	−196	689	517	93
86	C–½Mo	Forg. & ftg.	A234	WP1	K12821	...	...	3	(58)	−29	379	207	593
87	1Cr–½Mo	Forg. & ftg.	A182	F12	K11562	1	...	4	(9)	−29	414	221	649
88	1Cr–½Mo	Forg. & ftg.	A234	WP12	K12062	1	...	4	...	−29	414	221	649
89	1¼Cr–½Mo–Si	Forg. & ftg.	A182	F11	K11597	1	...	4	(9)	−29	414	207	649
90	1¼Cr–½Mo–Si	Forg. & ftg.	A234	WP11	K11597	1	...	4	...	−29	414	207	649
91	2¼Cr–1Mo	Forg. & ftg.	A182	F22	K21590	1	...	5A	(9) (72) (75)	−29	414	207	649
92	2¼Cr–1Mo	Forg. & ftg.	A234	WP22	K21590	1	...	5A	(72)	−29	414	207	649
93	5Cr–½Mo	Forg. & ftg.	A234	WP5	K41545	...	...	5B	...	−29	414	207	649
94	9Cr–1Mo	Forg. & ftg.	A234	WP9	K90941	...	...	5B	...	−29	414	207	649
95	3½Ni	Forg. & ftg.	A420	WPL3	K31918	...	...	9B	...	−101	448	241	343
96	3½Ni	Forg. & ftg.	A350	LF3	K32025	...	...	9B	(9)	−101	483	259	343
97	½Cr–½Mo	Forg. & ftg.	A182	F2	K12122	...	...	3	(9)	−29	483	276	538
98	C–½Mo	Forg. & ftg.	A182	F1	K12822	...	...	3	(9) (58)	−29	483	276	593
99	1Cr–½Mo	Forg. & ftg.	A182	F12	K11564	2	...	4	(9)	−29	483	276	649
100	1Cr–½Mo	Forg. & ftg.	A234	WP12	K12062	2	...	4	...	−29	483	276	649

Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

Line No.	Basic Allowable Stress, S, MPa, at Metal Temperature, °C [Notes (1) and (4b)] Min. Temp. to 40	65	100	125	150	175	200	225	250	275	300	325	350	375	400	425	450	475	500	525	550	575	600	625	650
70	161	161	161	161	161	161	161	161	161	161	161	161	161	161	159	155	151	146	93.5	49.9	40.7	...	...	...	...
71	161	161	161	161	161	161	161	158	156	154	152	149	147	144	141	138	134	109	68.0	42.3	30.5	23.2	16.5	...	...
72	172	172	172	172	172	172	172	172	172	172	172	172	171	168	165	160	154	104	68.0	42.3	33.1	...	...	...	...
73	172	172	172	172	172	172	172	170	168	165	163	161	158	155	152	148	144	109	68.0	42.3	30.5	23.2	16.5	...	...
74	172	172	172	172	172	172	172	172	169	166	164	161	159	156	153	149	146	104	73.7	52.0	36.3	25.2	17.6	12.3	8.27
75	172	172	171	169	167	166	165	165	165	164	164	162	159	156	130	126	104	80.6	61.7	46.4	34.7	25.5	17.8	11.4	6.89
76	172	172	171	168	167	167	167	167	167	167	167	167	167	167	167	167	167	98.2	73.5	54.7	40.6	29.2	20.6	15.2	8.96
77	172	172	171	168	167	167	167	167	167	167	167	167	167	167	167	167	167	119	88.4	64.0	44.6	30.0	19.7	12.8	8.27
78	184	184	184	184	184	184	184	184	184	184	184	184	184	184	183	178	172	104	68.0	42.3	33.1	...	...	...	...
79	184	184	184	184	184	184	184	184	184	184	184	184	184	184	183	178	172	104	68.0	42.3	33.1	...	...	...	...
80	184	184	184	184	184	184	184	184	184	184	184	184	184	184	183	178	172	104	68.0	42.3	33.1	...	...	...	...
81	195	195	195	195	195	195	195	195	194	193	192	190	187	183	178	172	165	156	147	137	115	87.0	64.7	45.1	29.6
82	230	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
83	218	218	218	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
84	230	230	230	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
85	230	230	230	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
86	126	126	126	126	124	122	120	119	117	115	114	112	110	108	106	103	100	97.1	68.0	42.3	30.5	23.2	16.5	...	...
87	138	129	124	120	117	115	112	110	109	107	106	105	103	102	100	98.7	96.8	94.6	92.0	61.1	40.4	26.4	17.4	11.6	7.58
88	138	138	132	128	125	122	120	118	116	114	113	112	110	109	107	105	103	101	92.1	61.1	40.4	26.4	17.4	11.6	7.58
89	138	131	126	124	121	119	116	115	113	111	109	107	106	104	102	99.6	97.2	94.5	73.7	52.0	36.3	25.2	17.6	12.3	8.27
90	138	131	126	124	121	119	116	115	113	111	109	107	106	104	102	99.6	97.2	94.5	73.7	52.0	36.3	25.2	17.6	12.3	8.27
91	138	132	128	126	125	124	124	124	124	124	124	124	124	124	123	122	121	99.6	80.9	63.3	47.5	34.2	23.5	15.3	9.65
92	138	132	128	126	125	124	124	124	124	124	124	124	124	124	123	122	121	99.6	80.9	63.3	47.5	34.2	23.5	15.3	9.65
93	138	129	124	122	120	119	119	118	118	117	117	116	114	112	110	106	103	80.6	61.7	46.4	34.7	25.5	17.8	11.4	6.89
94	138	129	124	122	120	119	119	118	118	117	117	116	114	112	110	106	103	98.3	87.5	61.2	42.9	29.9	20.6	14.4	10.3
95	149	149	147	144	142	140	138	135	132	128	124	119	113	...	...	...	...	...	...	...	...	...	...	...	...
96	161	160	157	155	152	150	148	145	142	137	133	128	122	...	...	...	...	...	...	...	...	...	...	...	...
97	161	161	161	161	161	161	161	158	156	154	152	149	147	144	141	138	134	129	93.5	49.9	40.7	...	...	...	...
98	161	161	161	161	161	161	161	158	156	154	152	149	147	144	141	138	134	109	68.0	42.3	30.5	23.2	16.5	...	...
99	161	161	157	155	155	153	150	147	145	143	141	139	138	136	134	132	129	126	92.1	61.1	40.4	26.4	17.4	11.6	7.58
100	161	161	157	155	155	153	150	147	145	143	141	139	138	136	134	132	129	126	92.1	61.1	40.4	26.4	17.4	11.6	7.58

Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

Line No.	Nominal Composition	Product Form	Spec. No.	Type/ Grade	UNS No.	Class/ Condition/ Temper	Size, mm	P-No. (5)	Notes	Min. Temp., °C (6)	Min. Tensile Str., MPa	Min. Yield Str., MPa	Max. Use Temp., °C
101	$1\frac{1}{4}$Cr–$\frac{1}{2}$Mo–Si	Forg. & ftg.	A182	F11	K11572	2	...	4	(9)	−29	483	276	649
102	$1\frac{1}{4}$Cr–$\frac{1}{2}$Mo–Si	Forg. & ftg.	A234	WP11	K11572	2	...	4	...	−29	483	276	649
103	5Cr–$\frac{1}{2}$Mo	Forg. & ftg.	A182	F5	K41545	...	...	5B	(9)	−29	483	276	649
104	3Cr–1Mo	Forg. & ftg.	A182	F21	K31545	...	...	5A	(9)	−29	517	310	649
105	$2\frac{1}{4}$Cr–1Mo	Forg. & ftg.	A182	F22	K21590	3	...	5A	(9) (72)	−29	517	310	649
106	$2\frac{1}{4}$Cr–1Mo	Forg. & ftg.	A234	WP22	K21590	3	...	5A	(72)	−29	517	310	649
107	9Cr–1Mo	Forg. & ftg.	A182	F9	K90941	...	...	5B	(9)	−29	586	379	649
108	9Cr–1Mo–V	Forg. & ftg.	A182	F91	K90901	...	≤75	15E	...	−29	586	414	649
109	9Cr–1Mo–V	Forg. & ftg.	A234	WP91	K90901	...	≤75	15E	...	−29	586	414	649
110	5Cr–$\frac{1}{2}$Mo	Forg. & ftg.	A182	F5a	K42544	...	...	5B	(9)	−29	621	448	649
111	9Ni	Forg. & ftg.	A420	WPL8	K81340	...	...	11A	(47)	−196	689	517	93
112	C–$\frac{1}{2}$Mo	Castings	A352	LC1	J12522	...	...	3	(9) (58)	−59	448	241	371
113	C–$\frac{1}{2}$Mo	Castings	A217	WC1	J12524	...	...	3	(9) (58)	−29	448	241	593
114	$2\frac{1}{2}$Ni	Castings	A352	LC2	J22500	...	...	9A	(9)	−73	483	276	343
115	$3\frac{1}{2}$Ni	Castings	A352	LC3	J31550	...	...	9B	(9)	−101	483	276	343
116	1Ni–$\frac{1}{2}$Cr–$\frac{1}{2}$Mo	Castings	A217	WC4	J12082	...	...	4	(9)	−29	483	276	538
117	$\frac{3}{4}$Ni–1Mo–$\frac{3}{4}$Cr	Castings	A217	WC5	J22000	...	...	4	(9)	−29	483	276	593
118	$1\frac{1}{4}$Cr–$\frac{1}{2}$Mo	Castings	A217	WC6	J12072	...	...	4	(9)	−29	483	276	649
119	$2\frac{1}{4}$Cr–1Mo	Castings	A217	WC9	J21890	...	...	5A	(9)	−29	483	276	649
120	5Cr–$\frac{1}{2}$Mo	Castings	A217	C5	J42045	...	...	5B	(9)	−29	621	414	649
121	9Cr–1Mo	Castings	A217	C12	J82090	...	...	5B	(9)	−29	621	414	649

Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

	Basic Allowable Stress, *S*, MPa, at Metal Temperature, °C [Notes (1) and (4b)]																								
Line No.	Min. Temp. to 40	65	100	125	150	175	200	225	250	275	300	325	350	375	400	425	450	475	500	525	550	575	600	625	650
101	*161*	*161*	*161*	*161*	*161*	158	155	153	150	148	146	143	141	138	136	133	130	**104**	**73.7**	**52.0**	**36.3**	**25.2**	**17.6**	**12.3**	**8.27**
102	*161*	*161*	*161*	*161*	*161*	158	155	153	150	148	146	143	141	138	136	133	130	**104**	**73.7**	**52.0**	**36.3**	**25.2**	**17.6**	**12.3**	**8.27**
103	*161*	*161*	*160*	*157*	*156*	*155*	*155*	*155*	*154*	*154*	*153*	*151*	*149*	*146*	*142*	*137*	*131*	**80.6**	**61.7**	**46.4**	**34.7**	**25.5**	**17.8**	**11.4**	**6.89**
104	*172*	*172*	*172*	*169*	*168*	*167*	*166*	*166*	*165*	*165*	*164*	*164*	*162*	*161*	*158*	*155*	*152*	**98.2**	**73.5**	**54.7**	**40.6**	**29.2**	**20.6**	**15.2**	**8.96**
105	*172*	*172*	*171*	*168*	*167*	*167*	*167*	*167*	*167*	*167*	*167*	*167*	*167*	*167*	*167*	*167*	*167*	**119**	**88.4**	**64.0**	**44.6**	**30.0**	**19.7**	**12.8**	**8.27**
106	*172*	*172*	*171*	*168*	*167*	*167*	*167*	*167*	*167*	*167*	*167*	*167*	*167*	*167*	*167*	*167*	*167*	**119**	**88.4**	**64.0**	**44.6**	**30.0**	**19.7**	**12.8**	**8.27**
107	*195*	*195*	*194*	*191*	*189*	*188*	*188*	*188*	*187*	*187*	*186*	*184*	*181*	*177*	*172*	*166*	*159*	*151*	**83.2**	**60.2**	**42.9**	**29.9**	**20.6**	**14.4**	**10.3**
108	*195*	*195*	*195*	*195*	*195*	*195*	*195*	*195*	*194*	*193*	*192*	*190*	*187*	*183*	*178*	*172*	*165*	*156*	*147*	*137*	**115**	**87.0**	**64.7**	**45.1**	**29.6**
109	*195*	*195*	*195*	*195*	*195*	*195*	*195*	*195*	*194*	*193*	*192*	*190*	*187*	*183*	*178*	*172*	*165*	*156*	*147*	*137*	**115**	**87.0**	**64.7**	**45.1**	**29.6**
110	*207*	*207*	*205*	*202*	*200*	*199*	*199*	*199*	*198*	*198*	*196*	*194*	*191*	*187*	*182*	*176*	*169*	**80.6**	**61.7**	**46.4**	**34.7**	**25.5**	**17.8**	**11.4**	**6.89**
111	*230*	*230*	*230*	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
112	*149*	*149*	*149*	148	145	143	140	138	137	135	133	131	129	127	...	...	...	...	...	...	...	...	...	...	...
113	*149*	*149*	*149*	148	145	143	140	138	137	135	133	131	129	126	123	120	117	**109**	**68.0**	**42.3**	**30.5**	**23.2**	**16.5**	...	...
114	*161*	*161*	*161*	*161*	*161*	160	158	155	151	147	142	136	131	...	...	...	...	...	...	...	...	...	...	...	...
115	*161*	*161*	*161*	*161*	*161*	160	158	155	151	147	142	136	131	...	...	...	...	...	...	...	...	...	...	...	...
116	*161*	*161*	*161*	*161*	*161*	*161*	*161*	*161*	159	158	156	154	152	149	146	142	137	131	**74.4**	**49.9**	**40.7**	...	...	...	...
117	*161*	*161*	*161*	*161*	*161*	*161*	*161*	*161*	159	158	156	154	152	149	146	142	137	131	**74.4**	**49.9**	**34.3**	**23.2**	**16.5**	...	...
118	*161*	*161*	*161*	*161*	*161*	158	155	153	150	148	146	143	141	138	136	133	130	**104**	**73.7**	**52.0**	**36.3**	**25.2**	**17.6**	**12.3**	**8.27**
119	*161*	*161*	*160*	*157*	*156*	*156*	*156*	*156*	*156*	*156*	*156*	*156*	*156*	*156*	*156*	*156*	*156*	**119**	**88.4**	**64.0**	**44.6**	**30.0**	**19.7**	**12.8**	**8.27**
120	*207*	*207*	*205*	*202*	*200*	*199*	*199*	*199*	*198*	*198*	*196*	*194*	*191*	*187*	*182*	*176*	*169*	**80.6**	**61.7**	**46.4**	**34.7**	**25.5**	**17.8**	**11.4**	**6.89**
121	*207*	*207*	*205*	*202*	*200*	*199*	*199*	*199*	*198*	*198*	*196*	*194*	*191*	*187*	*182*	*176*	*169*	*160*	**83.2**	**60.2**	**42.9**	**29.9**	**20.6**	**14.4**	**10.3**

Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

Line No.	Nominal Composition	Product Form	Spec. No.	Type/ Grade	UNS No.	Class/ Condition/ Temper	Size, mm	P-No. (5)
1	18Cr–10Ni–Ti	Smls. pipe	A312	TP321	S32100	...	>10	8
2	18Cr–10Ni–Ti	Smls. pipe	A376	TP321	S32100	...	>10	8
3	18Cr–8Ni	Tube	A213	TP304L	S30403	...	...	8
4	18Cr–8Ni	Tube	A269	TP304L	S30403	...	...	8
5	18Cr–8Ni	Tube	A270	TP304L	S30403	...	...	8
6	18Cr–8Ni	Smls. & wld. pipe	A312	TP304L	S30403	...	...	8
7	18Cr–8Ni	Wld. pipe	A358	304L	S30403	...	...	8
8	16Cr–12Ni–2Mo	Tube	A213	TP316L	S31603	...	...	8
9	16Cr–12Ni–2Mo	Tube	A269	TP316L	S31603	...	...	8
10	16Cr–12Ni–2Mo	Tube	A270	TP316L	S31603	...	...	8
11	16Cr–12Ni–2Mo	Smls. & wld. pipe	A312	TP316L	S31603	...	...	8
12	16Cr–12Ni–2Mo	Wld. pipe	A358	316L	S31603	...	...	8
13	16Cr–12Ni–2Mo–Ti	Tube	A213	TP316Ti	S31635	...	...	8
14	18Cr–10Ni–Ti	Smls. pipe	A312	TP321	S32100	...	>10	8
15	18Cr–10Ni–Ti	Smls. pipe	A376	TP321	S32100	...	>10	8
16	18Cr–10Ni–Ti	Smls. pipe	A312	TP321H	S32109	...	>10	8
17	18Cr–10Ni–Ti	Smls. pipe	A376	TP321H	S32109	...	>10	8
18	25Cr–12Ni	Pipe & tube	A451	CPH8	J93400	...	...	8
19	25Cr–20Ni	Pipe & tube	A451	CPK20	J94202	...	...	8
20	11Cr–Ti	Tube	A268	TP409	S40900	...	...	7
21	18Cr–Ti	Tube	A268	TP430Ti	S43036	...	...	7
22	16Cr–14Ni–2Mo	Pipe & tube	A451	CPF10MC	J92971	...	...	8
23	12Cr–Al	Tube	A268	TP405	S40500	...	...	7
24	13Cr	Tube	A268	TP410	S41000	...	...	6
25	17Cr	Tube	A268	TP430	S43000	...	...	7
26	18Cr–13Ni–3Mo	Smls. & wld. pipe	A312	TP317L	S31703	...	...	8
27	25Cr–20Ni	Smls. & wld. pipe	A312	TP310S	S31008	...	...	8
28	25Cr–20Ni	Wld. pipe	A358	310S	S31008	...	...	8
29	25Cr–20Ni	Pipe	A409	TP310S	S31008	...	...	8
30	18Cr–10Ni–Ti	Smls. pipe	A312	TP321	S32100	...	≤10	8
31	18Cr–10Ni–Ti	Wld. pipe	A312	TP321	S32100	...	...	8
32	18Cr–10Ni–Ti	Wld. pipe	A358	321	S32100	...	...	8
33	18Cr–10Ni–Ti	Smls. pipe	A376	TP321	S32100	...	≤10	8
34	18Cr–10Ni–Ti	Wld. pipe	A409	TP321	S32100	...	...	8
35	23Cr–12Ni	Smls. & wld. pipe	A312	TP309	...	...	...	8

Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

Line No.	Notes	Min. Temp., °C (6)	Min. Tensile Strength, MPa	Min. Yield Strength, MPa	Max. Use Temp., °C	Basic Allowable Stress, S, MPa, at Metal Temperature, °C [Notes (1), (3), and (4b)] Min. Temp. to 40	65	100	125	150	175	200
1	(28)	−254	485	170	816	115	115	115	115	115	115	115
2	(28) (36)	−254	485	170	816	115	115	115	115	115	115	115
3	(14) (36)	−254	483	172	816	115	115	115	115	115	114	110
4	(14) (36)	−254	483	172	816	115	115	115	115	115	114	110
5	(14)	−254	483	172	816	115	115	115	115	115	114	110
6	...	−254	483	172	816	115	115	115	115	115	114	110
7	(36)	−254	483	172	816	115	115	115	115	115	114	110
8	(14) (36)	−254	483	172	816	115	115	115	115	115	113	109
9	(14) (36)	−254	483	172	816	115	115	115	115	115	113	109
10	(14)	−254	483	172	816	115	115	115	115	115	113	109
11	...	−254	483	172	816	115	115	115	115	115	113	109
12	(36)	−254	483	172	816	115	115	115	115	115	113	109
13	(30)	−254	517	207	816	138	138	138	138	138	138	134
14	(28) (30)	−254	485	170	816	115	115	115	115	115	115	115
15	(28) (30) (36)	−254	485	170	816	115	115	115	115	115	115	115
16	(30)	−198	485	170	816	115	115	115	115	115	115	115
17	(30) (36)	−198	485	170	816	115	115	115	115	115	115	115
18	(26) (28) (35)	−198	448	193	816	129	129	129	129	*127*	*125*	*124*
19	(12) (28) (35) (39)	−198	448	193	816	129	129	129	129	*127*	*125*	*124*
20	(35)	−29	414	207	40	138	...	...	...	...	...	...
21	(35) (49)	−29	414	276	40	138	...	...	...	...	...	...
22	(28)	−198	483	207	40	138	...	...	...	...	...	...
23	(35)	−29	414	207	538	138	138	138	*137*	*135*	*134*	*133*
24	(35)	−29	414	207	649	138	138	138	*137*	*135*	*134*	*133*
25	(35) (49)	−29	414	241	649	*138*	*138*	*138*	*137*	*135*	*134*	*133*
26	...	−198	517	207	454	138	138	138	138	138	136	131
27	(28) (35)	−198	517	207	816	138	138	138	138	138	138	138
28	(28) (35) (36)	−198	517	207	816	138	138	138	138	138	138	138
29	(28) (31) (35) (36)	−198	517	207	816	138	138	138	138	138	138	138
30	(28)	−254	515	205	816	138	138	138	138	138	138	138
31	(28)	−254	515	205	816	138	138	138	138	138	138	138
32	(28) (36)	−254	515	205	816	138	138	138	138	138	138	138
33	(28) (36)	−254	515	205	816	138	138	138	138	138	138	138
34	(28) (36)	−254	515	205	816	138	138	138	138	138	138	138
35	(28) (35) (39)	−198	517	207	816	138	138	138	138	138	138	138

Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

	Basic Allowable Stress, *S*, MPa, at Metal Temperature, °C [Notes (1), (3), and (4b)]												
Line No.	225	250	275	300	325	350	375	400	425	450	475	500	525
1	115	112	109	106	104	102	100	99.0	97.0	96.3	95.3	94.4	93.6
2	115	112	109	106	104	102	100	99.0	97.0	96.3	95.3	94.4	93.6
3	106	103	99.9	97.7	95.7	94.1	92.6	91.3	90.0	88.7	87.3	85.6	83.7
4	106	103	99.9	97.7	95.7	94.1	92.6	91.3	90.0	88.7	87.3	85.6	83.7
5	106	103	*99.9*	*97.7*	95.7	94.1	92.6	91.3	90.0	88.7	87.3	85.6	83.7
6	106	103	99.9	97.7	95.7	94.1	92.6	91.3	90.0	88.7	87.3	85.6	83.7
7	106	103	99.9	97.7	95.7	94.1	92.6	91.3	90.0	88.7	87.3	85.6	83.7
8	106	103	100	98.1	96.1	94.3	92.6	90.9	89.3	87.6	85.9	84.2	82.5
9	106	103	100	98.1	96.1	94.3	92.6	90.9	89.3	87.6	85.9	84.2	82.5
10	106	103	100	98.1	96.1	94.3	*92.6*	90.9	89.3	87.6	85.9	84.2	82.5
11	106	103	100	98.1	96.1	94.3	92.6	90.9	89.3	87.6	85.9	84.2	82.5
12	106	103	100	98.1	96.1	94.3	92.6	90.9	89.3	87.6	85.9	84.2	82.5
13	129	124	120	117	115	113	112	111	110	109	108	107	106
14	115	112	109	106	104	102	100	99.0	97.0	96.3	95.3	94.4	93.6
15	115	112	109	106	104	102	100	99.0	97.0	96.3	95.3	94.4	93.6
16	115	112	109	106	104	102	100	99.0	97.0	96.3	95.3	94.4	93.6
17	115	112	109	106	104	102	100	99.0	97.0	96.3	95.3	94.4	93.6
18	*124*	123	121	119	117	115	112	109	106	103	100	96.9	93.7
19	*124*	123	121	119	117	115	112	109	106	103	100	96.9	93.7
20	...	...	...	...	...	...	...	...	...	...	...	...	...
21	...	...	...	...	...	...	...	...	...	...	...	...	...
22	...	...	...	...	...	...	...	...	...	...	...	...	...
23	*132*	*131*	*130*	*129*	*127*	*124*	*121*	*118*	*114*	*109*	*103*	**70.1**	**38.8**
24	*132*	*131*	*130*	*129*	*127*	*124*	*121*	*118*	*114*	*109*	**92.5**	**68.4**	**51.1**
25	*132*	*131*	*130*	*129*	*127*	*124*	*121*	*118*	*114*	*109*	**88.7**	**69.8**	**52.6**
26	127	123	120	118	115	113	111	109	107	105	103	...	...
27	137	134	131	129	127	125	123	122	120	119	117	116	**84.9**
28	137	134	131	129	127	125	123	122	120	119	117	116	**84.9**
29	137	134	131	129	127	125	123	122	120	119	117	116	**84.9**
30	138	135	131	128	125	122	120	119	117	115	114	113	112
31	138	135	131	128	125	122	120	119	117	115	114	113	112
32	138	135	131	128	125	122	120	119	117	115	114	113	112
33	138	135	131	128	125	122	120	119	117	115	114	113	112
34	138	135	131	128	125	122	120	119	117	115	114	113	112
35	138	135	133	131	129	127	125	124	122	121	119	117	**108**

Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

	Basic Allowable Stress, *S*, MPa, at Metal Temperature, °C [Notes (1), (3), and (4b)]											
Line No.	550	575	600	625	650	675	700	725	750	775	800	825
1	88.7	59.2	44.0	32.9	24.5	18.3	12.5	8.49	6.19	4.28	2.75	1.74
2	88.7	59.2	44.0	32.9	24.5	18.3	12.5	8.49	6.19	4.28	2.75	1.74
3	81.4	40.4	33.2	26.7	21.9	18.2	15.0	12.4	8.87	7.20	6.58	6.21
4	81.4	40.4	33.2	26.7	21.9	18.2	15.0	12.4	8.87	7.20	6.58	6.21
5	81.4	40.4	33.2	26.7	21.9	18.2	15.0	12.4	8.87	7.20	6.58	6.21
6	81.4	40.4	33.2	26.7	21.9	18.2	15.0	12.4	8.87	7.20	6.58	6.21
7	81.4	40.4	33.2	26.7	21.9	18.2	15.0	12.4	8.87	7.20	6.58	6.21
8	80.8	79.3	77.9	58.0	43.6	33.0	25.3	18.8	14.0	10.4	7.99	6.89
9	80.8	79.3	77.9	58.0	43.6	33.0	25.3	18.8	14.0	10.4	7.99	6.89
10	80.8	79.3	77.9	58.0	43.6	33.0	25.3	18.8	14.0	10.4	7.99	6.89
11	80.8	79.3	77.9	58.0	43.6	33.0	25.3	18.8	14.0	10.4	7.99	6.89
12	80.8	73.0	67.9	58.0	43.6	33.0	25.3	18.8	14.0	10.4	7.99	6.89
13	106	101	80.3	65.5	50.4	38.6	29.6	23.0	17.7	13.4	10.4	8.05
14	92.7	76.5	58.7	46.0	36.8	28.7	23.0	18.4	14.5	11.5	9.02	6.83
15	92.7	76.5	58.7	46.0	36.8	28.7	23.0	18.4	14.5	11.5	9.02	6.83
16	92.7	76.5	58.7	46.0	36.8	28.7	23.0	18.4	14.5	11.5	9.02	6.83
17	92.7	76.5	58.7	46.0	36.8	28.7	23.0	18.4	14.5	11.5	9.02	6.83
18	68.1	53.5	42.1	33.2	25.9	20.3	16.5	13.2	10.1	7.35	5.89	5.52
19	73.2	64.4	56.5	49.0	41.0	33.5	25.4	18.3	12.8	9.01	6.59	5.52
20	...	...	...	...	...	...	...	...	...	...	...	...
21	...	...	...	...	...	...	...	...	...	...	...	...
22	...	...	...	...	...	...	...	...	...	...	...	...
23	27.6	...	...	...	...	...	...	...	...	...	...	...
24	37.4	26.3	17.8	11.4	6.89	...	...	...	...	...	...	...
25	38.1	27.6	20.6	15.9	12.4	...	...	...	...	...	...	...
26	...	...	...	...	...	...	...	...	...	...	...	...
27	59.0	43.5	31.9	23.6	16.9	10.7	6.10	3.90	2.99	2.36	1.73	1.38
28	59.0	43.5	31.9	23.6	16.9	10.7	6.10	3.90	2.99	2.36	1.73	1.38
29	59.0	43.5	31.9	23.6	16.9	10.7	6.10	3.90	2.99	2.36	1.73	1.38
30	88.7	59.2	44.0	32.9	24.5	18.3	12.5	8.49	6.19	4.28	2.75	1.74
31	88.7	59.2	44.0	32.9	24.5	18.3	12.5	8.49	6.19	4.28	2.75	1.74
32	88.7	59.2	44.0	32.9	24.5	18.3	12.5	8.49	6.19	4.28	2.75	1.74
33	88.7	59.2	44.0	32.9	24.5	18.3	12.5	8.49	6.19	4.28	2.75	1.74
34	88.7	59.2	44.0	32.9	24.5	18.3	12.5	8.49	6.19	4.28	2.75	1.74
35	83.7	64.0	48.5	36.3	27.3	21.0	15.9	12.5	9.87	7.65	5.97	5.17

Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

Line No.	Nominal Composition	Product Form	Spec. No.	Type/ Grade	UNS No.	Class/ Condition/ Temper	Size, mm	P-No. (5)
36	23Cr–12Ni	Wld. pipe	A358	309S	S30908	...	...	8
37	18Cr–8Ni	Pipe & tube	A451	CPF8	J92600	...	...	8
38	18Cr–10Ni–Cb	Smls. & wld. pipe	A312	TP347	S34700	...	...	8
39	18Cr–10Ni–Cb	Wld. pipe	A358	347	S34700	...	...	8
40	18Cr–10Ni–Cb	Pipe	A376	TP347	S34700	...	...	8
41	18Cr–10Ni–Cb	Pipe	A409	TP347	S34700	...	...	8
42	18Cr–10Ni–Cb	Smls. & wld. pipe	A312	TP348	S34800	...	...	8
43	18Cr–10Ni–Cb	Wld. pipe	A358	348	S34800	...	...	8
44	18Cr–10Ni–Cb	Pipe	A376	TP348	S34800	...	...	8
45	18Cr–10Ni–Cb	Pipe	A409	TP348	S34800	...	...	8
46	25Cr–12Ni	Pipe & tube	A451	CPH10	J93402	...	...	8
47	25Cr–12Ni	Pipe & tube	A451	CPH20	J93402	...	...	8
48	25Cr–20Ni	Smls. & wld. pipe	A312	TP310H	S31009	...	...	8
49	18Cr–10Ni–Cb	Pipe & tube	A451	CPF8C	J92710	...	...	8
50	18Cr–10Ni–Ti	Smls. pipe	A312	TP321	S32100	...	≤10	8
51	18Cr–10Ni–Ti	Wld. pipe	A312	TP321	S32100	...	...	8
52	18Cr–10Ni–Ti	Wld. pipe	A358	321	S32100	...	...	8
53	18Cr–10Ni–Ti	Smls. pipe	A376	TP321	S32100	...	≤10	8
54	18Cr–10Ni–Ti	Wld. pipe	A409	TP321	S32100	...	...	8
55	18Cr–10Ni–Ti	Smls. pipe	A312	TP321H	S32109	...	≤10	8
56	18Cr–10Ni–Ti	Wld. pipe	A312	TP321H	S32109	...	...	8
57	18Cr–10Ni–Ti	Wld. pipe	A358	321H	S32109	...	...	8
58	18Cr–10Ni–Ti	Smls. pipe	A376	TP321H	S32109	...	≤10	8
59	16Cr–12Ni–2Mo	Tube	A213	TP316	S31600	...	...	8
60	16Cr–12Ni–2Mo	Tube	A269	TP316	S31600	...	...	8
61	16Cr–12Ni–2Mo	Tube	A270	TP316	S31600	...	...	8
62	16Cr–12Ni–2Mo	Smls. & wld. pipe	A312	TP316	S31600	...	...	8
63	16Cr–12Ni–2Mo	Wld. pipe	A358	316	S31600	...	...	8
64	16Cr–12Ni–2Mo	Pipe	A376	TP316	S31600	...	...	8
65	16Cr–12Ni–2Mo	Pipe	A409	TP316	S31600	...	...	8
66	18Cr–13Ni–3Mo	Smls. & wld. pipe	A312	TP317	S31700	...	...	8
67	18Cr–13Ni–3Mo	Pipe	A409	TP317	S31700	...	...	8
68	16Cr–12Ni–2Mo	Pipe	A376	TP316H	S31609	...	...	8

Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

Line No.	Notes	Min. Temp., °C (6)	Min. Tensile Strength, MPa	Min. Yield Strength, MPa	Max. Use Temp., °C	Basic Allowable Stress, S, MPa, at Metal Temperature, °C [Notes (1), (3), and (4b)] Min. Temp. to 40	65	100	125	150	175	200
36	(28) (31) (35) (36)	−198	517	207	816	138	138	138	138	138	138	138
37	(26) (28)	−254	483	207	816	138	138	138	138	138	134	129
38	...	−254	517	207	816	138	138	138	138	138	138	138
39	(30) (36)	−254	517	207	816	138	138	138	138	138	138	138
40	(30) (36)	−254	517	207	816	138	138	138	138	138	138	138
41	(30) (36)	−254	517	207	816	138	138	138	138	138	138	138
42	...	−198	517	207	816	138	138	138	138	138	138	138
43	(30) (36)	−198	517	207	816	138	138	138	138	138	138	138
44	(30) (36)	−198	517	207	816	138	138	138	138	138	138	138
45	(30) (36)	−198	517	207	816	138	138	138	138	138	138	138
46	(12) (14) (28) (35) (39)	−198	483	207	816	138	138	138	138	*137*	*135*	*134*
47	(12) (14) (28) (35) (39)	−198	483	207	816	138	138	138	138	*137*	*135*	*134*
48	(29) (35) (39)	−198	517	207	816	138	138	138	138	138	138	138
49	(28)	−198	483	207	816	138	138	138	138	138	134	129
50	(28) (30)	−254	515	205	816	138	138	138	138	138	138	138
51	(28) (30)	−254	515	205	816	138	138	138	138	138	138	138
52	(28) (30) (36)	−254	515	205	816	138	138	138	138	138	138	138
53	(28) (30) (36)	−254	515	205	816	138	138	138	138	138	138	138
54	(28) (30) (36)	−254	515	205	816	138	138	138	138	138	138	138
55	(30)	−198	515	205	816	138	138	138	138	138	138	138
56	(30)	−198	515	205	816	138	138	138	138	138	138	138
57	(30) (36)	−198	515	205	816	138	138	138	138	138	138	138
58	(30) (36)	−198	515	205	816	138	138	138	138	138	138	138
59	(14) (26) (28) (31) (36)	−254	517	207	816	138	138	138	138	138	138	134
60	(14) (26) (28) (31) (36)	−254	517	207	816	138	138	138	138	138	138	134
61	(14) (26) (28)	−254	517	207	816	138	138	138	138	138	138	134
62	(26) (28)	−254	517	207	816	138	138	138	138	138	138	134
63	(26) (28) (31) (36)	−254	517	207	816	138	138	138	138	138	138	134
64	(26) (28) (31) (36)	−254	517	207	816	138	138	138	138	138	138	134
65	(26) (28) (31) (36)	−254	517	207	816	138	138	138	138	138	138	134
66	(26) (28)	−198	517	207	816	138	138	138	138	138	138	134
67	(26) (28) (31) (36)	−198	517	207	816	138	138	138	138	138	138	134
68	(26) (31) (36)	−198	517	207	816	138	138	138	138	138	138	134

Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

	Basic Allowable Stress, *S*, MPa, at Metal Temperature, °C [Notes (1), (3), and (4b)]												
Line No.	**225**	**250**	**275**	**300**	**325**	**350**	**375**	**400**	**425**	**450**	**475**	**500**	**525**
36	138	135	133	131	129	127	125	124	122	121	119	117	**108**
37	125	122	119	116	113	111	109	107	105	103	101	99.1	**94.4**
38	138	138	*137*	135	132	130	128	127	126	126	125	125	125
39	138	138	*137*	135	132	130	128	127	126	126	125	125	125
40	138	138	*137*	135	132	130	128	127	126	126	125	125	125
41	138	138	*137*	135	132	130	128	127	126	126	125	125	125
42	138	138	*137*	135	132	130	128	127	126	126	125	125	125
43	138	138	*137*	135	132	130	128	127	126	126	125	125	125
44	138	138	*137*	135	132	130	128	127	126	126	125	125	125
45	138	138	*137*	135	132	130	128	127	126	126	125	125	125
46	133	131	129	128	125	123	120	117	114	111	107	104	100
47	133	131	129	128	125	123	120	117	114	111	107	104	100
48	137	134	131	129	127	125	123	122	120	119	117	116	**108**
49	125	122	119	116	113	111	109	107	105	103	101	99.1	97.3
50	138	135	131	128	125	122	120	119	117	115	114	113	112
51	138	135	131	128	125	122	120	119	117	115	114	113	112
52	138	135	131	128	125	122	120	119	117	115	114	113	112
53	138	135	131	128	125	122	120	119	117	115	114	113	112
54	138	135	131	128	125	122	120	119	117	115	114	113	112
55	138	135	131	128	125	122	120	119	117	115	114	113	112
56	138	135	131	128	125	122	120	119	117	115	114	113	112
57	138	135	131	128	125	122	120	119	117	115	114	113	112
58	138	135	131	128	125	122	120	119	117	115	114	113	112
59	129	125	122	119	116	114	112	111	110	109	108	107	106
60	129	125	122	119	116	114	112	111	110	109	108	107	106
61	129	125	122	119	116	114	112	111	110	109	108	107	106
62	129	125	122	119	116	114	112	111	110	109	108	107	106
63	129	125	122	119	116	114	112	111	110	109	108	107	106
64	129	125	122	119	116	114	112	111	110	109	108	107	106
65	129	125	122	119	116	114	112	111	110	109	108	107	106
66	129	125	122	119	116	114	112	111	110	109	108	107	106
67	129	125	122	119	116	114	112	111	110	109	108	107	106
68	129	125	122	119	116	114	112	111	110	109	108	107	106

Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

	Basic Allowable Stress, *S*, MPa, at Metal Temperature, °C [Notes (1), (3), and (4b)]											
Line No.	550	575	600	625	650	675	700	725	750	775	800	825
36	83.7	64.0	48.5	36.3	27.3	21.0	15.9	12.5	9.87	7.65	5.97	5.17
37	75.3	60.4	49.0	40.1	32.8	27.2	23.4	19.6	16.8	14.7	12.8	11.7
38	97.6	75.9	57.2	40.2	30.3	23.2	16.2	11.4	8.97	7.08	5.89	5.52
39	97.6	75.9	57.2	40.2	30.3	23.2	16.2	11.4	8.97	7.08	5.89	5.52
40	97.6	75.9	57.2	40.2	30.3	23.2	16.2	11.4	8.97	7.08	5.89	5.52
41	97.6	75.9	57.2	40.2	30.3	23.2	16.2	11.4	8.97	7.08	5.89	5.52
42	97.6	75.9	57.2	40.2	30.3	23.2	16.2	11.4	8.97	7.08	5.89	5.52
43	97.6	75.9	57.2	40.2	30.3	23.2	16.2	11.4	8.97	7.08	5.89	5.52
44	97.6	75.9	57.2	40.2	30.3	23.2	16.2	11.4	8.97	7.08	5.89	5.52
45	97.6	75.9	57.2	40.2	30.3	23.2	16.2	11.4	8.97	7.08	5.89	5.52
46	68.1	53.5	42.1	33.2	25.9	20.3	16.5	13.2	10.1	7.35	5.89	5.52
47	68.1	53.5	42.1	33.2	25.9	20.3	16.5	13.2	10.1	7.35	5.89	5.52
48	83.7	64.0	48.5	36.3	27.3	21.0	15.9	12.5	9.87	7.65	5.97	5.17
49	95.5	75.9	57.2	40.2	30.3	23.2	16.2	11.4	8.97	7.08	5.89	5.52
50	100	76.5	58.7	46.0	36.8	28.7	23.0	18.4	14.5	11.5	9.02	6.83
51	100	76.5	58.7	46.0	36.8	28.7	23.0	18.4	14.5	11.5	9.02	6.83
52	100	76.5	58.7	46.0	36.8	28.7	23.0	18.4	14.5	11.5	9.02	6.83
53	100	76.5	58.7	46.0	36.8	28.7	23.0	18.4	14.5	11.5	9.02	6.83
54	100	76.5	58.7	46.0	36.8	28.7	23.0	18.4	14.5	11.5	9.02	6.83
55	100	76.5	58.7	46.0	36.8	28.7	23.0	18.4	14.5	11.5	9.02	6.83
56	100	76.5	58.7	46.0	36.8	28.7	23.0	18.4	14.5	11.5	9.02	6.83
57	100	76.5	58.7	46.0	36.8	28.7	23.0	18.4	14.5	11.5	9.02	6.83
58	100	76.5	58.7	46.0	36.8	28.7	23.0	18.4	14.5	11.5	9.02	6.83
59	105	97.8	80.8	65.0	50.4	38.6	29.6	23.0	17.4	13.3	10.4	8.96
60	105	97.8	80.8	65.0	50.4	38.6	29.6	23.0	17.4	13.3	10.4	8.96
61	105	97.8	80.8	65.0	50.4	38.6	29.6	23.0	17.4	13.3	10.4	8.96
62	105	97.8	80.8	65.0	50.4	38.6	29.6	23.0	17.4	13.3	10.4	8.96
63	105	97.8	80.8	65.0	50.4	38.6	29.6	23.0	17.4	13.3	10.4	8.96
64	105	97.8	80.8	65.0	50.4	38.6	29.6	23.0	17.4	13.3	10.4	8.96
65	105	97.8	80.8	65.0	50.4	38.6	29.6	23.0	17.4	13.3	10.4	8.96
66	105	97.8	80.8	65.0	50.4	38.6	29.6	23.0	17.4	13.3	10.4	8.96
67	105	97.8	80.8	65.0	50.4	38.6	29.6	23.0	17.4	13.3	10.4	8.96
68	105	97.8	80.8	65.0	50.4	38.6	29.6	23.0	17.4	13.3	10.4	8.96

Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

Line No.	Nominal Composition	Product Form	Spec. No.	Type/ Grade	UNS No.	Class/ Condition/ Temper	Size, mm	P-No. (5)
69	16Cr–12Ni–2Mo	Smls. & wld. pipe	A312	TP316H	S31609	...	...	8
70	18Cr–10Ni–Cb	Pipe	A376	TP347H	S34709	...	...	8
71	18Cr–10Ni–Cb	Smls. & wld. pipe	A312	TP347	S34700	...	...	8
72	18Cr–10Ni–Cb	Wld. pipe	A358	347	S34700	...	...	8
73	18Cr–10Ni–Cb	Pipe	A376	TP347	S34700	...	...	8
74	18Cr–10Ni–Cb	Pipe	A409	TP347	S34700	...	...	8
75	18Cr–10Ni–Cb	Smls. & wld. pipe	A312	TP348	S34800	...	...	8
76	18Cr–10Ni–Cb	Wld. pipe	A358	348	S34800	...	...	8
77	18Cr–10Ni–Cb	Pipe	A376	TP348	S34800	...	...	8
78	18Cr–10Ni–Cb	Pipe	A409	TP348	S34800	...	...	8
79	18Cr–10Ni–Cb	Smls. & wld. pipe	A312	TP347H	S34709	...	...	8
80	18Cr–10Ni–Cb	Smls. & wld. pipe	A312	TP348H	S34809	...	...	8
81	18Cr–8Ni	Tube	A213	TP304	S30400	...	...	8
82	18Cr–8Ni	Tube	A269	TP304	S30400	...	...	8
83	18Cr–8Ni	Tube	A270	TP304	S30400	...	...	8
84	18Cr–8Ni	Smls. & wld. pipe	A312	TP304	S30400	...	...	8
85	18Cr–8Ni	Wld. pipe	A358	304	S30400	...	...	8
86	18Cr–8Ni	Pipe	A376	TP304	S30400	...	...	8
87	18Cr–8Ni	Pipe	A376	TP304H	S30409	...	...	8
88	18Cr–8Ni	Pipe	A409	TP304	S30400	...	...	8
89	18Cr–8Ni	Smls. & wld. pipe	A312	TP304H	S30409	...	...	8
90	18Cr–12Ni–2Mo	Pipe & tube	A451	CPF8M	J92900	...	...	8
91	44Fe–25Ni–21Cr–Mo	Wld. tube	A249	...	N08904	...	...	45
92	44Fe–25Ni–21Cr–Mo	Smls. & wld. pipe	A312	...	N08904	...	...	45
93	20Cr–Cu	Tube	A268	TP443	S44300	...	...	a
94	27Cr	Tube	A268	TP446-1	S44600	...	...	10I
95	12Cr	Wld. pipe	A1053	50	S41003	...	...	7
96	25Cr–8Ni–N	Pipe & tube	A451	CPE20N	J92802	...	...	8
97	23Cr–4Ni–Mo–Cu–N	Smls. & wld. tube	A789	...	S32304	...	...	10H
98	23Cr–4Ni–Mo–Cu–N	Smls. & wld. pipe	A790	...	S32304	...	...	10H
99	23Cr–4Ni–Mo–Cu–N	Pipe & tube	A928	2304	S32304	...	...	10H
100	20Cr–18Ni–6Mo	Pipe & tube	A813	...	S31254	...	...	8
101	20Cr–18Ni–6Mo	Pipe & tube	A814	...	S31254	...	...	8

Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

						Basic Allowable Stress, *S*, MPa, at Metal Temperature, °C [Notes (1), (3), and (4b)]						
Line No.	Notes	Min. Temp., °C (6)	Min. Tensile Strength, MPa	Min. Yield Strength, MPa	Max. Use Temp., °C	Min. Temp. to 40	65	100	125	150	175	200
69	(26)	−198	517	207	816	138	138	138	138	138	138	134
70	(30) (36)	−198	517	207	816	138	138	138	138	138	138	138
71	(28)	−254	517	207	816	138	138	138	138	138	138	138
72	(28) (30) (36)	−254	517	207	816	138	138	138	138	138	138	138
73	(28) (30) (36)	−254	517	207	816	138	138	138	138	138	138	138
74	(28) (30) (36)	−254	517	207	816	138	138	138	138	138	138	138
75	(28)	−198	517	207	816	138	138	138	138	138	138	138
76	(28) (30) (36)	−198	517	207	816	138	138	138	138	138	138	138
77	(28) (30) (36)	−198	517	207	816	138	138	138	138	138	138	138
78	(28) (30) (36)	−198	517	207	816	138	138	138	138	138	138	138
79	...	−198	517	207	816	138	138	138	138	138	138	138
80	...	−198	517	207	816	138	138	138	138	138	138	138
81	(14) (26) (28) (31) (36)	−254	517	207	816	138	138	138	138	138	134	129
82	(14) (26) (28) (31) (36)	−254	517	207	816	138	138	138	138	138	134	129
83	(14) (26) (28)	−254	517	207	816	138	138	138	138	138	134	129
84	(26) (28)	−254	517	207	816	138	138	138	138	138	134	129
85	(26) (28) (31) (36)	−254	517	207	816	138	138	138	138	138	134	129
86	(20) (26) (28) (31) (36)	−254	517	207	816	138	138	138	138	138	134	129
87	(26) (31) (36)	−198	517	207	816	138	138	138	138	138	134	129
88	(26) (28) (31) (36)	−254	517	207	816	138	138	138	138	138	134	129
89	(26)	−198	517	207	816	138	138	138	138	138	134	129
90	(26) (28)	−254	483	207	816	138	138	138	138	130	124	118
91	(26)	−198	490	220	260	143	143	143	143	141	135	130
92	(26)	−198	490	220	260	143	143	143	143	141	135	130
93	(7) (35)	−29	483	276	538	*161*	*161*	*161*	*161*	*161*	*161*	*161*
94	(35)	−29	483	276	538	*161*	*161*	*161*	*158*	*155*	*153*	*152*
95	...	−29	485	350	316	162	162	162	162	162	161	159
96	(35) (39)	−198	552	276	482	184	184	184	184	184	184	184
97	(25)	−51	600	400	316	*200*	*200*	*191*	*185*	*180*	*175*	*171*
98	(25)	−51	600	400	316	*200*	*200*	*191*	*185*	*180*	*175*	*171*
99	(25)	−51	600	400	316	*200*	*200*	*191*	*185*	*180*	*175*	*171*
100	...	−198	650	300	454	202	202	202	202	199	192	185
101	...	−198	650	300	454	202	202	202	202	199	192	185

Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

	Basic Allowable Stress, *S*, MPa, at Metal Temperature, °C [Notes (1), (3), and (4b)]												
Line No.	**225**	**250**	**275**	**300**	**325**	**350**	**375**	**400**	**425**	**450**	**475**	**500**	**525**
69	129	125	122	119	116	114	112	111	110	109	108	107	106
70	138	138	*137*	135	132	130	129	127	126	126	125	125	125
71	138	138	*137*	135	132	130	129	127	126	126	125	125	125
72	138	138	*137*	135	132	130	128	127	126	126	125	125	125
73	138	138	*137*	135	132	130	128	127	126	126	125	125	125
74	138	138	*137*	135	132	130	128	127	126	126	125	125	125
75	138	138	*137*	135	132	130	128	127	126	126	125	125	125
76	138	138	*137*	135	132	130	128	127	126	126	125	125	125
77	138	138	*137*	135	132	130	128	127	126	126	125	125	125
78	138	138	*137*	135	132	130	128	127	126	126	125	125	125
79	138	138	*137*	135	132	130	129	127	126	126	125	125	125
80	138	138	*137*	135	132	130	129	127	126	126	125	125	125
81	125	122	119	116	113	111	109	107	105	103	101	99.1	97.3
82	125	122	119	116	113	111	109	107	105	103	101	99.1	97.3
83	125	122	119	116	113	111	109	107	105	103	101	99.1	97.3
84	125	122	119	116	113	111	109	107	105	103	101	99.1	97.3
85	125	122	119	116	113	111	109	107	105	103	101	99.1	97.3
86	125	122	119	116	113	111	109	107	105	103	101	99.1	97.3
87	125	122	119	116	113	111	109	107	105	103	101	99.1	97.3
88	125	122	119	116	113	111	109	107	105	103	101	99.1	97.3
89	125	122	119	116	113	111	109	107	105	103	101	99.1	97.3
90	114	110	107	104	102	101	99.3	98.1	97.0	95.9	94.7	93.3	91.5
91	125	120	116	...	...	...	...	...	...	...	...	...	...
92	125	120	116	...	...	...	...	...	...	...	...	...	...
93	*161*	*161*	*161*	*161*	*161*	**97.0**	**84.3**	**73.3**	**64.0**	**55.8**	**43.9**	**31.7**	**21.4**
94	*150*	*149*	*147*	*145*	*144*	*141*	*139*	*136*	*132*	*128*	*122*	*116*	*109*
95	156	154	152	149	146	...	...	...	...	...	...	...	...
96	184	184	184	184	184	184	184	184	184	184	184	184	...
97	*166*	*161*	*153*	*143*	111	...	...	...	...	...	...	...	...
98	*166*	*161*	*153*	*143*	111	...	...	...	...	...	...	...	...
99	*166*	*161*	*153*	*143*	*111*	...	...	...	...	...	...	...	...
100	180	175	171	168	165	164	162	161	160	159	158	...	...
101	180	175	171	168	165	164	162	161	160	159	158	...	...

Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

	Basic Allowable Stress, *S*, MPa, at Metal Temperature, °C [Notes (1), (3), and (4b)]											
Line No.	550	575	600	625	650	675	700	725	750	775	800	825
69	105	**97.8**	**80.8**	**65.0**	**50.4**	**38.6**	**29.6**	**23.0**	**17.4**	**13.3**	**10.4**	**8.96**
70	125	**112**	**90.6**	**69.6**	**53.8**	**41.4**	**31.8**	**24.0**	**18.8**	**14.6**	**10.9**	**8.96**
71	125	**112**	**90.6**	**69.6**	**53.8**	**41.4**	**31.8**	**24.0**	**18.8**	**14.6**	**10.9**	**8.96**
72	125	**112**	**90.6**	**69.6**	**53.8**	**41.4**	**31.8**	**24.0**	**18.8**	**14.6**	**10.9**	**8.96**
73	125	**112**	**90.6**	**69.6**	**53.8**	**41.4**	**31.8**	**24.0**	**18.8**	**14.6**	**10.9**	**8.96**
74	125	**112**	**90.6**	**69.6**	**53.8**	**41.4**	**31.8**	**24.0**	**18.8**	**14.6**	**10.9**	**8.96**
75	125	**112**	**90.6**	**69.6**	**53.8**	**41.4**	**31.8**	**24.0**	**18.8**	**14.6**	**10.9**	**8.96**
76	125	**112**	**90.6**	**69.6**	**53.8**	**41.4**	**31.8**	**24.0**	**18.8**	**14.6**	**10.9**	**8.96**
77	125	**112**	**90.6**	**69.6**	**53.8**	**41.4**	**31.8**	**24.0**	**18.8**	**14.6**	**10.9**	**8.96**
78	125	**112**	**90.6**	**69.6**	**53.8**	**41.4**	**31.8**	**24.0**	**18.8**	**14.6**	**10.9**	**8.96**
79	125	**112**	**90.6**	**69.6**	**53.8**	**41.4**	**31.8**	**24.0**	**18.8**	**14.6**	**10.9**	**8.96**
80	125	**112**	**90.6**	**69.6**	**53.8**	**41.4**	**31.8**	**24.0**	**18.8**	**14.6**	**10.9**	**8.96**
81	95.5	**78.9**	**63.8**	**51.6**	**41.6**	**32.9**	**26.5**	**21.3**	**17.2**	**14.1**	**11.2**	**9.65**
82	95.5	**78.9**	**63.8**	**51.6**	**41.6**	**32.9**	**26.5**	**21.3**	**17.2**	**14.1**	**11.2**	**9.65**
83	95.5	**78.9**	**63.8**	**51.6**	**41.6**	**32.9**	**26.5**	**21.3**	**17.2**	**14.1**	**11.2**	**9.65**
84	95.5	**78.9**	**63.8**	**51.6**	**41.6**	**32.9**	**26.5**	**21.3**	**17.2**	**14.1**	**11.2**	**9.65**
85	95.5	**78.9**	**63.8**	**51.6**	**41.6**	**32.9**	**26.5**	**21.3**	**17.2**	**14.1**	**11.2**	**9.65**
86	95.5	**78.9**	**63.8**	**51.6**	**41.6**	**32.9**	**26.5**	**21.3**	**17.2**	**14.1**	**11.2**	**9.65**
87	95.5	**78.9**	**63.8**	**51.6**	**41.6**	**32.9**	**26.5**	**21.3**	**17.2**	**14.1**	**11.2**	**9.65**
88	95.5	**78.9**	**63.8**	**51.6**	**41.6**	**32.9**	**26.5**	**21.3**	**17.2**	**14.1**	**11.2**	**9.65**
89	95.5	**78.9**	**63.8**	**51.6**	**41.6**	**32.9**	**26.5**	**21.3**	**17.2**	**14.1**	**11.2**	**9.65**
90	89.1	**72.7**	**57.7**	**46.0**	**36.9**	**30.1**	**24.3**	**20.3**	**17.0**	**14.3**	**12.1**	**11.0**
91	...	...	...	...	...	...	...	...	...	...	...	...
92	...	...	...	...	...	...	...	...	...	...	...	...
93	**17.2**	...	...	...	...	...	...	...	...	...	...	...
94	*104*	...	...	...	...	...	...	...	...	...	...	...
95	...	...	...	...	...	...	...	...	...	...	...	...
96	...	...	...	...	...	...	...	...	...	...	...	...
97	...	...	...	...	...	...	...	...	...	...	...	...
98	...	...	...	...	...	...	...	...	...	...	...	...
99	...	...	...	...	...	...	...	...	...	...	...	...
100	...	...	...	...	...	...	...	...	...	...	...	...
101	...	...	...	...	...	...	...	...	...	...	...	...

Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

Line No.	Nominal Composition	Product Form	Spec. No.	Type/ Grade	UNS No.	Class/ Condition/ Temper	Size, mm	P-No. (5)
102	13Cr	Pipe & tube	A426	CPCA15	J91150	...	...	6
103	20Cr–18Ni–6Mo	Wld. pipe	A358	...	S31254	...	>5.0	8
104	20Cr–18Ni–6Mo	Wld. pipe	A358	...	S31254	...	≤5.0	8
105	22Cr–5Ni–3Mo–N	Smls. & wld. tube	A789	...	S31803	...	...	10H
106	22Cr–5Ni–3Mo–N	Smls. & wld. pipe	A790	...	S31803	...	...	10H
107	22Cr–5Ni–3Mo–N	Pipe & tube	A928	...	S31803	...	...	10H
108	20Cr–18Ni–6Mo	Pipe & tube	A249	...	S31254	...	>5.00	8
109	20Cr–18Ni–6Mo	Pipe & tube	A249	...	S31254	...	≤5.00	8
110	20Cr–18Ni–6Mo	Pipe & tube	A312	...	S31254	...	>5.00	8
111	20Cr–18Ni–6Mo	Pipe & tube	A312	...	S31254	...	≤5.00	8
112	26Cr–4Ni–Mo	Smls. & wld. pipe	A790	...	S32900	...	...	10H
113	46Fe–24Ni–21Cr–6Mo–Cu–N	Smls. & wld. pipe	A312	...	N08367	...	>5.0	45
114	46Fe–24Ni–21Cr–6Mo–Cu–N	Wld. pipe	A358	...	N08367	...	>5.0	45
115	46Fe–24Ni–21Cr–6Mo–Cu–N	Wld. pipe	A813	...	N08367	...	>5.0	45
116	46Fe–24Ni–21Cr–6Mo–Cu–N	Wld. pipe	A814	...	N08367	...	>5.0	45
117	46Fe–24Ni–21Cr–6Mo–Cu–N	Smls. & wld. pipe	A312	...	N08367	...	≤5.0	45
118	46Fe–24Ni–21Cr–6Mo–Cu–N	Wld. pipe	A358	...	N08367	...	≤5.0	45
119	46Fe–24Ni–21Cr–6Mo–Cu–N	Wld. pipe	A813	...	N08367	...	≤5.0	45
120	46Fe–24Ni–21Cr–6Mo–Cu–N	Wld. pipe	A814	...	N08367	...	≤5.0	45
121	21Cr–5Mn–1½Ni–Cu–N	Smls. & wld. tube	A789	...	S32101	...	>5.0	10H
122	21Cr–5Mn–1½Ni–Cu–N	Smls. & wld. pipe	A790	...	S32101	...	>5.0	10H
123	24Cr–4Ni–3Mn–1.5Mo–N	Smls. & wld. tube	A789	...	S82441	...	≥10.0	10H
124	24Cr–4Ni–3Mn–1.5Mo–N	Smls. & wld. pipe	A790	...	S82441	...	≥10.0	10H
125	21Cr–5Mn–1½Ni–Cu–N	Smls. & wld. tube	A789	...	S32101	...	≤5.0	10H
126	21Cr–5Mn–1½Ni–Cu–N	Smls. & wld. pipe	A790	...	S32101	...	≤5.0	10H
127	21Cr–3½Ni–1¾Mo–N	Smls. & wld. tube	A789	...	S32003	...	>5.00	10H
128	21Cr–3½Ni–1¾Mo–N	Smls. & wld. pipe	A790	...	S32003	...	>5.00	10H
129	21Cr–3½Ni–1¾Mo–N	Pipe & tube	A928	...	S32003	...	>5.00	10H
130	22Cr–5Ni–3Mo–N	Pipe & tube	A928	2205	S32205	...	...	10H
131	21Cr–3½Ni–1¾Mo–N	Smls. & wld. tube	A789	...	S32003	...	≤5.00	10H
132	21Cr–3½Ni–1¾Mo–N	Smls. & wld. pipe	A790	...	S32003	...	≤5.00	10H
133	21Cr–3½Ni–1¾Mo–N	Pipe & tube	A928	...	S32003	...	≤5.00	10H

Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

Line No.	Notes	Min. Temp., °C (6)	Min. Tensile Strength, MPa	Min. Yield Strength, MPa	Max. Use Temp., °C	Basic Allowable Stress, S, MPa, at Metal Temperature, °C [Notes (1), (3), and (4b)] Min. Temp. to 40	65	100	125	150	175	200
102	(10) (35)	−29	621	448	40	*207*	...	...	...	...	...	...
103	...	−198	655	310	475	207	207	207	207	203	196	189
104	...	−198	690	310	475	207	207	207	207	203	196	189
105	(25)	−51	621	448	316	*207*	*207*	*207*	*204*	*199*	*196*	*193*
106	(25)	−51	621	448	316	*207*	*207*	*207*	*204*	*199*	*196*	*193*
107	(25)	−51	621	448	316	*207*	*207*	*207*	*204*	*199*	*196*	*193*
108	...	−198	655	310	454	207	207	207	207	203	196	190
109	...	−198	675	310	454	207	207	207	207	203	196	190
110	...	−198	655	310	454	207	207	207	207	203	196	190
111	...	−198	675	310	454	207	207	207	207	203	196	190
112	(25)	−29	621	483	40	*207*	...	...	...	...	...	...
113	(26)	−198	655	310	427	207	207	207	207	206	202	198
114	(26)	−198	655	310	427	207	207	207	207	206	202	198
115	(26)	−198	655	310	427	207	207	207	207	206	202	198
116	(26)	−198	655	310	427	207	207	207	207	206	202	198
117	(26)	−198	690	310	427	207	207	207	207	207	207	205
118	(26)	−198	690	310	427	207	207	207	207	207	207	205
119	(26)	−198	690	310	427	207	207	207	207	207	207	205
120	(26)	−198	690	310	427	207	207	207	207	207	207	205
121	(25)	−29	650	450	316	*217*	*217*	*215*	*211*	*206*	*203*	*199*
122	(25)	−29	650	450	316	*217*	*217*	*215*	*211*	*206*	*203*	*199*
123	(25)	−51	680	480	316	*227*	*227*	*227*	*227*	*227*	*227*	*227*
124	(25)	−51	680	480	316	*227*	*227*	*227*	*227*	*227*	*227*	*227*
125	(25)	−29	700	530	316	*233*	*233*	*231*	*227*	*222*	*219*	*215*
126	(25)	−29	700	530	316	*233*	*233*	*231*	*227*	*222*	*219*	*215*
127	(25)	−51	655	450	343	*218*	*218*	*210*	*203*	*199*	*197*	*197*
128	(25)	−51	655	450	343	*218*	*218*	*210*	*203*	*199*	*197*	*197*
129	(25)	−51	655	450	343	*218*	*218*	*210*	*203*	*199*	*197*	*197*
130	(25)	−51	655	450	343	*218*	*218*	*218*	*215*	*210*	*206*	*203*
131	(25)	−51	690	485	343	*230*	*230*	*221*	*214*	*209*	*207*	*207*
132	(25)	−51	690	485	343	*230*	*230*	*221*	*214*	*209*	*207*	*207*
133	(25)	−51	690	485	343	*230*	*230*	*221*	*214*	*209*	*207*	*207*

Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

	Basic Allowable Stress, *S*, MPa, at Metal Temperature, °C [Notes (1), (3), and (4b)]												
Line No.	225	250	275	300	325	350	375	400	425	450	475	500	525
102	...	...	...	...	...	...	...	...	...	...	...	...	...
103	184	179	175	172	169	167	165	165	164	163	161	...	...
104	184	179	175	172	169	167	165	165	164	163	161	...	...
105	*190*	*188*	*187*	*186*	*185*	...	...	...	...	...	...	...	...
106	*190*	*188*	*187*	*186*	*185*	...	...	...	...	...	...	...	...
107	*190*	*188*	*187*	*186*	*185*	...	...	...	...	...	...	...	...
108	184	179	175	172	169	167	166	165	164	163	161	...	...
109	184	179	175	172	169	167	166	165	164	163	161	...	...
110	184	179	175	172	169	167	166	165	164	163	161	...	...
111	184	179	175	172	169	167	166	165	164	163	161	...	...
112	...	...	...	...	...	...	...	...	...	...	...	...	...
113	195	192	188	184	179	176	173	170	167	166	...	...	...
114	195	192	188	184	179	176	173	170	167	166	...	...	...
115	195	192	188	184	179	176	173	170	167	166	...	...	...
116	195	192	188	184	179	176	173	170	167	166	...	...	...
117	199	194	188	184	179	176	173	170	167	166	...	...	...
118	199	194	188	184	179	176	173	170	167	166	...	...	...
119	199	194	188	184	179	176	173	170	167	166	...	...	...
120	199	194	188	184	179	176	173	170	167	166	...	...	...
121	*199*	*199*	*199*	*199*	*199*	...	...	...	...	...	...	...	...
122	*199*	*199*	*199*	*199*	*199*	...	...	...	...	...	...	...	...
123	*227*	*227*	*227*	*227*	*227*	...	...	...	...	...	...	...	...
124	*227*	*227*	*227*	*227*	*227*	...	...	...	...	...	...	...	...
125	*214*	*214*	*214*	*214*	*214*	...	...	...	...	...	...	...	...
126	*214*	*214*	*214*	*214*	*214*	...	...	...	...	...	...	...	...
127	*197*	*197*	*197*	*197*	*197*	*197*	...	...	...	...	...	...	...
128	*197*	*197*	*197*	*197*	*197*	*197*	...	...	...	...	...	...	...
129	*197*	*197*	*197*	*197*	*197*	*197*	...	...	...	...	...	...	...
130	*201*	*199*	*197*	*196*	*196*	*195*	...	...	...	...	...	...	...
131	*207*	*207*	*207*	*207*	*207*	*207*	...	...	...	...	...	...	...
132	*207*	*207*	*207*	*207*	*207*	*207*	...	...	...	...	...	...	...
133	*207*	*207*	*207*	*207*	*207*	*207*	...	...	...	...	...	...	...

Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

	Basic Allowable Stress, *S*, MPa, at Metal Temperature, °C [Notes (1), (3), and (4b)]											
Line No.	550	575	600	625	650	675	700	725	750	775	800	825
102	...	...	...	...	...	...	...	...	...	...	...	...
103	...	...	...	...	...	...	...	...	...	...	...	...
104	...	...	...	...	...	...	...	...	...	...	...	...
105	...	...	...	...	...	...	...	...	...	...	...	...
106	...	...	...	...	...	...	...	...	...	...	...	...
107	...	...	...	...	...	...	...	...	...	...	...	...
108	...	...	...	...	...	...	...	...	...	...	...	...
109	...	...	...	...	...	...	...	...	...	...	...	...
110	...	...	...	...	...	...	...	...	...	...	...	...
111	...	...	...	...	...	...	...	...	...	...	...	...
112	...	...	...	...	...	...	...	...	...	...	...	...
113	...	...	...	...	...	...	...	...	...	...	...	...
114	...	...	...	...	...	...	...	...	...	...	...	...
115	...	...	...	...	...	...	...	...	...	...	...	...
116	...	...	...	...	...	...	...	...	...	...	...	...
117	...	...	...	...	...	...	...	...	...	...	...	...
118	...	...	...	...	...	...	...	...	...	...	...	...
119	...	...	...	...	...	...	...	...	...	...	...	...
120	...	...	...	...	...	...	...	...	...	...	...	...
121	...	...	...	...	...	...	...	...	...	...	...	...
122	...	...	...	...	...	...	...	...	...	...	...	...
123	...	...	...	...	...	...	...	...	...	...	...	...
124	...	...	...	...	...	...	...	...	...	...	...	...
125	...	...	...	...	...	...	...	...	...	...	...	...
126	...	...	...	...	...	...	...	...	...	...	...	...
127	...	...	...	...	...	...	...	...	...	...	...	...
128	...	...	...	...	...	...	...	...	...	...	...	...
129	...	...	...	...	...	...	...	...	...	...	...	...
130	...	...	...	...	...	...	...	...	...	...	...	...
131	...	...	...	...	...	...	...	...	...	...	...	...
132	...	...	...	...	...	...	...	...	...	...	...	...
133	...	...	...	...	...	...	...	...	...	...	...	...

Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

Line No.	Nominal Composition	Product Form	Spec. No.	Type/ Grade	UNS No.	Class/ Condition/ Temper	Size, mm	P-No. (5)
134	24Cr–4Ni–3Mn–1.5Mo–N	Smls. & wld. tube	A789	...	S82441	...	<10.0	10H
135	24Cr–4Ni–3Mn–1.5Mo–N	Smls. & wld. pipe	A790	...	S82441	...	<10.0	10H
136	25Cr–8Ni–3Mo–W–Cu–N	Smls. & wld. tube	A789	...	S32760	...	...	10H
137	25Cr–8Ni–3Mo–W–Cu–N	Smls. & wld. pipe	A790	...	S32760	...	...	10H
138	29Cr–6.5Ni–2Mo–N	Smls. & wld. tube	A789	...	S32906	...	≥10	10H
139	29Cr–6.5Ni–2Mo–N	Smls. & wld. pipe	A790	...	S32906	...	≥10	10H
140	24Cr–17Ni–6Mn–4$\frac{1}{2}$Mo–N	Pipe & tube	A358	...	S34565	...	...	8
141	25Cr–7Ni–4Mo–N	Smls. & wld. tube	A789	...	S32750	...	...	10H
142	25Cr–7Ni–4Mo–N	Smls. & wld. pipe	A790	2507	S32750	...	...	10H
143	25Cr–7Ni–4Mo–N	Pipe & tube	A928	2507	S32750	...	...	10H
144	29Cr–6.5Ni–2Mo–N	Smls. & wld. tube	A789	...	S32906	...	<10	10H
145	29Cr–6.5Ni–2Mo–N	Smls. & wld. pipe	A790	...	S32906	...	<10	10H
146	18Cr–11Ni	Plate & sheet	A240	305	S30500	...	...	8
147	12Cr–Al	Plate & sheet	A240	405	S40500	...	...	7
148	18Cr–8Ni	Plate & sheet	A240	304L	S30403	...	...	8
149	16Cr–12Ni–2Mo	Plate & sheet	A240	316L	S31603	...	...	8
150	18Cr–8Ni	Plate & sheet	A240	302	S30200	...	...	8
151	12Cr–1Ni	Plate, sheet, strip	A1010	40	S41003	...	...	7
152	12Cr–1Ni	Plate, sheet, strip	A1010	50	S41003	...	...	7
153	13Cr	Plate & sheet	A240	410S	S41008	...	...	7
154	13Cr	Plate & sheet	A240	410	S41000	...	...	6
155	15Cr	Plate & sheet	A240	429	S42900	...	...	6
156	17Cr	Plate & sheet	A240	430	S43000	...	...	7
157	18Cr–13Ni–3Mo	Plate & sheet	A240	317L	S31703	...	...	8
158	25Cr–20Ni	Plate & sheet	A240	310S	S31008	...	...	8
159	18Cr–10Ni–Ti	Plate, sheet, strip	A240	321	S32100	...	...	8
160	23Cr–12Ni	Plate & sheet	A240	309S	S30908	...	...	8
161	18Cr–10Ni–Cb	Plate & sheet	A240	347	S34700	...	...	8
162	18Cr–10Ni–Cb	Plate & sheet	A240	348	S34800	...	...	8

Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

						Basic Allowable Stress, *S*, MPa, at Metal Temperature, °C [Notes (1), (3), and (4b)]						
Line No.	Notes	Min. Temp., °C (6)	Min. Tensile Strength, MPa	Min. Yield Strength, MPa	Max. Use Temp., °C	Min. Temp. to 40	65	100	125	150	175	200
134	(25)	−51	740	540	316	*247*	*247*	*247*	*247*	*247*	*247*	*247*
135	(25)	−51	740	540	316	*247*	*247*	*247*	*247*	*247*	*247*	*247*
136	(25)	−51	750	550	316	*250*	*250*	*248*	*243*	*238*	*236*	*234*
137	(25)	−51	750	550	316	*250*	*250*	*248*	*243*	*238*	*236*	*234*
138	(25)	−51	750	550	316	*251*	*251*	*249*	*243*	*238*	*235*	*231*
139	(25)	−51	750	550	316	*251*	*251*	*249*	*243*	*238*	*235*	*231*
140	(36)	−198	795	415	427	*264*	*264*	260	253	247	242	238
141	(25)	−51	800	550	316	*267*	*265*	*264*	*257*	*251*	*247*	*243*
142	(25)	−51	800	550	316	*267*	*265*	*264*	*257*	*251*	*247*	*243*
143	(25)	−51	800	552	316	*267*	*265*	*264*	*257*	*251*	*247*	*243*
144	(25)	−51	800	650	316	*267*	*267*	*265*	*259*	*253*	*250*	*246*
145	(25)	−51	800	650	316	*267*	*267*	*265*	*259*	*253*	*250*	*246*
146	(26) (36) (39)	−198	483	172	40	115	...	...	...	...	...	...
147	(35)	−29	414	172	538	115	109	105	103	102	101	100
148	(36)	−254	483	172	816	115	115	115	115	115	114	110
149	(36)	−254	483	172	816	115	115	115	115	115	113	109
150	(26) (36)	−198	517	207	538	138	138	138	138	138	134	129
151	...	−29	455	275	316	152	152	152	152	152	151	149
152	...	−29	485	350	316	162	162	162	162	162	161	159
153	(35) (50)	−29	414	207	649	*138*	130	126	124	122	121	120
154	(35)	−29	448	207	649	138	130	126	124	122	121	120
155	(35)	−29	448	207	649	138	130	126	124	122	121	120
156	(35)	−29	448	207	649	138	130	126	124	122	121	120
157	(36)	−198	517	207	454	138	138	138	138	138	136	131
158	(28) (31) (35) (36)	−198	517	207	816	138	138	138	138	138	138	138
159	(28) (31) (36)	−198	515	205	816	138	138	138	138	138	138	138
160	(28) (35) (36)	−198	517	207	816	138	138	138	138	138	138	138
161	(36)	−254	517	207	816	138	138	138	138	138	138	138
162	(36)	−198	517	207	816	138	138	138	138	138	138	138

Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

	Basic Allowable Stress, *S*, MPa, at Metal Temperature, °C [Notes (1), (3), and (4b)]												
Line No.	225	250	275	300	325	350	375	400	425	450	475	500	525
134	*247*	*247*	*247*	*247*	*247*	...	...	...	...	...	...	...	...
135	*247*	*247*	*247*	*247*	*247*	...	...	...	...	...	...	...	...
136	*233*	*233*	*233*	*233*	*233*	...	...	...	...	...	...	...	...
137	*233*	*233*	*233*	*233*	*233*	...	...	...	...	...	...	...	...
138	*230*	*228*	*228*	*228*	*228*	...	...	...	...	...	...	...	...
139	*230*	*228*	*228*	*228*	*228*	...	...	...	...	...	...	...	...
140	235	234	232	231	229	228	226	223	221	218	...	...	...
141	*241*	*238*	*237*	*237*	*236*	...	...	...	...	...	...	...	...
142	*241*	*238*	*237*	*237*	*236*	...	...	...	...	...	...	...	...
143	*241*	*238*	*237*	*237*	*236*	...	...	...	...	...	...	...	...
144	*245*	*243*	*243*	*242*	*242*	...	...	...	...	...	...	...	...
145	*245*	*243*	*243*	*242*	*242*	...	...	...	...	...	...	...	...
146	...	...	...	...	...	...	...	...	...	...	...	...	...
147	99.7	99.1	98.4	97.5	96.2	94.7	92.6	90.1	87.0	83.4	79.2	**70.1**	**38.8**
148	106	103	99.9	97.7	95.7	94.1	92.6	91.3	90.0	88.7	87.3	85.6	83.7
149	106	103	100	98.1	96.1	94.3	92.6	90.9	89.3	87.6	85.9	84.2	82.5
150	125	122	119	116	113	111	109	107	105	103	101	99.1	97.3
151	147	145	142	140	137	...	...	...	...	...	...	...	...
152	156	154	152	149	146	...	...	...	...	...	...	...	...
153	120	119	118	117	115	114	111	108	104	100	**92.5**	**68.4**	**51.1**
154	120	119	118	117	115	114	111	108	104	100	**92.5**	**68.4**	**51.1**
155	120	119	118	117	115	114	111	108	104	100	**88.7**	**69.8**	**52.6**
156	120	119	118	117	115	114	111	108	104	100	**88.7**	**69.8**	**52.6**
157	127	123	120	118	115	113	111	109	107	105	103	...	...
158	137	134	131	129	127	125	123	122	120	119	117	116	**84.9**
159	138	135	131	128	125	122	120	119	117	115	114	113	112
160	138	135	133	131	129	127	125	124	122	121	119	117	**108**
161	138	138	*137*	135	132	130	128	127	126	126	125	125	125
162	138	138	*137*	135	132	130	128	127	126	126	125	125	125

Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

	Basic Allowable Stress, *S*, MPa, at Metal Temperature, °C [Notes (1), (3), and (4b)]											
Line No.	550	575	600	625	650	675	700	725	750	775	800	825
134	...	...	...	...	...	...	...	...	...	...	...	...
135	...	...	...	...	...	...	...	...	...	...	...	...
136	...	...	...	...	...	...	...	...	...	...	...	...
137	...	...	...	...	...	...	...	...	...	...	...	...
138	...	...	...	...	...	...	...	...	...	...	...	...
139	...	...	...	...	...	...	...	...	...	...	...	...
140	...	...	...	...	...	...	...	...	...	...	...	...
141	...	...	...	...	...	...	...	...	...	...	...	...
142	...	...	...	...	...	...	...	...	...	...	...	...
143	...	...	...	...	...	...	...	...	...	...	...	...
144	...	...	...	...	...	...	...	...	...	...	...	...
145	...	...	...	...	...	...	...	...	...	...	...	...
146	...	...	...	...	...	...	...	...	...	...	...	...
147	**27.6**	...	...	...	...	...	...	...	...	...	...	...
148	81.4	**40.4**	**33.2**	**26.7**	**21.9**	**18.2**	**15.0**	**12.4**	**8.87**	**7.20**	**6.58**	**6.21**
149	80.8	**73.0**	**67.9**	**58.0**	**43.6**	**33.0**	**25.3**	**18.8**	**14.0**	**10.4**	**7.99**	**6.89**
150	96.4	...	...	...	...	...	...	...	...	...	...	...
151	...	...	...	...	...	...	...	...	...	...	...	...
152	...	...	...	...	...	...	...	...	...	...	...	...
153	**37.4**	**26.3**	**17.8**	**11.4**	**6.89**	...	...	...	...	...	...	...
154	**37.4**	**26.3**	**17.8**	**11.4**	**6.89**	...	...	...	...	...	...	...
155	**38.1**	**27.6**	**20.6**	**15.9**	**12.4**	...	...	...	...	...	...	...
156	**38.1**	**27.6**	**20.6**	**15.9**	**12.4**	...	...	...	...	...	...	...
157	...	...	...	...	...	...	...	...	...	...	...	...
158	**59.0**	**43.5**	**31.9**	**23.6**	**16.9**	**10.7**	**6.10**	**3.90**	**2.99**	**2.36**	**1.73**	**1.38**
159	**88.7**	**59.2**	**44.0**	**32.9**	**24.5**	**18.3**	**12.5**	**8.49**	**6.19**	**4.28**	**2.75**	**1.74**
160	**83.7**	**64.0**	**48.5**	**36.3**	**27.3**	**21.0**	**15.9**	**12.5**	**9.87**	**7.65**	**5.97**	**5.17**
161	**97.6**	**75.9**	**57.2**	**40.2**	**30.3**	**23.2**	**16.2**	**11.4**	**8.97**	**7.08**	**5.89**	**5.52**
162	**97.6**	**75.9**	**57.2**	**40.2**	**30.3**	**23.2**	**16.2**	**11.4**	**8.97**	**7.08**	**5.89**	**5.52**

Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

Line No.	Nominal Composition	Product Form	Spec. No.	Type/ Grade	UNS No.	Class/ Condition/ Temper	Size, mm	P-No. (5)
163	25Cr–20Ni	Plate & sheet	A240	310H	S31009	...	...	8
164	18Cr–10Ni–Ti	Plate, sheet, strip	A240	321	S32100	...	...	8
165	18Cr–10Ni–Ti	Plate, sheet, strip	A240	321H	S32109	...	...	8
166	16Cr–12Ni–2Mo	Plate & sheet	A240	316	S31600	...	...	8
167	18Cr–13Ni–3Mo	Plate & sheet	A240	317	S31700	...	...	8
168	18Cr–10Ni–Cb	Plate & sheet	A240	347	S34700	...	...	8
169	18Cr–10Ni–Cb	Plate & sheet	A240	348	S34800	...	...	8
170	18Cr–8Ni	Plate & sheet	A240	304	S30400	...	...	8
171	44Fe–25Ni–21Cr–Mo	Plate & sheet	A240	904L	N08904	...	...	45
172	23Cr–4Ni–Mo–Cu–N	Plate & sheet	A240	2304	S32304	...	...	10H
173	22Cr–5Ni–3Mo–N	Plate & sheet	A240	...	S31803	...	...	10H
174	16Cr–4Ni–6Mn	Plate & sheet	A240	201LN	S20153	...	...	8
175	20Cr–18Ni–6Mo	Plate	A240	...	S31254	...	>5.0	8
176	20Cr–18Ni–6Mo	Sheet	A240	...	S31254	...	≤5.0	8
177	46Fe–24Ni–21Cr–6Mo–Cu–N	Plate	A240	...	N08367	...	>5.0	45
178	46Fe–24Ni–21Cr–6Mo–Cu–N	Sheet & strip	A240	...	N08367	...	≤5.0	45
179	21Cr–5Mn–1.5Ni–Cu–N	Plate & sheet	A240	...	S32101	...	>5.0	10H
180	24Cr–4Ni–3Mn–1.5Mo–N	Plate & sheet	A240	...	S82441	...	≥10.0	10H
181	21Cr–5Mn–1.5Ni–Cu–N	Plate & sheet	A240	...	S32101	...	≤5.0	10H
182	21Cr–3$\frac{1}{2}$Ni–1$\frac{3}{4}$Mo–N	Plate & sheet	A240	...	S32003	...	>5.00	10H
183	21Cr–3$\frac{1}{2}$Ni–1$\frac{3}{4}$Mo–N	Plate & sheet	A240	...	S32003	...	≤5.00	10H
184	24Cr–4Ni–3Mn–1.5Mo–N	Plate & sheet	A240	...	S82441	...	<10.0	10H
185	29Cr–6.5Ni–2Mo–N	Plate & sheet	A240	...	S32906	...	≥10.0	10H
186	29Cr–6.5Ni–2Mo–N	Plate & sheet	A240	...	S32906	...	≤10.0	10H
187	25Cr–8Ni–3Mo–W–Cu–N	Plate & sheet	A240	...	S32760	...	...	10H
188	25Cr–7Ni–4Mo–N	Plate & sheet	A240	2507	S32750	...	...	10H
189	18Cr–13Ni–3Mo	Forgings & fittings	A182	F317L	S31703	...	≤125	8
190	18Cr–8Ni	Forgings & fittings	A182	F304L	S30403	...	...	8
191	18Cr–8Ni	Forgings & fittings	A403	WP304L	S30403	...	...	8
192	16Cr–12Ni–2Mo	Forgings & fittings	A182	F316L	S31603	...	...	8

Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

Line No.	Notes	Min. Temp., °C (6)	Min. Tensile Strength, MPa	Min. Yield Strength, MPa	Max. Use Temp., °C	Basic Allowable Stress, S, MPa, at Metal Temperature, °C [Notes (1), (3), and (4b)] Min. Temp. to 40	65	100	125	150	175	200
163	(29) (35) (39)	−198	517	207	816	138	138	138	138	138	138	138
164	(28) (30) (36)	−198	515	205	816	138	138	138	138	138	138	138
165	(30) (36)	−198	515	205	816	138	138	138	138	138	138	138
166	(26) (28) (36)	−254	517	207	816	138	138	138	138	138	138	134
167	(26) (28) (36)	−198	517	207	816	138	138	138	138	138	138	134
168	(28) (36)	−254	517	207	816	138	138	138	138	138	138	138
169	(28) (36)	−198	517	207	816	138	138	138	138	138	138	138
170	(26) (28) (36)	−254	517	207	816	138	138	138	138	138	134	129
171	(26)	−198	490	220	260	143	143	143	143	141	135	130
172	(25)	−51	600	400	316	*200*	*200*	*191*	*185*	*180*	*175*	*171*
173	(25)	−51	620	450	316	*207*	*207*	*207*	*204*	*199*	*196*	*193*
174	...	−198	655	310	454	207	*206*	*187*	*177*	*170*	*165*	*162*
175	...	−254	655	310	454	207	207	207	207	203	196	190
176	...	−254	690	310	454	207	207	207	207	203	196	190
177	(26)	−198	655	310	427	207	207	207	207	206	202	198
178	(26)	−198	690	310	427	207	207	207	207	207	207	205
179	(25)	−29	650	450	316	*217*	*217*	*217*	*211*	*206*	*203*	*199*
180	(25)	−51	680	480	316	*227*	*227*	*227*	*227*	*227*	*227*	*227*
181	(25)	−29	700	530	316	*233*	*233*	*231*	*227*	*222*	*219*	*215*
182	(25)	−51	655	450	343	218	218	210	203	199	197	197
183	(25)	−51	690	485	343	230	230	221	214	209	207	207
184	(25)	−51	740	540	316	*247*	*247*	*247*	*247*	*247*	*247*	*247*
185	(25)	−51	750	550	316	*251*	*251*	*249*	*243*	*238*	*235*	*231*
186	(25)	−51	800	650	316	*267*	*267*	*265*	*259*	*253*	*250*	*246*
187	(25)	−51	750	550	316	*250*	*250*	*248*	*243*	*238*	*236*	*234*
188	(25)	−51	800	550	316	*267*	*265*	*264*	*257*	*251*	*247*	*243*
189	(9) (21a)	−198	483	172	454	115	115	115	115	115	113	109
190	(9) (21a)	−254	483	172	816	115	115	115	115	115	114	110
191	(32) (37)	−254	483	172	816	115	115	115	115	115	114	110
192	(9) (21a)	−254	483	172	816	115	115	115	115	115	113	109

Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

Line No.	Basic Allowable Stress, *S*, MPa, at Metal Temperature, °C [Notes (1), (3), and (4b)]												
	225	250	275	300	325	350	375	400	425	450	475	500	525
163	137	134	131	129	127	125	123	122	120	119	117	116	**108**
164	138	135	131	128	125	122	120	119	117	115	114	113	112
165	138	135	131	128	125	122	120	119	117	115	114	113	112
166	129	125	122	119	116	114	112	111	110	109	108	107	106
167	129	125	122	119	116	114	112	111	110	109	108	107	106
168	138	138	*137*	135	132	130	128	127	126	126	125	125	125
169	138	138	*137*	135	132	130	128	127	126	126	125	125	125
170	125	122	119	116	113	111	109	107	105	103	101	99.1	97.3
171	125	120	116	...	...	...	...	...	...	...	...	...	...
172	*166*	*161*	*153*	*143*	*111*	...	...	...	...	...	...	...	...
173	*190*	*188*	*187*	*186*	*185*	...	...	...	...	...	...	...	...
174	*160*	*159*	*158*	*158*	*158*	*157*	*156*	*154*	*152*	*149*	*146*	...	...
175	184	179	175	172	169	167	166	165	164	163	161	...	...
176	184	179	175	172	169	167	166	165	164	163	161	...	...
177	195	192	188	184	179	176	173	170	167	166	...	...	...
178	199	194	188	184	179	176	173	170	167	166	...	...	...
179	*199*	*199*	*199*	*199*	*199*	...	...	...	...	...	...	...	...
180	*227*	*227*	*227*	*227*	*227*	...	...	...	...	...	...	...	...
181	*214*	*214*	*214*	*214*	*214*	...	...	...	...	...	...	...	...
182	197	197	197	197	197	197	...	...	...	...	...	...	...
183	207	207	207	207	207	207	...	...	...	...	...	...	...
184	*247*	*247*	*247*	*247*	*247*	...	...	...	...	...	...	...	...
185	*230*	*228*	*228*	*228*	*228*	...	...	...	...	...	...	...	...
186	*245*	*243*	*243*	*242*	*242*	...	...	...	...	...	...	...	...
187	*233*	*233*	*233*	*233*	*233*	...	...	...	...	...	...	...	...
188	*241*	*238*	*237*	*237*	*236*	...	...	...	...	...	...	...	...
189	106	103	100	98.1	96.1	94.3	92.6	90.9	89.3	87.6	85.9	...	...
190	106	103	99.9	97.7	95.7	94.1	92.6	91.3	90.0	88.7	87.3	85.6	83.7
191	106	103	99.9	97.7	95.7	94.1	92.6	91.3	90.0	88.7	87.3	85.6	83.7
192	106	103	100	98.1	96.1	94.3	92.6	90.9	89.3	87.6	85.9	84.2	82.5

Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

Line No.	Basic Allowable Stress, *S*, MPa, at Metal Temperature, °C [Notes (1), (3), and (4b)]											
	550	575	600	625	650	675	700	725	750	775	800	825
163	**83.7**	**64.0**	**48.5**	**36.3**	**27.3**	**21.0**	**15.9**	**12.5**	**9.87**	**7.65**	**5.97**	**5.17**
164	**100**	**76.5**	**58.7**	**46.0**	**36.8**	**28.7**	**23.0**	**18.4**	**14.5**	**11.5**	**9.02**	**6.83**
165	**100**	**76.5**	**58.7**	**46.0**	**36.8**	**28.7**	**23.0**	**18.4**	**14.5**	**11.5**	**9.02**	**6.83**
166	105	**97.8**	**80.8**	**65.0**	**50.4**	**38.6**	**29.6**	**23.0**	**17.4**	**13.3**	**10.4**	**8.96**
167	105	**97.8**	**80.8**	**65.0**	**50.4**	**38.6**	**29.6**	**23.0**	**17.4**	**13.3**	**10.4**	**8.96**
168	125	**112**	**90.6**	**69.6**	**53.8**	**41.4**	**31.8**	**24.0**	**18.8**	**14.6**	**10.9**	**8.96**
169	125	**112**	**90.6**	**69.6**	**53.8**	**41.4**	**31.8**	**24.0**	**18.8**	**14.6**	**10.9**	**8.96**
170	95.5	**78.9**	**63.8**	**51.6**	**41.6**	**32.9**	**26.5**	**21.3**	**17.2**	**14.1**	**11.2**	**9.65**
171	...	...	...	...	...	...	...	...	...	...	...	...
172	...	...	...	...	...	...	...	...	...	...	...	...
173	...	...	...	...	...	...	...	...	...	...	...	...
174	...	...	...	...	...	...	...	...	...	...	...	...
175	...	...	...	...	...	...	...	...	...	...	...	...
176	...	...	...	...	...	...	...	...	...	...	...	...
177	...	...	...	...	...	...	...	...	...	...	...	...
178	...	...	...	...	...	...	...	...	...	...	...	...
179	...	...	...	...	...	...	...	...	...	...	...	...
180	...	...	...	...	...	...	...	...	...	...	...	...
181	...	...	...	...	...	...	...	...	...	...	...	...
182	...	...	...	...	...	...	...	...	...	...	...	...
183	...	...	...	...	...	...	...	...	...	...	...	...
184	...	...	...	...	...	...	...	...	...	...	...	...
185	...	...	...	...	...	...	...	...	...	...	...	...
186	...	...	...	...	...	...	...	...	...	...	...	...
187	...	...	...	...	...	...	...	...	...	...	...	...
188	...	...	...	...	...	...	...	...	...	...	...	...
189	...	...	...	...	...	...	...	...	...	...	...	...
190	81.4	**40.4**	**33.2**	**26.7**	**21.9**	**18.2**	**15.0**	**12.4**	**8.87**	**7.20**	**6.58**	**6.21**
191	81.4	**40.4**	**33.2**	**26.7**	**21.9**	**18.2**	**15.0**	**12.4**	**8.87**	**7.20**	**6.58**	**6.21**
192	80.8	**73.0**	**67.9**	**58.0**	**43.6**	**33.0**	**25.3**	**18.8**	**14.0**	**10.4**	**7.99**	**6.89**

Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

Line No.	Nominal Composition	Product Form	Spec. No.	Type/ Grade	UNS No.	Class/ Condition/ Temper	Size, mm	P-No. (5)
193	16Cr–12Ni–2Mo	Forgings & fittings	A403	WP316L	S31603	...	...	8
194	18Cr–13Ni–3Mo	Forgings & fittings	A403	WP317L	S31703	...	...	8
195	25Cr–20Ni	Forgings & fittings	A182	F310	S31000	...	...	8
196	25Cr–20Ni	Forgings & fittings	A403	WP310S	S31008	...	...	8
197	18Cr–10Ni–Ti	Smls. fittings	A403	WP321	S32100	...	>10	8
198	18Cr–10Ni–Ti	Forgings	A182	F321	S32100	...	...	8
199	18Cr–10Ni–Ti	Smls. fittings	A403	WP321	S32100	...	≤10	8
200	18Cr–10Ni–Ti	Wld. fittings	A403	WP321	S32100	...	...	8
201	23Cr–12Ni	Forgings & fittings	A403	WP309	S30900	...	...	8
202	25Cr–20Ni	Forgings & fittings	A182	F310H	S31009	...	...	8
203	25Cr–20Ni	Forgings & fittings	A403	WP310H	S31009	...	...	8
204	18Cr–10Ni–Cb	Forgings & fittings	A182	F347	S34700	...	...	8
205	18Cr–10Ni–Cb	Forgings & fittings	A403	WP347	S34700	...	...	8
206	18Cr–10Ni–Cb	Forgings & fittings	A182	F348	S34800	...	...	8
207	18Cr–10Ni–Cb	Forgings & fittings	A403	WP348	S34800	...	...	8
208	18Cr–10Ni–Ti	Smls. fittings	A403	WP321	S32100	...	>10	8
209	18Cr–10Ni–Ti	Smls. fittings	A403	WP321H	S32109	...	>10	8
210	18Cr–10Ni–Ti	Forgings	A182	F321	S32100	...	...	8
211	18Cr–10Ni–Ti	Forgings	A182	F321H	S32109	...	...	8
212	18Cr–10Ni–Ti	Smls. fittings	A403	WP321	S32100	...	≤10	8
213	18Cr–10Ni–Ti	Smls. fittings	A403	WP321H	S32109	...	≤10	8
214	18Cr–10Ni–Ti	Wld. fittings	A403	WP321	S32100	...	...	8
215	18Cr–10Ni–Ti	Wld. fittings	A403	WP321H	S32109	...	...	8
216	16Cr–12Ni–2Mo	Forgings & fittings	A403	WP316H	S31609	...	...	8
217	16Cr–12Ni–2Mo	Forgings & fittings	A182	F316H	S31609	...	...	8
218	18Cr–10Ni–Cb	Forgings & fittings	A403	WP347H	S34709	...	...	8
219	18Cr–10Ni–Cb	Forgings & fittings	A182	F347	S34700	...	...	8
220	18Cr–10Ni–Cb	Forgings & fittings	A403	WP347	S34700	...	...	8
221	18Cr–10Ni–Cb	Forgings & fittings	A182	F348	S34800	...	...	8
222	18Cr–10Ni–Cb	Forgings & fittings	A403	WP348	S34800	...	...	8
223	18Cr–10Ni–Cb	Forgings & fittings	A182	F347H	S34709	...	...	8
224	18Cr–10Ni–Cb	Forgings & fittings	A182	F348H	S34809	...	...	8
225	16Cr–12Ni–2Mo	Forgings & fittings	A182	F316	S31600	...	...	8

Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

Line No.	Notes	Min. Temp., °C (6)	Min. Tensile Strength, MPa	Min. Yield Strength, MPa	Max. Use Temp., °C	Basic Allowable Stress, S, MPa, at Metal Temperature, °C [Notes (1), (3), and (4b)] Min. Temp. to 40	65	100	125	150	175	200
193	(32) (37)	−254	483	172	816	115	115	115	115	115	113	109
194	(32) (37)	−198	517	207	454	138	138	138	138	138	136	131
195	(9) (35) (39)	−198	517	207	816	138	138	138	138	138	138	138
196	(28) (32) (35) (37)	−198	517	207	816	138	138	138	138	138	138	138
197	(28)	−198	485	170	816	115	115	115	115	115	115	115
198	(9) (21) (28)	−198	515	205	816	138	138	138	138	138	138	138
199	(28)	−198	515	205	816	138	138	138	138	138	138	138
200	(28)	−198	515	205	816	138	138	138	138	138	138	138
201	(28) (32) (35) (37) (39)	−198	517	207	816	138	138	138	138	138	138	138
202	(9) (21) (29) (35) (39)	−198	517	207	816	138	138	138	138	138	138	138
203	(29) (32) (35) (37) (39)	−198	517	207	816	138	138	138	138	138	138	138
204	(9) (21)	−254	517	207	816	138	138	138	138	138	138	138
205	(32) (37)	−254	517	207	816	138	138	138	138	138	138	138
206	(9) (21)	−198	517	207	816	138	138	138	138	138	138	138
207	(32) (37)	−198	517	207	816	138	138	138	138	138	138	138
208	(28) (30)	−198	485	170	816	115	115	115	115	115	115	115
209	(30)	−198	485	170	816	115	115	115	115	115	115	115
210	(9) (21) (28) (30)	−198	515	205	816	138	138	138	138	138	138	138
211	(9) (21)	−198	515	205	816	138	138	138	138	138	138	138
212	(28) (30)	−198	515	205	816	138	138	138	138	138	138	138
213	(30)	−198	515	205	816	138	138	138	138	138	138	138
214	(28) (30)	−198	515	205	816	138	138	138	138	138	138	138
215	(30)	−198	515	205	816	138	138	138	138	138	138	138
216	(26) (32) (37)	−198	517	207	816	138	138	138	138	138	138	134
217	(9) (21) (26)	−198	517	207	816	138	138	138	138	138	138	134
218	(32) (37)	−198	517	207	816	138	138	138	138	138	138	138
219	(9) (21) (28)	−254	517	207	816	138	138	138	138	138	138	138
220	(28) (32) (37)	−254	517	207	816	138	138	138	138	138	138	138
221	(9) (21) (28)	−198	517	207	816	138	138	138	138	138	138	138
222	(28) (32) (37)	−198	517	207	816	138	138	138	138	138	138	138
223	(9) (21)	−198	517	207	816	138	138	138	138	138	138	138
224	(9) (21)	−198	517	207	816	138	138	138	138	138	138	138
225	(9) (21) (26) (28)	−198	517	207	816	138	138	138	138	138	138	134

Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

	Basic Allowable Stress, *S*, MPa, at Metal Temperature, °C [Notes (1), (3), and (4b)]												
Line No.	**225**	**250**	**275**	**300**	**325**	**350**	**375**	**400**	**425**	**450**	**475**	**500**	**525**
193	106	103	100	98.1	96.1	94.3	92.6	90.9	89.3	87.6	85.9	84.2	82.5
194	127	123	120	118	115	113	111	109	107	105	103	...	...
195	137	134	131	129	127	125	123	122	120	119	117	116	**84.9**
196	137	134	131	129	127	125	123	122	120	119	117	116	**84.9**
197	115	112	109	106	104	102	100	99.0	97.0	96.3	95.3	94.4	93.6
198	138	135	131	128	125	122	120	119	117	115	114	113	112
199	138	135	131	128	125	122	120	119	117	115	114	113	112
200	138	135	131	128	125	122	120	119	117	115	114	113	112
201	138	135	133	131	129	127	125	124	122	121	119	117	**108**
202	137	134	131	129	127	125	123	122	120	119	117	116	**108**
203	137	134	131	129	127	125	123	122	120	119	117	116	**108**
204	138	138	*137*	135	132	130	128	127	126	126	125	125	125
205	138	138	*137*	135	132	130	128	127	126	126	125	125	125
206	138	138	*137*	135	132	130	128	127	126	126	125	125	125
207	138	138	*137*	135	132	130	128	127	126	126	125	125	125
208	115	112	109	106	104	102	100	99.0	97.0	96.3	95.3	94.4	93.6
209	115	112	109	106	104	102	100	99.0	97.0	96.3	95.3	94.4	93.6
210	138	135	131	128	125	122	120	119	117	115	114	113	112
211	138	135	131	128	125	122	120	119	117	115	114	113	112
212	138	135	131	128	125	122	120	119	117	115	114	113	112
213	138	135	131	128	125	122	120	119	117	115	114	113	112
214	138	135	131	128	125	122	120	119	117	115	114	113	112
215	138	135	131	128	125	122	120	119	117	115	114	113	112
216	129	125	122	119	116	114	112	111	110	109	108	107	106
217	129	125	122	119	116	114	112	111	110	109	108	107	106
218	138	138	*137*	135	132	130	129	127	126	126	125	125	125
219	138	138	*137*	135	132	130	128	127	126	126	125	125	125
220	138	138	*137*	135	132	130	129	127	126	126	125	125	125
221	138	138	*137*	135	132	130	128	127	126	126	125	125	125
222	138	138	*137*	135	132	130	128	127	126	126	125	125	125
223	138	138	*137*	135	132	130	129	127	126	126	125	125	125
224	138	138	*137*	135	132	130	129	127	126	126	125	125	125
225	129	125	122	119	116	114	112	111	110	109	108	107	106

Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

Line No.	Basic Allowable Stress, *S*, MPa, at Metal Temperature, °C [Notes (1), (3), and (4b)]											
	550	575	600	625	650	675	700	725	750	775	800	825
193	80.8	73.0	67.9	58.0	43.6	33.0	25.3	18.8	14.0	10.4	7.99	6.89
194	...	...	...	...	...	...	...	...	...	...	...	...
195	59.0	43.5	31.9	23.6	16.9	10.7	6.10	3.90	2.99	2.36	1.73	1.38
196	59.0	43.5	31.9	23.6	16.9	10.7	6.10	3.90	2.99	2.36	1.73	1.38
197	88.7	59.2	44.0	32.9	24.5	18.3	12.5	8.49	6.19	4.28	2.75	1.74
198	88.7	59.2	44.0	32.9	24.5	18.3	12.5	8.49	6.19	4.28	2.75	1.74
199	88.7	59.2	44.0	32.9	24.5	18.3	12.5	8.49	6.19	4.28	2.75	1.74
200	88.7	59.2	44.0	32.9	24.5	18.3	12.5	8.49	6.19	4.28	2.75	1.74
201	83.7	64.0	48.5	36.3	27.3	21.0	15.9	12.5	9.87	7.65	5.97	5.17
202	83.7	64.0	48.5	36.3	27.3	21.0	15.9	12.5	9.87	7.65	5.97	5.17
203	83.7	64.0	48.5	36.3	27.3	21.0	15.9	12.5	9.87	7.65	5.97	5.17
204	97.6	75.9	57.2	40.2	30.3	23.2	16.2	11.4	8.97	7.08	5.89	5.52
205	97.6	75.9	57.2	40.2	30.3	23.2	16.2	11.4	8.97	7.08	5.89	5.52
206	97.6	75.9	57.2	40.2	30.3	23.2	16.2	11.4	8.97	7.08	5.89	5.52
207	97.6	75.9	57.2	40.2	30.3	23.2	16.2	11.4	8.97	7.08	5.89	5.52
208	92.7	76.5	58.7	46.0	36.8	28.7	23.0	18.4	14.5	11.5	9.02	6.83
209	92.7	76.5	58.7	46.0	36.8	28.7	23.0	18.4	14.5	11.5	9.02	6.83
210	100	76.5	58.7	46.0	36.8	28.7	23.0	18.4	14.5	11.5	9.02	6.83
211	100	76.5	58.7	46.0	36.8	28.7	23.0	18.4	14.5	11.5	9.02	6.83
212	100	76.5	58.7	46.0	36.8	28.7	23.0	18.4	14.5	11.5	9.02	6.83
213	100	76.5	58.7	46.0	36.8	28.7	23.0	18.4	14.5	11.5	9.02	6.83
214	100	76.5	58.7	46.0	36.8	28.7	23.0	18.4	14.5	11.5	9.02	6.83
215	100	76.5	58.7	46.0	36.8	28.7	23.0	18.4	14.5	11.5	9.02	6.83
216	105	97.8	80.8	65.0	50.4	38.6	29.6	23.0	17.4	13.3	10.4	8.96
217	105	97.8	80.8	65.0	50.4	38.6	29.6	23.0	17.4	13.3	10.4	8.96
218	125	112	90.6	69.6	53.8	41.4	31.8	24.0	18.8	14.6	10.9	8.96
219	125	112	90.6	69.6	53.8	41.4	31.8	24.0	18.8	14.6	10.9	8.96
220	125	112	90.6	69.6	53.8	41.4	31.8	24.0	18.8	14.6	10.9	8.96
221	125	112	90.6	69.6	53.8	41.4	31.8	24.0	18.8	14.6	10.9	8.96
222	125	112	90.6	69.6	53.8	41.4	31.8	24.0	18.8	14.6	10.9	8.96
223	125	112	90.6	69.6	53.8	41.4	31.8	24.0	18.8	14.6	10.9	8.96
224	125	112	90.6	69.6	53.8	41.4	31.8	24.0	18.8	14.6	10.9	8.96
225	105	97.8	80.8	65.0	50.4	38.6	29.6	23.0	17.4	13.3	10.4	8.96

Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

Line No.	Nominal Composition	Product Form	Spec. No.	Type/ Grade	UNS No.	Class/ Condition/ Temper	Size, mm	P-No. (5)
226	16Cr–12Ni–2Mo	Forgings & fittings	A403	WP316	S31600	...	...	8
227	18Cr–13Ni–3Mo	Forgings & fittings	A403	WP317	S31700	...	...	8
228	18Cr–8Ni	Forgings & fittings	A182	F304	S30400	...	...	8
229	18Cr–8Ni	Forgings & fittings	A403	WP304	S30400	...	...	8
230	18Cr–8Ni	Forgings & fittings	A403	WP304H	S30409	...	...	8
231	18Cr–8Ni	Forgings & fittings	A182	F304H	S30409	...	...	8
232	44Fe–25Ni–21Cr–Mo	Forgings	A182	F904L	N08904	...	...	45
233	13Cr	Forgings & fittings	A182	F6a	S41000	1	...	6
234	13Cr	Forgings & fittings	A182	F6a	S41000	2	...	6
235	20Cr–18Ni–6Mo	Forgings	A182	F44	S31254	...	...	8
236	20Cr–18Ni–6Mo	Fittings	A403	WPS31254	S31254	...	...	8
237	23Cr–4Ni–Mo–Cu–N	Forgings	A182	F68	S32304	...	...	10H
238	22Cr–5Ni–3Mo–N	Forgings	A182	F51	S31803	...	...	10H
239	22Cr–5Ni–3Mo–N	Fittings	A815	WPS31803	S31803	...	...	10H
240	46Fe–24Ni–21Cr–6Mo–Cu–N	Forgings	A182	F62	N08367	...	...	45
241	46Fe–24Ni–21Cr–6Mo–Cu–N	Fittings	A403	WP6XN	N08367	...	...	45
242	21Cr–5Mn–1½Ni–Cu–N	Fittings	A815	WPS32101	S32101	...	...	10H
243	25Cr–8Ni–3Mo–W–Cu–N	Forgings & fittings	A182	F55	S32760	...	...	10H
244	25Cr–8Ni–3Mo–W–Cu–N	Forgings & fittings	A815	WPS32760	S32760	...	...	10H
245	25Cr–7Ni–4Mo–N	Forgings & fittings	A182	F53	S32750	...	≤50	10H
246	25Cr–7Ni–4Mo–N	Forgings & fittings	A815	WPS32750	S32750	...	...	10H
247	18Cr–8Ni	Bar	A479	304	S30400	...	...	8
248	18Cr–8Ni	Bar	A479	304H	S30409	...	...	8
249	18Cr–8Ni	Bar	A479	304L	S30403	...	...	8
250	16Cr–12Ni–2Mo	Bar	A479	316	S31600	...	...	8
251	16Cr–12Ni–2Mo	Bar	A479	316H	S31609	...	...	8
252	16Cr–12Ni–2Mo	Bar	A479	316L	S31603	...	...	8
253	18Cr–10Ni–Ti	Bar	A479	321	S32100	...	...	8
254	18Cr–10Ni–Ti	Bar	A479	321	S32100	...	...	8
255	18Cr–10Ni–Ti	Bar	A479	321H	S32109	...	...	8
256	18Cr–10Ni–Cb	Bar	A479	347	S34700	...	...	8
257	18Cr–10Ni–Cb	Bar	A479	347	S34700	...	...	8

Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

Line No.	Notes	Min. Temp., °C (6)	Min. Tensile Strength, MPa	Min. Yield Strength, MPa	Max. Use Temp., °C	Basic Allowable Stress, S, MPa, at Metal Temperature, °C [Notes (1), (3), and (4b)] Min. Temp. to 40	65	100	125	150	175	200
226	(26) (28) (32) (37)	−254	517	207	816	138	138	138	138	138	138	134
227	(26) (28) (32)	−198	517	207	816	138	138	138	138	138	138	134
228	(9) (21) (26) (28)	−254	517	207	816	138	138	138	138	138	134	129
229	(26) (28) (32) (37)	−254	517	207	816	138	138	138	138	138	134	129
230	(26) (32) (37)	−198	517	207	816	138	138	138	138	138	134	129
231	(9) (21) (26)	−198	517	207	816	138	138	138	138	138	134	129
232	(26)	−198	490	220	260	143	143	143	143	141	135	130
233	(35)	−29	483	276	538	*161*	*161*	*161*	*160*	*158*	*156*	*155*
234	(35)	−29	586	379	649	*195*	*195*	*195*	*194*	*191*	*190*	*188*
235	...	−198	650	300	454	202	202	202	202	199	192	185
236	...	−198	650	300	454	202	202	202	202	199	192	185
237	(25)	−51	600	400	316	*200*	*200*	*191*	*185*	*180*	*175*	*171*
238	(25)	−51	620	450	316	*207*	*207*	*207*	*204*	*199*	*196*	*193*
239	(25)	−51	620	450	316	*207*	*207*	*207*	*204*	*199*	*196*	*193*
240	(26)	−198	655	310	427	207	207	207	207	206	202	198
241	(26)	−198	655	310	427	207	207	207	207	206	202	198
242	(25)	−29	650	450	316	*217*	*217*	*215*	*211*	*206*	*203*	*199*
243	(25)	−51	750	550	316	*250*	*250*	*248*	*243*	*238*	*236*	*234*
244	(25)	−51	750	550	316	*250*	*250*	*248*	*243*	*238*	*236*	*234*
245	(25)	−51	800	550	316	*267*	*265*	*264*	*257*	*251*	*247*	*243*
246	(25)	−51	800	550	316	*267*	*265*	*264*	*257*	*251*	*247*	*243*
247	(26) (28)	−254	517	207	816	138	138	138	138	138	134	129
248	(26)	−198	517	207	816	138	138	138	138	138	134	129
249	...	−254	483	172	816	115	115	115	115	115	114	110
250	(26) (28)	−198	517	207	816	138	138	138	138	138	138	134
251	(26)	−198	517	207	816	138	138	138	138	138	138	134
252	...	−254	483	172	816	115	115	115	115	115	113	109
253	(28)	−198	515	205	816	138	138	138	138	138	138	138
254	(28) (30)	−198	515	205	816	138	138	138	138	138	138	138
255	(30)	−198	515	205	816	138	138	138	138	138	138	138
256	...	−254	517	207	816	138	138	138	138	138	138	138
257	(28) (30)	−254	517	207	816	138	138	138	138	138	138	138

Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

Line No.	Basic Allowable Stress, *S*, MPa, at Metal Temperature, °C [Notes (1), (3), and (4b)]												
	225	250	275	300	325	350	375	400	425	450	475	500	525
226	129	125	122	119	116	114	112	111	110	109	108	107	106
227	129	125	122	119	116	114	112	111	110	109	108	107	106
228	125	122	119	116	113	111	109	107	105	103	101	99.1	97.3
229	125	122	119	116	113	111	109	107	105	103	101	99.1	97.3
230	125	122	119	116	113	111	109	107	105	103	101	99.1	97.3
231	125	122	119	116	113	111	109	107	105	103	101	99.1	97.3
232	125	120	116	...	...	...	...	...	...	...	...	...	...
233	*154*	*153*	*152*	*150*	*148*	*145*	*142*	*137*	*133*	**125**	**92.5**	**68.4**	**51.1**
234	*187*	*186*	*184*	*182*	*180*	*176*	*172*	*167*	*161*	**125**	**92.5**	**68.4**	**51.1**
235	180	175	171	168	165	164	162	161	160	159	158	...	...
236	180	175	171	168	165	164	162	161	160	159	158	...	...
237	*166*	*161*	*153*	*143*	*111*	...	...	...	...	...	...	...	...
238	*190*	*188*	*187*	*186*	*185*	...	...	...	...	...	...	...	...
239	*190*	*188*	*187*	*186*	*185*	...	...	...	...	...	...	...	...
240	195	192	188	184	179	176	173	170	167	166	...	...	...
241	195	192	188	184	179	176	173	170	167	166	...	...	...
242	*199*	*199*	*199*	*199*	*199*	...	...	...	...	...	...	...	...
243	*233*	*233*	*233*	*233*	*233*	...	...	...	...	...	...	...	...
244	*233*	*233*	*233*	*233*	*233*	...	...	...	...	...	...	...	...
245	*241*	*238*	*237*	*237*	*236*	...	...	...	...	...	...	...	...
246	*241*	*238*	*237*	*237*	*236*	...	...	...	...	...	...	...	...
247	125	122	119	116	113	111	109	107	105	103	101	99.1	97.3
248	125	122	119	116	113	111	109	107	105	103	101	99.1	97.3
249	106	103	99.9	97.7	95.7	94.1	92.6	91.3	90.0	88.7	87.3	85.6	83.7
250	129	125	122	119	116	114	112	111	110	109	108	107	106
251	129	125	122	119	116	114	112	111	110	109	108	107	106
252	106	103	100	98.1	96.1	94.3	92.6	90.9	89.3	87.6	85.9	84.2	82.5
253	138	135	131	128	125	122	120	119	117	115	114	113	112
254	138	135	131	128	125	122	120	119	117	115	114	113	112
255	138	135	131	128	125	122	120	119	117	115	114	113	112
256	138	138	*137*	135	132	130	128	127	126	126	125	125	125
257	138	138	*137*	135	132	130	128	127	126	126	125	125	125

Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

Line No.	Basic Allowable Stress, *S*, MPa, at Metal Temperature, °C [Notes (1), (3), and (4b)]											
	550	575	600	625	650	675	700	725	750	775	800	825
226	105	**97.8**	**80.8**	**65.0**	**50.4**	**38.6**	**29.6**	**23.0**	**17.4**	**13.3**	**10.4**	**8.96**
227	105	**97.8**	**80.8**	**65.0**	**50.4**	**38.6**	**29.6**	**23.0**	**17.4**	**13.3**	**10.4**	**8.96**
228	95.5	**78.9**	**63.8**	**51.6**	**41.6**	**32.9**	**26.5**	**21.3**	**17.2**	**14.1**	**11.2**	**9.65**
229	95.5	**78.9**	**63.8**	**51.6**	**41.6**	**32.9**	**26.5**	**21.3**	**17.2**	**14.1**	**11.2**	**9.65**
230	95.5	**78.9**	**63.8**	**51.6**	**41.6**	**32.9**	**26.5**	**21.3**	**17.2**	**14.1**	**11.2**	**9.65**
231	95.5	**78.9**	**63.8**	**51.6**	**41.6**	**32.9**	**26.5**	**21.3**	**17.2**	**14.1**	**11.2**	**9.65**
232	...	...	...	...	...	...	...	...	...	...	...	...
233	**44.1**	...	...	...	...	...	...	...	...	...	...	...
234	**37.4**	**26.3**	**17.8**	**11.4**	**6.89**	...	...	...	...	...	...	...
235	...	...	...	...	...	...	...	...	...	...	...	...
236	...	...	...	...	...	...	...	...	...	...	...	...
237	...	...	...	...	...	...	...	...	...	...	...	...
238	...	...	...	...	...	...	...	...	...	...	...	...
239	...	...	...	...	...	...	...	...	...	...	...	...
240	...	...	...	...	...	...	...	...	...	...	...	...
241	...	...	...	...	...	...	...	...	...	...	...	...
242	...	...	...	...	...	...	...	...	...	...	...	...
243	...	...	...	...	...	...	...	...	...	...	...	...
244	...	...	...	...	...	...	...	...	...	...	...	...
245	...	...	...	...	...	...	...	...	...	...	...	...
246	...	...	...	...	...	...	...	...	...	...	...	...
247	95.5	**78.9**	**63.8**	**51.6**	**41.6**	**32.9**	**26.5**	**21.3**	**17.2**	**14.1**	**11.2**	**9.65**
248	95.5	**78.9**	**63.8**	**51.6**	**41.6**	**32.9**	**26.5**	**21.3**	**17.2**	**14.1**	**11.2**	**9.65**
249	81.4	**40.4**	**33.2**	**26.7**	**21.9**	**18.2**	**15.0**	**12.4**	**8.87**	**7.20**	**6.58**	**6.21**
250	105	**97.8**	**80.8**	**65.0**	**50.4**	**38.6**	**29.6**	**23.0**	**17.4**	**13.3**	**10.4**	**8.96**
251	105	**97.8**	**80.8**	**65.0**	**50.4**	**38.6**	**29.6**	**23.0**	**17.4**	**13.3**	**10.4**	**8.96**
252	80.8	**73.0**	**67.9**	**58.0**	**43.6**	**33.0**	**25.3**	**18.8**	**14.0**	**10.4**	**7.99**	**6.89**
253	**88.7**	**59.2**	**44.0**	**32.9**	**24.5**	**18.3**	**12.5**	**8.49**	**6.19**	**4.28**	**2.75**	**1.74**
254	**100**	**76.5**	**58.7**	**46.0**	**36.8**	**28.7**	**23.0**	**18.4**	**14.5**	**11.5**	**9.02**	**6.83**
255	**100**	**76.5**	**58.7**	**46.0**	**36.8**	**28.7**	**23.0**	**18.4**	**14.5**	**11.5**	**9.02**	**6.83**
256	**97.6**	**75.9**	**57.2**	**40.2**	**30.3**	**23.2**	**16.2**	**11.4**	**8.97**	**7.08**	**5.89**	**5.52**
257	125	**112**	**90.6**	**69.6**	**53.8**	**41.4**	**31.8**	**24.0**	**18.8**	**14.6**	**10.9**	**8.96**

Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

Line No.	Nominal Composition	Product Form	Spec. No.	Type/ Grade	UNS No.	Class/ Condition/ Temper	Size, mm	P-No. (5)
258	18Cr–10Ni–Cb	Bar	A479	347H	S34709	...	...	8
259	44Fe–25Ni–21Cr–Mo	Bar	A479	904L	N08904	...	...	45
260	22Cr–5Ni–3Mo–N	Bar	A479	...	S31803	...	...	10H
261	20Cr–18Ni–6Mo	Bar	A479	...	S31254	...	...	8
262	46Fe–24Ni–21Cr–6Mo–Cu–N	Bar	A479	...	N08367	...	...	45
263	21Cr–5Mn–1.5Ni–Cu–N	Bar	A479	...	S32101	...	...	10H
264	24Cr–4Ni–3Mn–1.5Mo–N	Bar	A479	...	S82441	...	≥11.0	10H
265	22Cr–13Ni–5Mn	Bar	A479	XM-19	S20910	Annealed	...	8
266	24Cr–4Ni–3Mn–1.5Mo–N	Bar	A479	...	S82441	...	<11.0	10H
267	29Cr–6.5Ni–2Mo–N	Bar	A479	...	S32906	...	...	10H
268	25Cr–7Ni–4Mo–N	Bar	A479	...	S32750	...	≤50	10H
269	29Ni–20Cr–3Cu–2Mo	Castings	A351	CN7M	N08007	...	...	45
270	35Ni–15Cr–½Mo	Castings	A351	HT30	N08603	...	...	45
271	25Cr–12Ni	Castings	A351	CH8	J93400	...	...	8
272	25Cr–20Ni	Castings	A351	CK20	J94202	...	...	8
273	16Cr–14Ni–2Mo	Castings	A351	CF10MC	...	...	...	8
274	18Cr–8Ni	Castings	A351	CF3	J92500	...	...	8
275	18Cr–12Ni–2Mo	Castings	A351	CF3M	J92800	...	...	8
276	18Cr–8Ni	Castings	A351	CF8	J92600	...	...	8
277	25Cr–12Ni	Castings	A351	CH10	J93401	...	...	8
278	25Cr–12Ni	Castings	A351	CH20	J93402	...	...	8
279	18Cr–10Ni–Cb	Castings	A351	CF8C	J92710	...	...	8
280	18Cr–12Ni–2Mo	Castings	A351	CF8M	J92900	...	...	8
281	25Cr–20Ni–½Mo	Castings	A351	HK40	J94204	...	...	8
282	25Cr–20Ni–½Mo	Castings	A351	HK30	J94203	...	...	8
283	18Cr–8Ni	Castings	A351	CF3A	J92500	...	...	8
284	18Cr–8Ni	Castings	A351	CF8A	J92600	...	...	8
285	25Cr–8Ni–N	Castings	A351	CE20N	J92802	...	...	8
286	12Cr	Castings	A217	CA15	J91150	...	...	6
287	24Cr–10Ni–4Mo–N	Castings	A995	2A	J93345	...	...	10H
288	25Cr–8Ni–3Mo–W–Cu–N	Castings	A995	6A	J93380	...	...	10H
289	13Cr–4Ni	Castings	A487	CA6NM	J91540	...	...	6

Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

Line No.	Notes	Min. Temp., °C (6)	Min. Tensile Strength, MPa	Min. Yield Strength, MPa	Max. Use Temp., °C	Basic Allowable Stress, S, MPa, at Metal Temperature, °C [Notes (1), (3), and (4b)] Min. Temp. to 40	65	100	125	150	175	200
258	...	−198	517	207	816	138	138	138	138	138	138	138
259	(26)	−198	490	220	260	143	143	143	143	141	135	130
260	(25)	−51	620	450	316	*207*	*207*	*207*	*204*	*199*	*196*	*193*
261	...	−198	655	310	454	207	207	207	207	203	196	190
262	(26)	−198	655	310	427	207	207	207	207	206	202	198
263	(25)	−29	650	450	316	*217*	*217*	*215*	*211*	*206*	*203*	*199*
264	(25)	−51	680	480	316	*227*	*227*	*227*	*227*	*227*	*227*	*227*
265	...	−198	690	380	649	230	*230*	*227*	*221*	*217*	*213*	*210*
266	(25)	−51	740	540	316	*247*	*247*	*247*	*247*	*247*	*247*	*247*
267	(25)	−51	750	550	316	*251*	*251*	*249*	*243*	*238*	*235*	*231*
268	(25)	−51	800	550	316	*267*	*265*	*264*	*257*	*251*	*247*	*243*
269	(9) (30)	−198	427	172	40	115	...	...	...	...	...	...
270	(36) (39)	−198	448	193	40	129	...	...	...	...	...	...
271	(9) (31)	−198	448	193	816	129	129	129	129	*127*	*125*	*124*
272	(9) (27) (31) (35) (39)	−198	448	193	816	129	129	129	129	*127*	*125*	*124*
273	(30)	−198	483	207	40	138	...	...	...	...	...	...
274	(9)	−254	483	207	427	138	138	138	138	138	134	129
275	(9)	−254	483	207	454	138	138	138	138	138	138	133
276	(9) (26) (27) (31)	−254	483	207	816	138	138	138	138	138	134	129
277	(27) (31) (35)	−198	483	207	816	138	*138*	*138*	*138*	*137*	*136*	*134*
278	(9) (27) (31) (35) (39)	−198	483	207	816	138	*138*	*138*	*138*	*137*	*136*	*134*
279	(9) (28)	−198	485	205	816	138	138	138	138	138	138	*135*
280	(9) (26) (27) (30)	−254	483	207	816	138	138	138	138	138	134	129
281	(35) (36) (39)	−198	427	241	40	142	...	...	...	...	...	...
282	(35) (39)	−198	448	241	40	149	...	...	...	...	...	...
283	(9) (56)	−254	531	241	371	161	161	161	*160*	*156*	*153*	151
284	(9) (26) (56)	−254	531	241	371	161	161	161	*160*	*156*	*153*	151
285	(35) (39)	−198	552	276	482	184	184	184	184	184	184	184
286	(35)	−29	621	448	649	*207*	*207*	*207*	*205*	*203*	*201*	*199*
287	(9)	−51	655	448	316	*218*	*218*	*216*	*208*	*201*	*197*	*195*
288	(9) (25)	−51	689	448	316	*230*	*230*	*227*	*221*	*216*	*212*	*209*
289	(9) (35)	−29	758	552	371	*253*	*253*	*253*	*251*	*248*	*245*	*244*

Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

	Basic Allowable Stress, *S*, MPa, at Metal Temperature, °C [Notes (1), (3), and (4b)]												
Line No.	**225**	**250**	**275**	**300**	**325**	**350**	**375**	**400**	**425**	**450**	**475**	**500**	**525**
258	138	138	*137*	135	132	130	128	127	126	126	125	125	125
259	125	120	116	…	…	…	…	…	…	…	…	…	…
260	*190*	*188*	*187*	*186*	*185*	…	…	…	…	…	…	…	…
261	184	179	175	172	169	167	166	165	164	163	161	…	…
262	195	192	188	184	179	176	173	170	167	166	…	…	…
263	*199*	*199*	*199*	*199*	*199*	…	…	…	…	…	…	…	…
264	*227*	*227*	*227*	*227*	*227*	…	…	…	…	…	…	…	…
265	*207*	*205*	*204*	*202*	*201*	*200*	*199*	*197*	*195*	*193*	*191*	*188*	*183*
266	*247*	*247*	*247*	*247*	*247*	…	…	…	…	…	…	…	…
267	*230*	*228*	*228*	*228*	*228*	…	…	…	…	…	…	…	…
268	*241*	*238*	*237*	*237*	*236*	…	…	…	…	…	…	…	…
269	…	…	…	…	…	…	…	…	…	…	…	…	…
270	…	…	…	…	…	…	…	…	…	…	…	…	…
271	*124*	123	121	119	117	115	112	109	106	103	100	96.9	93.7
272	*124*	123	121	119	117	115	112	109	106	103	100	96.9	93.7
273	…	…	…	…	…	…	…	…	…	…	…	…	…
274	125	122	119	116	113	111	109	107	105	103	…	…	…
275	129	125	122	119	116	114	112	111	109	108	107	…	…
276	125	122	119	116	113	111	109	107	105	103	101	99.1	**94.4**
277	*132*	*131*	*130*	*128*	*125*	*123*	*120*	*117*	*114*	*110*	*107*	*104*	*101*
278	*132*	*131*	*130*	*128*	*125*	*123*	*120*	*117*	*114*	*110*	*107*	*104*	*101*
279	*132*	*130*	*128*	*127*	*127*	*126*	*126*	*126*	125	125	124	124	124
280	125	122	119	116	113	111	109	107	105	103	101	99.1	97.3
281	…	…	…	…	…	…	…	…	…	…	…	…	…
282	…	…	…	…	…	…	…	…	…	…	…	…	…
283	146	142	138	135	132	130	127	…	…	…	…	…	…
284	146	142	138	135	132	130	127	…	…	…	…	…	…
285	184	184	184	184	184	184	184	184	184	184	184	184	…
286	*198*	*197*	*195*	*193*	*190*	*187*	*182*	**120**	**116**	**105**	**82.1**	**59.9**	**41.8**
287	*194*	*194*	*194*	*194*	*194*	…	…	…	…	…	…	…	…
288	*207*	*206*	*205*	*204*	*204*	…	…	…	…	…	…	…	…
289	*242*	*240*	*238*	*236*	*232*	*228*	*224*	…	…	…	…	…	…

Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

	Basic Allowable Stress, *S*, MPa, at Metal Temperature, °C [Notes (1), (3), and (4b)]											
Line No.	**550**	**575**	**600**	**625**	**650**	**675**	**700**	**725**	**750**	**775**	**800**	**825**
258	125	**112**	**90.6**	**69.6**	**53.8**	**41.4**	**31.8**	**24.0**	**18.8**	**14.6**	**10.9**	**8.96**
259	...	...	...	...	...	...	...	...	...	...	...	...
260	...	...	...	...	...	...	...	...	...	...	...	...
261	...	...	...	...	...	...	...	...	...	...	...	...
262	...	...	...	...	...	...	...	...	...	...	...	...
263	...	...	...	...	...	...	...	...	...	...	...	...
264	...	...	...	...	...	...	...	...	...	...	...	...
265	*179*	*174*	132	83.6	56.1	...	...	...	...	...	...	...
266	...	...	...	...	...	...	...	...	...	...	...	...
267	...	...	...	...	...	...	...	...	...	...	...	...
268	...	...	...	...	...	...	...	...	...	...	...	...
269	...	...	...	...	...	...	...	...	...	...	...	...
270	...	...	...	...	...	...	...	...	...	...	...	...
271	**68.1**	**53.5**	**42.1**	**33.2**	**25.9**	**20.3**	**16.5**	**13.2**	**10.1**	**7.35**	**5.89**	**5.52**
272	**73.2**	**64.4**	**56.5**	**49.0**	**41.0**	**33.5**	**25.4**	**18.3**	**12.8**	**9.01**	**6.59**	**5.52**
273	...	...	...	...	...	...	...	...	...	...	...	...
274	...	...	...	...	...	...	...	...	...	...	...	...
275	...	...	...	...	...	...	...	...	...	...	...	...
276	**75.3**	**60.4**	**49.0**	**40.1**	**32.8**	**27.2**	**23.4**	**19.6**	**16.8**	**14.7**	**12.8**	**11.7**
277	**68.2**	**53.7**	**42.1**	**33.2**	**25.9**	**20.3**	**16.4**	**13.3**	**10.2**	**7.25**	**5.74**	**5.33**
278	**68.2**	**53.7**	**42.1**	**33.2**	**25.9**	**20.3**	**16.4**	**13.3**	**10.2**	**7.25**	**5.74**	**5.33**
279	**98.3**	**77.2**	**57.7**	**39.9**	**30.0**	**23.2**	**16.3**	**11.2**	**8.93**	**7.08**	**5.77**	**5.32**
280	95.5	**75.9**	**57.2**	**40.2**	**30.3**	**23.2**	**16.2**	**11.4**	**8.97**	**7.08**	**5.89**	**5.52**
281	...	...	...	...	...	...	...	...	...	...	...	...
282	...	...	...	...	...	...	...	...	...	...	...	...
283	...	...	...	...	...	...	...	...	...	...	...	...
284	...	...	...	...	...	...	...	...	...	...	...	...
285	...	...	...	...	...	...	...	...	...	...	...	...
286	**28.7**	**20.1**	**14.3**	**9.77**	**6.89**	...	...	...	...	...	...	...
287	...	...	...	...	...	...	...	...	...	...	...	...
288	...	...	...	...	...	...	...	...	...	...	...	...
289	...	...	...	...	...	...	...	...	...	...	...	...

Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

Line No.	Nominal Composition	Product Form	Spec. No.	UNS No.	Class/ Condition/ Temper	Size, mm	P-No. (5)(7)	Notes	Min. Temp., °C (6)	Min. Tensile Str., MPa	Min. Yield Str., MPa
1	99.95Cu–P	Pipe	B42	C10200	O61	...	31	...	−269	207	62
2	99.9Cu–P	Pipe	B42	C12000	O61	...	31	...	−269	207	62
3	99.9Cu–P	Pipe	B42	C12200	O61	...	31	...	−269	207	62
4	99.95Cu–P	Tube	B75	C10200	O50	...	31	...	−269	207	62
5	99.95Cu–P	Tube	B75	C10200	O60	...	31	...	−269	207	62
6	99.9Cu–P	Tube	B75	C12000	O50	...	31	...	−269	207	62
7	99.9Cu–P	Tube	B75	C12000	O60	...	31	...	−269	207	62
8	99.9Cu–P	Tube	B75	C12200	O50	...	31	...	−269	207	62
9	99.9Cu–P	Tube	B75	C12200	O60	...	31	...	−269	207	62
10	99.9Cu–P	Tube	B68	C12200	O50	...	31	(24)	−269	207	62
11	99.9Cu–P	Tube	B68	C12200	O60	...	31	(24)	−269	207	62
12	99.9Cu–P	Tube	B88	C12200	O50	...	31	(24)	−269	207	62
13	99.9Cu–P	Tube	B88	C12200	O60	...	31	(24)	−269	207	62
14	99.9Cu–P	Tube	B280	C12200	O60	...	31	(24)	−269	207	62
15	85Cu–15Zn	Pipe	B43	C23000	O61	...	32	...	−269	276	83
16	90Cu–10Ni	Pipe & tube	B467	C70600	WO50	>114 O.D.	34	(14)	−269	262	90
17	90Cu–10Ni	Pipe & tube	B467	C70600	WO61	>114 O.D.	34	(14)	−269	262	90
18	90Cu–10Ni	Pipe & tube	B466	C70600	Annealed	...	34	(14)	−269	262	90
19	90Cu–10Ni	Pipe & tube	B467	C70600	WO50	≤114 O.D.	34	(14)	−269	276	103
20	90Cu–10Ni	Pipe & tube	B467	C70600	WO61	≤114 O.D.	34	(14)	−269	276	103
21	70Cu–30Ni	Pipe & tube	B467	C71500	WO50	>114 O.D.	34	(14)	−269	310	103
22	70Cu–30Ni	Pipe & tube	B467	C71500	WO61	>114 O.D.	34	(14)	−269	310	103
23	80Cu–20Ni	Pipe & tube	B466	C71000	Annealed	≤114 O.D.	34	(14)	−269	310	110
24	99.95Cu–P	Pipe	B42	C10200	H55	DN 64 thru 300	31	(14) (34)	−269	248	207
25	99.9Cu–P	Pipe	B42	C12000	H55	DN 64 thru 300	31	(14) (34)	−269	248	207
26	99.9Cu–P	Pipe	B42	C12200	H55	DN 64 thru 300	31	(14) (34)	−269	248	207
27	99.95Cu–P	Tube	B75	C10200	H58	...	31	(14) (34)	−269	248	207
28	99.9Cu–P	Tube	B75	C12000	H58	...	31	(14) (34)	−269	248	207
29	99.9Cu–P	Tube	B75	C12200	H58	...	31	(14) (34)	−269	248	207
30	99.9Cu–P	Tube	B88	C12200	H58	...	31	(14) (24) (34)	−269	248	207
31	70Cu–30Ni	Pipe & tube	B466	C71500	O60	...	34	(14)	−269	359	124
32	70Cu–30Ni	Pipe & tube	B467	C71500	WO50	≤114 O.D.	34	(14)	−269	345	138
33	70Cu–30Ni	Pipe & tube	B467	C71500	WO61	≤114 O.D.	34	(14)	−269	345	138
34	99.95Cu–P	Pipe	B42	C10200	H80	DN 6 thru 50	31	(14) (34)	−269	310	276
35	99.9Cu–P	Pipe	B42	C12000	H80	DN 6 thru 50	31	(14) (34)	−269	310	276
36	99.9Cu–P	Pipe	B42	C12200	H80	DN 6 thru 50	31	(14) (34)	−269	310	276
37	99.95Cu–P	Tube	B75	C10200	H80	...	31	(14) (34)	−269	310	276
38	99.9Cu–P	Tube	B75	C12000	H80	...	31	(14) (34)	−269	310	276

Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

Line No.	Max. Use Temp., °C	Basic Allowable Stress, *S*, MPa, at Metal Temperature, °C [Notes (1) and (4b)]													
		Min. Temp. to 40	65	100	125	150	175	200	225	250	275	300	325	350	375
1	260	41.4	34.9	33.5	32.9	32.2	**28.0**	**21.7**	**16.7**	**12.9**	**11.6**	...	...	...	...
2	260	41.4	34.9	33.5	32.9	32.2	**28.0**	**21.7**	**16.7**	**12.9**	**11.6**	...	...	...	...
3	260	41.4	34.9	33.5	32.9	32.2	**28.0**	**21.7**	**16.7**	**12.9**	**11.6**	...	...	...	...
4	260	41.4	34.9	33.5	32.9	32.2	**28.0**	**21.7**	**16.7**	**12.9**	**11.6**	...	...	...	...
5	260	41.4	34.9	33.5	32.9	32.2	**28.0**	**21.7**	**16.7**	**12.9**	**11.6**	...	...	...	...
6	260	41.4	34.9	33.5	32.9	32.2	**28.0**	**21.7**	**16.7**	**12.9**	**11.6**	...	...	...	...
7	260	41.4	34.9	33.5	32.9	32.2	**28.0**	**21.7**	**16.7**	**12.9**	**11.6**	...	...	...	...
8	260	41.4	34.9	33.5	32.9	32.2	**28.0**	**21.7**	**16.7**	**12.9**	**11.6**	...	...	...	...
9	260	41.4	34.9	33.5	32.9	32.2	**28.0**	**21.7**	**16.7**	**12.9**	**11.6**	...	...	...	...
10	260	41.4	34.9	33.5	32.9	32.2	**28.0**	**21.7**	**16.7**	**12.9**	**11.6**	...	...	...	...
11	260	41.4	34.9	33.5	32.9	32.2	**28.0**	**21.7**	**16.7**	**12.9**	**11.6**	...	...	...	...
12	260	41.4	34.9	33.5	32.9	32.2	**28.0**	**21.7**	**16.7**	**12.9**	**11.6**	...	...	...	...
13	260	41.4	34.9	33.5	32.9	32.2	**28.0**	**21.7**	**16.7**	**12.9**	**11.6**	...	...	...	...
14	260	41.4	34.9	33.5	32.9	32.2	**28.0**	**21.7**	**16.7**	**12.9**	**11.6**	...	...	...	...
15	232	55.2	54.7	54.7	54.7	54.7	54.7	**36.4**	**17.5**	**13.8**	...	...	...	...	...
16	316	59.8	58.0	56.1	54.9	53.8	52.9	52.0	51.2	50.4	49.7	**45.1**	**39.3**	...	...
17	316	59.8	58.0	56.1	54.9	53.8	52.9	52.0	51.2	50.4	49.7	**45.1**	**39.3**	...	...
18	316	59.8	58.0	56.1	54.9	53.8	52.9	52.0	51.2	50.4	49.7	**45.1**	**39.3**	...	...
19	316	68.9	67.0	65.1	63.7	62.4	61.1	60.0	59.1	58.3	**51.3**	**45.1**	**39.3**	...	...
20	316	68.9	67.0	65.1	63.7	62.4	61.1	60.0	59.1	58.3	**51.3**	**45.1**	**39.3**	...	...
21	371	68.9	66.6	64.6	63.2	61.9	60.7	59.5	58.4	57.4	**56.2**	**55.5**	**54.9**	**54.3**	**53.8**
22	371	68.9	66.6	64.6	63.2	61.9	60.7	59.5	58.4	57.4	**56.2**	**55.5**	**54.9**	**54.3**	**53.8**
23	371	73.5	72.8	72.1	71.4	70.6	69.6	68.3	66.6	64.7	62.4	60.0	**56.2**	**51.9**	**48.3**
24	204	*82.7*	*80.0*	*74.1*	*71.3*	*69.2*	*67.4*	*65.7*	*65.3*	...	...	...	...	...	...
25	204	*82.7*	*80.0*	*74.1*	*71.3*	*69.2*	*67.4*	*65.7*	*65.3*	...	...	...	...	...	...
26	204	*82.7*	*80.0*	*74.1*	*71.3*	*69.2*	*67.4*	*65.7*	*65.3*	...	...	...	...	...	...
27	204	*82.7*	*80.0*	*74.1*	*71.3*	*69.2*	*67.4*	*65.7*	*65.3*	...	...	...	...	...	...
28	204	*82.7*	*80.0*	*74.1*	*71.3*	*69.2*	*67.4*	*65.7*	*65.3*	...	...	...	...	...	...
29	204	*82.7*	*80.0*	*74.1*	*71.3*	*69.2*	*67.4*	*65.7*	*65.3*	...	...	...	...	...	...
30	204	*82.7*	*80.0*	*74.1*	*71.3*	*69.2*	*67.4*	*65.7*	*65.3*	...	...	...	...	...	...
31	371	82.7	79.8	77.5	75.9	74.3	72.9	71.5	70.2	68.9	67.8	66.8	65.9	65.3	64.8
32	371	91.9	88.7	86.1	84.3	82.6	81.0	79.4	78.0	76.6	75.3	74.2	73.2	72.5	71.7
33	371	91.9	88.7	86.1	84.3	82.6	81.0	79.4	78.0	76.6	75.3	74.2	73.2	72.5	71.7
34	204	*103*	*100*	*92.6*	*89.1*	*86.5*	*84.3*	**35.8**	**29.6**	...	...	...	...	...	...
35	204	*103*	*100*	*92.6*	*89.1*	*86.5*	*84.3*	**35.8**	**29.6**	...	...	...	...	...	...
36	204	*103*	*100*	*92.6*	*89.1*	*86.5*	*84.3*	**35.8**	**29.6**	...	...	...	...	...	...
37	204	*103*	*100*	*92.6*	*89.1*	*86.5*	*84.3*	**35.8**	**29.6**	...	...	...	...	...	...
38	204	*103*	*100*	*92.6*	*89.1*	*86.5*	*84.3*	**35.8**	**29.6**	...	...	...	...	...	...

Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

Line No.	Nominal Composition	Product Form	Spec. No.	UNS No.	Class/ Condition/ Temper	Size, mm	P-No. (5)(7)	Notes	Min. Temp., °C (6)	Min. Tensile Str., MPa	Min. Yield Str., MPa
39	99.9Cu–P	Tube	B75	C12200	H80	...	31	(14) (34)	−269	310	276
40	99.95Cu–P	Plate & sheet	B152	C10200	O25	...	31	(14) (24)	−269	207	69
41	99.95Cu–Ag	Plate & sheet	B152	C10400	O25	...	31	(14) (24)	−269	207	69
42	99.95Cu–Ag	Plate & sheet	B152	C10500	O25	...	31	(14) (24)	−269	207	69
43	99.95Cu–Ag	Plate & sheet	B152	C10700	O25	...	31	(14) (24)	−269	207	69
44	99.9Cu–P	Plate & sheet	B152	C12200	O25	...	31	(14) (24)	−269	207	69
45	99.9Cu–P	Plate & sheet	B152	C12300	O25	...	31	(14) (24)	−269	207	69
46	90Cu–10Ni	Plate & sheet	B171	C70600	...	≤64 thk.	34	(14)	−269	276	103
47	97Cu–3Si	Plate & sheet	B96	C65500	O61	...	33	...	−269	345	124
48	70Cu–30Ni	Plate & sheet	B171	C71500	...	≤64 thk.	34	(14)	−269	345	138
49	90Cu–7Al–3Fe	Plate & sheet	B169	C61400	O25	≤50 thk.	35	(13)	−269	483	207
50	90Cu–7Al–3Fe	Plate & sheet	B169	C61400	O60	≤50 thk.	35	(13)	−269	483	207
51	99.9Cu	Forgings	B283	C11000	...	...	31	(14)	−269	228	76
52	97Cu–3Si	Forgings	B283	C65500	...	...	33	(14)	−269	359	124
53	60Cu–38Zn–2Pb	Forgings	B283	C37700	...	...	a	(14)	−198	400	159
54	60Cu–37Zn–2Pb–Sn	Forgings	B283	C48500	...	...	a	(14)	−198	427	165
55	60Cu–39Zn–Sn	Forgings	B283	C46400	...	...	32	(14)	−254	441	179
56	59Cu–39Zn–Fe–Sn	Forgings	B283	C67500	...	...	32	(14)	−198	496	234
57	85Cu–5Sn–5Zn–5Pb	Castings	B62	C83600	...	...	a	(9)	−198	207	97
58	57Cu–20Zn–12Ni–9Pb–2Sn	Castings	B584	C97300	...	...	a	...	−198	207	103
59	64Cu–20Ni–8Zn–4Sn–4Pb	Castings	B584	C97600	...	...	a	...	−198	276	117
60	87Cu–8Sn–4Zn–1Pb	Castings	B584	C92300	...	...	a	...	−198	248	110
61	88Cu–Sn–Zn–Pb	Castings	B584	C92200	...	...	a	...	−198	234	110
62	88Cu–Sn–Zn–Pb	Castings	B61	C92200	...	...	a	(9)	−198	234	110
63	88Cu–8Sn–4Zn	Castings	B584	C90300	...	...	b	...	−198	276	124
64	88Cu–10Sn–2Zn	Castings	B584	C90500	...	...	b	...	−198	276	124
65	58Cu–38Zn–1Sn–1Pb–1Fe	Castings	B584	C86400	...	...	a	(9)	−198	414	138
66	66Cu–25Ni–5Sn–2Pb–2Zn	Castings	B584	C97800	...	...	a	...	−198	345	152
67	58Cu–39Zn–1Fe–1Al–1Mn	Castings	B584	C86500	...	...	b	...	−198	448	172
68	88Cu–9Al–3Fe	Castings	B148	C95200	...	...	35	(9)	−254	448	172
69	89Cu–10Al–1Fe	Castings	B148	C95300	...	...	35	(9)	−254	448	172

Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

Line No.	Max. Use Temp., °C	Basic Allowable Stress, *S*, MPa, at Metal Temperature, °C [Notes (1) and (4b)]													
		Min. Temp. to 40	65	100	125	150	175	200	225	250	275	300	325	350	375
39	204	*103*	*100*	*92.6*	*89.1*	*86.5*	*84.3*	**35.8**	**29.6**	...	...	...	...	...	...
40	260	46.0	39.1	37.1	36.5	**34.2**	**28.0**	**21.7**	**16.7**	**12.9**	**11.6**	...	...	...	...
41	260	46.0	39.1	37.1	36.5	**34.2**	**28.0**	**21.7**	**16.7**	**12.9**	**11.6**	...	...	...	...
42	260	46.0	39.1	37.1	36.5	**34.2**	**28.0**	**21.7**	**16.7**	**12.9**	**11.6**	...	...	...	...
43	260	46.0	39.1	37.1	36.5	**34.2**	**28.0**	**21.7**	**16.7**	**12.9**	**11.6**	...	...	...	...
44	260	46.0	39.1	37.1	36.5	**34.2**	**28.0**	**21.7**	**16.7**	**12.9**	**11.6**	...	...	...	...
45	260	46.0	39.1	37.1	36.5	**34.2**	**28.0**	**21.7**	**16.7**	**12.9**	**11.6**	...	...	...	...
46	316	68.9	67.0	65.1	63.7	62.4	61.1	60.0	59.1	58.3	**51.3**	**45.1**	**39.3**	...	...
47	204	82.7	82.7	82.7	82.7	82.7	**75.4**	**50.8**	**31.9**	...	...	...	...	...	...
48	371	91.9	88.7	86.1	84.3	82.6	81.0	79.4	78.0	76.6	75.3	74.2	73.2	72.5	71.7
49	260	138	137	136	135	135	134	133	131	130	130	...	...	...	...
50	260	138	137	136	135	135	134	133	131	130	130	...	...	...	...
51	260	50.6	42.8	40.8	40.2	**34.2**	**28.0**	**21.7**	**16.7**	**12.9**	**11.6**	...	...	...	...
52	204	82.7	82.7	82.7	82.7	82.7	**75.4**	**50.8**	**31.9**	...	...	...	...	...	...
53	204	106	99.8	94.5	91.1	**71.4**	**52.8**	**17.0**	**13.8**	...	...	...	...	...	...
54	204	110	110	110	110	110	110	110	110	...	...	...	...	...	...
55	204	120	120	120	120	*118*	*118*	**20.0**	**17.2**	...	...	...	...	...	...
56	204	156	156	156	156	156	156	156	156	...	...	...	...	...	...
57	232	64.4	64.4	62.6	59.1	55.7	53.0	51.2	50.3	50.1	...	...	...	...	...
58	40	68.9	...	...	...	...	...	...	...	...	...	...	...	...	...
59	149	78.1	69.6	64.9	62.5	60.3	...	...	...	...	...	...	...	...	...
60	204	73.5	73.5	73.5	73.5	73.5	73.5	73.5	73.5	...	...	...	...	...	...
61	204	73.5	66.4	65.3	64.6	63.3	61.5	59.6	58.1	...	...	...	...	...	...
62	288	73.5	66.4	65.3	64.6	63.3	61.5	59.6	58.1	57.5	57.5	57.3	...	...	...
63	204	82.7	82.7	82.7	82.7	82.7	82.7	82.7	82.7	...	...	...	...	...	...
64	204	82.7	82.7	82.7	82.7	82.7	82.7	82.7	82.7	...	...	...	...	...	...
65	177	91.9	91.9	91.9	91.9	91.9	91.9	91.9	...	...	...	...	...	...	...
66	177	101	101	101	101	101	101	101	...	...	...	...	...	...	...
67	177	115	115	115	115	115	115	115	...	...	...	...	...	...	...
68	316	115	108	104	102	99.8	98.6	97.8	97.5	97.4	97.4	**65.9**	**43.7**	...	...
69	316	115	115	115	115	115	115	115	115	115	115	115	115	...	...

Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

Line No.	Nominal Composition	Product Form	Spec. No.	UNS No.	Class/ Condition/ Temper	Size, mm	P-No. (5)(7)	Notes	Min. Temp., °C (6)	Min. Tensile Str., MPa	Min. Yield Str., MPa
70	90Cu–7Al–3Si	Castings	B148	C95600	...	...	35	...	−198	414	193
71	85Cu–11Al–4Fe	Castings	B148	C95400	...	...	35	...	−198	517	207
72	58Cu–34Zn–2Fe–2Al–2Mn	Castings	B584	C86700	...	...	a	...	−198	552	221
73	82Cu–11Al–4Fe–3Mn	Castings	B148	C95500	...	...	35	...	−269	621	276
74	63Cu–27Zn–4Al–3Fe–3Mn	Castings	B584	C86200	...	...	b	...	−198	621	310
75	61Cu–27Zn–6Al–3Fe–3Mn	Castings	B584	C86300	...	...	b	...	−198	758	414
76	75Cu–21.5Zn–3Si	Rod	B371	C69300	H02	≤12	a	...	−198	585	310
77	75Cu–21.5Zn–3Si	Rod	B371	C69300	H02	>12, ≤25	a	...	−198	515	240
78	75Cu–21.5Zn–3Si	Rod	B371	C69300	H02	>25, ≤50	a	...	−198	480	205

Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

Line No.	Max. Use Temp., °C	Basic Allowable Stress, *S*, MPa, at Metal Temperature, °C [Notes (1) and (4b)]													
		Min. Temp. to 40	65	100	125	150	175	200	225	250	275	300	325	350	375
70	40	129	...	...	...	...	...	...	...	...	...	...	...	...	...
71	260	138	131	128	128	128	128	128	128	**101**	**95.8**	...	...	...	...
72	177	147	147	147	147	147	147	147	...	...	...	...	...	...	...
73	260	184	184	184	184	184	184	184	184	184	184	...	...	...	...
74	177	*207*	*207*	*207*	*207*	*207*	*207*	*207*	...	...	...	...	...	...	...
75	177	*253*	*253*	*253*	*253*	*253*	*253*	*253*	...	...	...	...	...	...	...
76	149	195	179	176	176	176	...	...	...	...	...	...	...	...	...
77	149	161	139	137	137	137	...	...	...	...	...	...	...	...	...
78	149	138	119	117	117	117	...	...	...	...	...	...	...	...	...

Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

Line No.	Nominal Composition	Product Form	Spec. No.	Type/ Grade	UNS No.	Class/ Condition/ Temper	Size, mm	P-No. (5)
1	99.0Ni–Low C	Pipe & tube	B161	...	N02201	Annealed	>125	41
2	99.0Ni–Low C	Pipe & tube	B725	...	N02201	Annealed	>125	41
3	99.0Ni	Pipe & tube	B161	...	N02200	Annealed	>125	41
4	99.0Ni	Pipe & tube	B725	...	N02200	Annealed	>125	41
5	99.0Ni–Low C	Pipe & tube	B161	...	N02201	Annealed	≤125	41
6	99.0Ni–Low C	Pipe & tube	B725	...	N02201	Annealed	≤125	41
7	99.0Ni	Pipe & tube	B161	...	N02200	Annealed	≤125	41
8	99.0Ni	Pipe & tube	B725	...	N02200	Annealed	≤125	41
9	67Ni–30Cu	Pipe & tube	B165	...	N04400	Annealed	>125	42
10	67Ni–30Cu	Pipe & tube	B725	...	N04400	Annealed	>125	42
11	33Ni–42Fe–21Cr	Pipe & tube	B407	...	N08800	H.F. or H.F. ann.	...	45
12	72Ni–15Cr–8Fe	Pipe & tube	B167	...	N06600	H.F. or H.F. ann.	>125	43
13	33Ni–42Fe–21Cr	Pipe & tube	B407	...	N08810	C.D. sol. ann. or H.F. ann.	...	45
14	33Ni–42Fe–21Cr	Pipe & tube	B514	...	N08810	Annealed	...	45
15	33Ni–42Fe–21Cr–Al–Ti	Pipe & tube	B407	...	N08811	C.D. sol. ann. or H.F. ann.	...	45
16	67Ni–30Cu	Pipe & tube	B165	...	N04400	Annealed	≤125	42
17	67Ni–30Cu	Pipe & tube	B725	...	N04400	Annealed	≤125	42
18	26Ni–22Cr–5Mo–Ti	Pipe & tube	B619	...	N08320	Sol. ann.	...	45
19	26Ni–22Cr–5Mo–Ti	Pipe & tube	B622	...	N08320	Sol. ann.	...	45
20	99.0Ni–Low C	Pipe & tube	B161	...	N02201	Str. rel.	...	41
21	99.0Ni–Low C	Pipe & tube	B725	...	N02201	Str. rel.	...	41
22	33Ni–42Fe–21Cr	Pipe & tube	B514	...	N08800	Annealed	...	45
23	72Ni–15Cr–8Fe	Pipe & tube	B167	...	N06600	H.F. or H.F. ann.	≤125	43
24	72Ni–15Cr–8Fe	Pipe & tube	B167	...	N06600	C.D. ann.	>125	43
25	33Ni–42Fe–21Cr	Pipe & tube	B407	...	N08800	C.D. ann.	...	45
26	31Ni–31Fe–29Cr–Mo	Pipe & tube	B668	...	N08028	Sol. ann.	...	45
27	99.0Ni	Pipe & tube	B161	...	N02200	Str. rel.	...	41
28	99.0Ni	Pipe & tube	B725	...	N02200	Str. rel.	...	41
29	35Ni–35Fe–20Cr–Cb	Pipe & tube	B464	...	N08020	Annealed	...	45
30	35Ni–35Fe–20Cr–Cb	Pipe & tube	B474	...	N08020	Annealed	...	45
31	35Ni–35Fe–20Cr–Cb	Pipe & tube	B729	...	N08020	Annealed	...	45
32	42Ni–21.5Cr–3Mo–2.3Cu	Smls. tube	B163	...	N08825	Annealed	...	45
33	42Ni–21.5Cr–3Mo–2.3Cu	Pipe & tube	B423	...	N08825	C.D. ann.	...	45
34	42Ni–21.5Cr–3Mo–2.3Cu	Pipe & tube	B474	...	N08825	Annealed	...	45
35	42Ni–21.5Cr–3Mo–2.3Cu	Wld. tube	B704	...	N08825	Annealed	...	45

Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

Line No.	Notes	Min. Temp., °C (6)	Min. Tensile Str., MPa	Min. Yield Str., MPa	Max. Use Temp., °C	Basic Allowable Stress, S, MPa, at Metal Temperature, °C [Notes (1) and (4b)] Min. Temp. to 40	65	100	125	150	175	200	225	250
1	...	−198	345	69	649	46.0	44.7	43.9	43.6	43.3	43.2	43.2	43.2	43.2
2	...	−198	345	69	649	46.0	44.7	43.9	43.6	43.3	43.2	43.2	43.2	43.2
3	...	−198	379	83	316	55.2	55.2	55.2	55.2	55.2	55.2	55.2	55.2	55.2
4	...	−198	379	83	316	55.2	55.2	55.2	55.2	55.2	55.2	55.2	55.2	55.2
5	...	−198	345	83	649	55.2	53.8	52.8	52.3	51.9	51.7	51.6	51.6	51.6
6	...	−198	345	83	649	55.2	53.8	52.8	52.3	51.9	51.7	51.6	51.6	51.6
7	...	−198	379	103	316	68.9	68.9	68.9	68.9	68.9	68.9	68.9	68.9	68.9
8	...	−198	379	103	316	68.9	68.9	68.9	68.9	68.9	68.9	68.9	68.9	68.9
9	...	−198	483	172	482	115	106	99.7	96.2	93.6	91.9	90.9	90.4	90.4
10	...	−198	483	172	482	115	106	99.7	96.2	93.6	91.9	90.9	90.4	90.4
11	...	−198	448	172	816	115	115	115	115	115	115	115	115	115
12	...	−198	517	172	649	115	115	115	115	115	115	115	115	115
13	(62)	−198	448	172	899	115	115	115	115	115	115	115	115	115
14	(62)	−198	448	172	899	115	115	115	115	115	115	115	115	115
15	(62)	−198	448	172	899	115	115	115	115	115	115	115	115	115
16	...	−198	483	193	482	129	119	112	108	105	103	102	101	101
17	...	−198	483	193	482	129	119	112	108	105	103	102	101	101
18	...	−198	517	193	427	129	129	129	129	129	129	129	129	129
19	...	−198	517	193	427	129	129	129	129	129	129	129	129	129
20	...	−198	414	207	316	*138*	*138*	*138*	*137*	*137*	*137*	*137*	*137*	*136*
21	...	−198	414	207	316	*138*	*138*	*138*	*137*	*137*	*137*	*137*	*137*	*136*
22	...	−198	517	207	816	138	138	138	138	138	138	138	138	138
23	...	−198	552	207	649	138	138	138	138	138	138	138	138	138
24	...	−198	552	207	649	138	138	138	138	138	138	138	138	138
25	(61)	−198	517	207	816	138	138	138	138	138	138	138	138	138
26	...	−198	505	215	454	143	*143*	*143*	*143*	*143*	*143*	*143*	*143*	*143*
27	...	−198	448	276	316	*149*	*149*	*149*	*149*	*149*	*149*	*149*	*149*	*148*
28	...	−198	448	276	316	*149*	*149*	*149*	*149*	*149*	*149*	*149*	*149*	*148*
29	...	−198	552	241	427	161	161	161	161	161	161	161	161	161
30	...	−198	552	241	427	161	161	161	161	161	161	161	161	161
31	...	−198	552	241	427	161	161	161	161	161	161	161	161	161
32	...	−198	585	240	538	161	161	161	161	161	161	161	161	161
33	...	−198	585	240	538	161	161	161	161	161	161	161	161	161
34	...	−198	585	240	538	161	161	161	161	161	161	161	161	161
35	...	−198	585	240	538	161	161	161	161	161	161	161	161	161

Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

Line No.	Basic Allowable Stress, *S*, MPa, at Metal Temperature, °C [Notes (1) and (4b)]												
	275	300	325	350	375	400	425	450	475	500	525	550	575
1	43.2	43.2	43.1	42.9	42.6	42.1	41.5	40.7	**33.1**	**27.4**	**22.8**	**18.7**	**15.6**
2	43.2	43.2	43.1	42.9	42.6	42.1	41.5	40.7	**33.1**	**27.4**	**22.8**	**18.7**	**15.6**
3	55.2	55.2	55.2	...	...	...	...	...	...	...	...	...	...
4	55.2	55.2	55.2	...	...	...	...	...	...	...	...	...	...
5	51.6	51.6	51.6	51.5	51.2	50.7	49.9	**41.4**	**33.1**	**27.4**	**22.8**	**18.7**	**15.6**
6	51.6	51.6	51.6	51.5	51.2	50.7	49.9	**41.4**	**33.1**	**27.4**	**22.8**	**18.7**	**15.6**
7	68.9	68.9	68.9	...	...	...	...	...	...	...	...	...	...
8	68.9	68.9	68.9	...	...	...	...	...	...	...	...	...	...
9	90.4	90.4	90.4	90.4	89.8	89.0	88.0	**79.7**	**59.9**	**55.2**	...	...	...
10	90.4	90.4	90.4	90.4	89.8	89.0	88.0	**79.7**	**59.9**	**55.2**	...	...	...
11	115	115	115	115	115	115	115	115	115	115	115	113	**107**
12	115	115	115	115	115	115	115	115	115	**84.8**	**58.4**	**39.7**	**27.0**
13	115	115	113	110	108	106	104	102	100	98.6	97.1	95.7	**91.8**
14	115	115	113	110	108	106	104	102	100	98.6	97.1	95.7	**91.8**
15	115	115	113	110	108	106	104	102	100	98.6	97.1	95.7	**92.5**
16	101	101	101	101	100	99.6	98.6	**79.7**	**59.9**	**55.2**	...	...	...
17	101	101	101	101	100	99.6	98.6	**79.7**	**59.9**	**55.2**	...	...	...
18	129	129	127	125	122	121	119	119	...	...	...	...	...
19	129	129	127	125	122	121	119	119	...	...	...	...	...
20	*135*	*133*	*130*	...	...	...	...	...	...	...	...	...	...
21	*135*	*133*	*130*	...	...	...	...	...	...	...	...	...	...
22	138	138	138	138	138	138	138	138	138	138	138	136	**107**
23	138	138	138	138	138	138	138	138	138	**84.8**	**58.4**	**39.7**	**27.0**
24	138	138	138	138	138	138	138	138	138	**84.8**	**58.4**	**39.7**	**27.0**
25	138	138	138	138	138	138	138	138	138	138	138	136	**107**
26	**140**	**137**	**133**	**130**	**125**	**122**	**119**	**116**	**113**	...	...	...	...
27	*146*	*144*	*141*	...	...	...	...	...	...	...	...	...	...
28	*146*	*144*	*141*	...	...	...	...	...	...	...	...	...	...
29	161	161	161	161	161	160	157	156	...	...	...	...	...
30	161	161	161	161	161	160	157	156	...	...	...	...	...
31	161	161	161	161	161	160	157	156	...	...	...	...	...
32	161	161	161	161	161	160	159	158	157	156	155	153	...
33	161	161	161	161	161	160	159	158	157	156	155	153	...
34	161	161	161	161	161	160	159	158	157	156	155	153	...
35	161	161	161	161	161	160	159	158	157	156	155	153	...

Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

	Basic Allowable Stress, *S*, MPa, at Metal Temperature, °C [Notes (1) and (4b)]												
Line No.	600	625	650	675	700	725	750	775	800	825	850	875	900
1	12.9	10.0	8.27	...	...	...	...	...	...	...	...	...	...
2	12.9	10.0	8.27	...	...	...	...	...	...	...	...	...	...
3	...	...	...	...	...	...	...	...	...	...	...	...	...
4	...	...	...	...	...	...	...	...	...	...	...	...	...
5	12.9	10.0	8.27	...	...	...	...	...	...	...	...	...	...
6	12.9	10.0	8.27	...	...	...	...	...	...	...	...	...	...
7	...	...	...	...	...	...	...	...	...	...	...	...	...
8	...	...	...	...	...	...	...	...	...	...	...	...	...
9	...	...	...	...	...	...	...	...	...	...	...	...	...
10	...	...	...	...	...	...	...	...	...	...	...	...	...
11	83.8	63.9	44.7	29.8	15.5	11.7	8.68	7.20	6.25	5.11	...	...	...
12	19.2	15.0	13.8	...	...	...	...	...	...	...	...	...	...
13	75.7	62.6	50.6	41.2	33.6	27.7	22.6	18.3	15.0	11.9	9.03	7.35	5.86
14	75.7	62.6	50.6	41.2	33.6	27.7	22.6	18.3	15.0	11.9	9.03	7.35	5.86
15	84.5	69.5	56.7	46.8	38.5	31.5	25.5	20.7	17.0	13.9	11.2	9.33	7.58
16	...	...	...	...	...	...	...	...	...	...	...	...	...
17	...	...	...	...	...	...	...	...	...	...	...	...	...
18	...	...	...	...	...	...	...	...	...	...	...	...	...
19	...	...	...	...	...	...	...	...	...	...	...	...	...
20	...	...	...	...	...	...	...	...	...	...	...	...	...
21	...	...	...	...	...	...	...	...	...	...	...	...	...
22	83.8	63.9	44.7	29.8	15.5	11.7	8.68	7.20	6.25	5.11	...	...	...
23	19.2	15.0	13.8	...	...	...	...	...	...	...	...	...	...
24	19.2	15.0	13.8	...	...	...	...	...	...	...	...	...	...
25	83.8	63.9	44.7	29.8	15.5	11.7	8.68	7.20	6.25	5.11	...	...	...
26	...	...	...	...	...	...	...	...	...	...	...	...	...
27	...	...	...	...	...	...	...	...	...	...	...	...	...
28	...	...	...	...	...	...	...	...	...	...	...	...	...
29	...	...	...	...	...	...	...	...	...	...	...	...	...
30	...	...	...	...	...	...	...	...	...	...	...	...	...
31	...	...	...	...	...	...	...	...	...	...	...	...	...
32	...	...	...	...	...	...	...	...	...	...	...	...	...
33	...	...	...	...	...	...	...	...	...	...	...	...	...
34	...	...	...	...	...	...	...	...	...	...	...	...	...
35	...	...	...	...	...	...	...	...	...	...	...	...	...

Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

Line No.	Nominal Composition	Product Form	Spec. No.	Type/ Grade	UNS No.	Class/ Condition/ Temper	Size, mm	P-No. (5)
36	42Ni–21.5Cr–3Mo–2.3Cu	Pipe & tube	B705	...	N08825	Annealed	...	45
37	47Ni–22Cr–19Fe–6Mo	Pipe & tube	B619	...	N06007	Sol. ann.	...	45
38	47Ni–22Cr–19Fe–6Mo	Pipe & tube	B622	...	N06007	Sol. ann.	...	45
39	40Ni–29Cr–15Fe–5Mo	Pipe & tube	B619	...	N06030	Sol. ann.	...	45
40	40Ni–29Cr–15Fe–5Mo	Pipe & tube	B622	...	N06030	Sol. ann.	...	45
41	40Ni–29Cr–15Fe–5Mo	Pipe & tube	B626	...	N06030	Sol. ann.	...	45
42	72Ni–15Cr–8Fe	Pipe & tube	B167	...	N06600	C.D. ann.	≤125	43
43	72Ni–15Cr–8Fe	Pipe & tube	B517	...	N06600	C.D. ann.	...	43
44	58Ni–29Cr–9Fe	Tube	B163	...	N06690	Annealed	≤75	43
45	58Ni–29Cr–9Fe	Pipe & tube	B167	...	N06690	C.D. ann.	≤125	43
46	37Ni–33Fe–25Cr	Pipe & tube	B163	...	N08120	Sol. ann.	...	45
47	37Ni–33Fe–25Cr	Pipe & tube	B407	...	N08120	Sol. ann.	...	45
48	37Ni–33Fe–25Cr	Pipe & tube	B514	...	N08120	Sol. ann.	...	45
49	37Ni–33Fe–25Cr	Pipe & tube	B515	...	N08120	Sol. ann.	...	45
50	61Ni–16Mo–16Cr	Pipe & tube	B619	...	N06455	Sol. ann.	...	43
51	47Ni–22Cr–9Mo–18Fe	Pipe & tube	B619	...	N06002	Sol. ann.	...	43
52	47Ni–22Cr–9Mo–18Fe	Pipe & tube	B622	...	N06002	Sol. ann.	...	43
53	31Ni–33Fe–27Cr–6.5Mo–Cu–N	Pipe & tube	B619	...	N08031	Annealed	...	45
54	31Ni–33Fe–27Cr–6.5Mo–Cu–N	Pipe & tube	B622	...	N08031	Annealed	...	45
55	61Ni–16Mo–16Cr	Pipe & tube	B622	...	N06455	Sol. ann.	...	43
56	54Ni–16Mo–15Cr	Pipe & tube	B619	...	N10276	Sol. ann.	...	43
57	54Ni–16Mo–15Cr	Pipe & tube	B622	...	N10276	Sol. ann.	...	43
58	54Ni–16Mo–15Cr	Pipe & tube	B626	...	N10276	Sol. ann.	...	43
59	67Ni–30Cu	Pipe & tube	B165	...	N04400	Str. rel.	...	42
60	67Ni–30Cu	Pipe & tube	B725	...	N04400	Str. rel.	...	42
61	46Fe–24Ni–21Cr–6Mo–Cu–N	Pipe & tube	B675	...	N08367	Annealed	>5	45
62	46Fe–24Ni–21Cr–6Mo–Cu–N	Pipe & tube	B690	...	N08367	Annealed	>5	45
63	46Fe–24Ni–21Cr–6Mo–Cu–N	Pipe & tube	B804	...	N08367	Annealed	>5	45
64	46Fe–24Ni–21Cr–6Mo–Cu–N	Pipe & tube	B675	...	N08367	Annealed	≤5	45
65	46Fe–24Ni–21Cr–6Mo–Cu–N	Pipe & tube	B690	...	N08367	Annealed	≤5	45
66	46Fe–24Ni–21Cr–6Mo–Cu–N	Pipe & tube	B804	...	N08367	Annealed	≤5	45
67	55Ni–21Cr–13.5Mo	Pipe & tube	B619	...	N06022	Sol. ann.	...	43

Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

Line No.	Notes	Min. Temp., °C (6)	Min. Tensile Str., MPa	Min. Yield Str., MPa	Max. Use Temp., °C	Basic Allowable Stress, S, MPa, at Metal Temperature, °C [Notes (1) and (4b)] Min. Temp. to 40	65	100	125	150	175	200	225	250
36	...	−198	585	240	538	161	161	161	161	161	161	161	161	161
37	...	−198	621	241	538	161	161	161	161	161	161	161	161	161
38	...	−198	621	241	427	161	161	161	161	161	161	161	161	161
39	...	−198	586	241	427	161	161	161	161	161	161	161	157	154
40	...	−198	586	241	427	161	161	161	161	161	161	161	157	154
41	...	−198	586	241	427	161	161	161	161	161	161	161	157	154
42	...	−198	552	241	649	161	161	161	161	161	161	161	161	161
43	...	−198	552	241	649	161	161	161	161	161	161	161	161	161
44	...	−198	586	241	482	160	160	160	160	160	160	160	160	160
45	...	−198	586	240	482	160	160	160	160	160	160	160	160	160
46	...	−198	621	276	899	184	184	184	184	184	184	184	180	175
47	...	−198	621	276	899	184	184	184	184	184	184	184	180	175
48	...	−198	621	276	899	184	184	184	184	184	184	184	180	175
49	...	−198	621	276	899	184	184	184	184	184	184	184	180	175
50	...	−198	689	276	427	184	184	184	184	184	184	184	184	184
51	...	−198	689	276	816	184	184	184	184	184	184	184	184	178
52	...	−198	689	276	816	184	184	184	184	184	184	184	184	178
53	...	−198	648	276	427	184	184	184	184	184	177	171	166	162
54	...	−198	648	276	427	184	184	184	184	184	177	171	166	162
55	...	−198	689	276	427	184	184	184	184	184	184	184	184	184
56	...	−198	689	283	677	188	188	188	188	188	188	188	188	187
57	...	−198	689	283	677	188	188	188	188	188	188	188	188	187
58	...	−198	689	283	677	188	188	188	188	188	188	188	188	187
59	(54)	−198	586	379	260	*195*	*195*	*195*	*195*	*195*	*195*	*195*	*195*	*195*
60	(54)	−198	586	379	260	*195*	*195*	*195*	*195*	*195*	*195*	*195*	*195*	*195*
61	...	−198	655	310	427	207	207	207	207	*206*	*202*	*198*	*195*	*192*
62	...	−198	655	310	427	207	207	207	207	*206*	*202*	*198*	*195*	*192*
63	...	−198	655	310	427	207	207	207	207	*206*	*202*	*198*	*195*	*192*
64	...	−198	689	310	427	207	207	207	207	*206*	*202*	*198*	*195*	*192*
65	...	−198	689	310	427	207	207	207	207	*206*	*202*	*198*	*195*	*192*
66	...	−198	689	310	427	207	207	207	207	*206*	*202*	*198*	*195*	*192*
67	...	−198	689	310	427	207	207	207	207	207	207	207	204	202

Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

	Basic Allowable Stress, *S*, MPa, at Metal Temperature, °C [Notes (1) and (4b)]												
Line No.	**275**	**300**	**325**	**350**	**375**	**400**	**425**	**450**	**475**	**500**	**525**	**550**	**575**
36	161	161	161	161	161	160	159	158	157	156	155	153	...
37	160	158	156	154	153	152	151	150	149	**136**	**132**	**130**	...
38	160	158	156	154	153	152	151	150	...	...	...	...	...
39	151	148	146	143	141	138	136	136	...	...	...	...	...
40	151	148	146	143	141	138	136	136	...	...	...	...	...
41	151	148	146	143	141	138	136	136	...	...	...	...	...
42	161	161	161	161	161	161	161	161	161	**84.8**	**58.4**	**39.7**	**27.0**
43	161	161	161	161	161	161	161	161	161	**84.8**	**58.4**	**39.7**	**27.0**
44	160	160	160	160	160	160	160	160	160	160	...	...	...
45	160	160	160	160	160	160	160	160	160	160	...	...	...
46	170	166	163	160	158	156	154	153	153	152	151	151	151
47	170	166	163	160	158	156	154	153	153	152	151	151	151
48	170	166	163	160	158	156	154	153	153	152	151	151	151
49	170	166	163	160	158	156	154	153	153	152	151	151	151
50	184	184	184	184	183	180	178	178	...	...	...	...	...
51	173	169	165	162	160	158	157	155	154	**135**	**134**	**133**	**129**
52	173	169	165	162	160	158	157	155	154	**135**	**134**	**133**	**129**
53	158	155	152	149	**74.2**	**61.1**	**50.3**	**49.6**	...	...	...	...	...
54	158	155	152	149	**74.2**	**61.1**	**50.3**	**49.6**	...	...	...	...	...
55	184	184	184	184	182	180	178	178	...	...	...	...	...
56	183	177	172	169	165	162	159	157	156	155	154	**143**	**118**
57	183	177	172	169	165	162	159	157	156	155	154	**143**	**118**
58	183	177	172	169	165	162	159	157	156	155	154	**143**	**118**
59	*195*	...	...	...	...	...	...	...	...	...	...	...	...
60	*195*	...	...	...	...	...	...	...	...	...	...	...	...
61	188	183	179	176	173	170	168	167	...	...	...	...	...
62	188	183	179	176	173	170	168	167	...	...	...	...	...
63	188	183	179	176	173	170	168	167	...	...	...	...	...
64	188	183	179	176	173	170	168	167	...	...	...	...	...
65	188	183	179	176	173	170	168	167	...	...	...	...	...
66	188	183	179	176	173	170	168	167	...	...	...	...	...
67	197	193	189	185	182	180	177	177	...	...	...	...	...

Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

	Basic Allowable Stress, *S*, MPa, at Metal Temperature, °C [Notes (1) and (4b)]												
Line No.	600	625	650	675	700	725	750	775	800	825	850	875	900
36	...	...	...	...	...	...	...	...	...	...	...	...	...
37	...	...	...	...	...	...	...	...	...	...	...	...	...
38	...	...	...	...	...	...	...	...	...	...	...	...	...
39	...	...	...	...	...	...	...	...	...	...	...	...	...
40	...	...	...	...	...	...	...	...	...	...	...	...	...
41	...	...	...	...	...	...	...	...	...	...	...	...	...
42	19.2	15.0	13.8	...	...	...	...	...	...	...	...	...	...
43	19.2	15.0	13.8	...	...	...	...	...	...	...	...	...	...
44	...	...	...	...	...	...	...	...	...	...	...	...	...
45	...	...	...	...	...	...	...	...	...	...	...	...	...
46	117	96.2	79.3	65.6	54.4	45.0	37.2	30.6	25.1	20.5	16.5	13.0	9.8
47	117	96.2	79.3	65.6	54.4	45.0	37.2	30.6	25.1	20.5	16.5	13.0	9.8
48	117	96.2	79.3	65.6	54.4	45.0	37.2	30.6	25.1	20.5	16.5	13.0	9.8
49	117	96.2	79.3	65.6	54.4	45.0	37.2	30.6	25.1	20.5	16.5	13.0	9.8
50	...	...	...	...	...	...	...	...	...	...	...	...	...
51	115	94.2	77.3	64.9	54.7	44.7	36.1	29.2	23.6	20.7	...	...	...
52	115	94.2	77.3	64.9	54.7	44.7	36.1	29.2	23.6	20.7	...	...	...
53	...	...	...	...	...	...	...	...	...	...	...	...	...
54	...	...	...	...	...	...	...	...	...	...	...	...	...
55	...	...	...	...	...	...	...	...	...	...	...	...	...
56	99.1	81.6	67.0	54.6	42.2	...	...	...	...	...	...	...	...
57	99.1	81.6	67.0	54.6	42.2	...	...	...	...	...	...	...	...
58	99.1	81.6	67.0	54.6	42.2	...	...	...	...	...	...	...	...
59	...	...	...	...	...	...	...	...	...	...	...	...	...
60	...	...	...	...	...	...	...	...	...	...	...	...	...
61	...	...	...	...	...	...	...	...	...	...	...	...	...
62	...	...	...	...	...	...	...	...	...	...	...	...	...
63	...	...	...	...	...	...	...	...	...	...	...	...	...
64	...	...	...	...	...	...	...	...	...	...	...	...	...
65	...	...	...	...	...	...	...	...	...	...	...	...	...
66	...	...	...	...	...	...	...	...	...	...	...	...	...
67	...	...	...	...	...	...	...	...	...	...	...	...	...

Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

Line No.	Nominal Composition	Product Form	Spec. No.	Type/ Grade	UNS No.	Class/ Condition/ Temper	Size, mm	P-No. (5)
68	55Ni–21Cr–13.5Mo	Pipe & tube	B622	...	N06022	Sol. ann.	...	43
69	58Ni–33Cr–8Mo	Pipe & tube	B619	...	N06035	Sol. ann.	...	43
70	58Ni–33Cr–8Mo	Pipe & tube	B622	...	N06035	Sol. ann.	...	43
71	58Ni–33Cr–8Mo	Pipe & tube	B626	...	N06035	Sol. ann.	...	43
72	59Ni–23Cr–16Mo	Pipe & tube	B619	...	N06059	Sol. ann.	...	43
73	59Ni–23Cr–16Mo	Pipe & tube	B622	...	N06059	Sol. ann.	...	43
74	59Ni–23Cr–16Mo	Wld. tube	B626	...	N06059	Sol. ann.	All	43
75	59Ni–23Cr–16Mo–1.6Cu	Pipe & tube	B619	...	N06200	Sol. ann.	All	43
76	59Ni–23Cr–16Mo–1.6Cu	Pipe & tube	B622	...	N06200	Sol. ann.	All	43
77	59Ni–23Cr–16Mo–1.6Cu	Pipe & tube	B626	...	N06200	Sol. ann.	All	43
78	62Ni–22Mo–15Cr	Pipe & tube	B619	...	N10362	Sol. ann.	All	43
79	62Ni–22Mo–15Cr	Pipe & tube	B622	...	N10362	Sol. ann.	All	43
80	62Ni–22Mo–15Cr	Pipe & tube	B626	...	N10362	Sol. ann.	All	43
81	62Ni–28Mo–5Fe	Pipe & tube	B619	...	N10001	Sol. ann.	...	44
82	62Ni–28Mo–5Fe	Pipe & tube	B622	...	N10001	Sol. ann.	...	44
83	65Ni–28Mo–2Fe	Pipe & tube	B619	...	N10665	Sol. ann.	...	44
84	65Ni–28Mo–2Fe	Pipe & tube	B622	...	N10665	Sol. ann.	...	44
85	65Ni–29.5Mo–2Fe–2Cr	Pipe & tube	B619	...	N10675	Sol. ann.	...	44
86	65Ni–29.5Mo–2Fe–2Cr	Pipe & tube	B622	...	N10675	Sol. ann.	...	44
87	65Ni–29.5Mo–2Fe–2Cr	Pipe & tube	B626	...	N10675	Sol. ann.	...	44
88	60Ni–22Cr–9Mo–3.5Cb	Pipe & tube	B444	1	N06625	Annealed	...	43
89	60Ni–22Cr–9Mo–3.5Cb	Pipe & tube	B705	1	N06625	Annealed	...	43
90	57Ni–22Cr–14W–2Mo–La	Pipe & tube	B619	...	N06230	Sol. ann.	...	43
91	57Ni–22Cr–14W–2Mo–La	Pipe & tube	B622	...	N06230	Sol. ann.	...	43
92	57Ni–22Cr–14W–2Mo–La	Pipe & tube	B626	...	N06230	Sol. ann.	...	43
93	33Cr–31Ni–32Fe–1.5Mo–0.6Cu–N	Pipe	B619	...	R20033	Sol. ann.	...	45
94	33Cr–31Ni–32Fe–1.5Mo–0.6Cu–N	Pipe & tube	B622	...	R20033	Sol. ann.	...	45
95	33Cr–31Ni–32Fe–1.5Mo–0.6Cu–N	Tube	B626	...	R20033	Sol. ann.	...	45
96	99.0Ni–Low C	Plate	B162	...	N02201	H.R. ann.	...	41
97	99.0Ni–Low C	Plate	B162	...	N02201	H.R. as R.	...	41
98	99.0Ni	Plate	B162	...	N02200	H.R. ann.	...	41
99	99.0Ni	Plate	B162	...	N02200	H.R. as R.	...	41
100	33Ni–42Fe–21Cr	Pl. & sht.	B409	...	N08810	Annealed	All	45
101	33Ni–42Fe–21Cr–Al–Ti	Pl. & sht.	B409	...	N08811	Annealed	All	45
102	26Ni–22Cr–5Mo–Ti	Pl. & sht.	B620	...	N08320	Sol. ann.	All	45
103	67Ni–30Cu	Plate	B127	...	N04400	H.R. ann.	...	42
104	47Ni–22Cr–19Fe–6Mo	Pl. & sht.	B582	...	N06007	Sol. ann.	>19	45

Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

Line No.	Notes	Min. Temp., °C (6)	Min. Tensile Str., MPa	Min. Yield Str., MPa	Max. Use Temp., °C	Basic Allowable Stress, S, MPa, at Metal Temperature, °C [Notes (1) and (4b)]								
						Min. Temp. to 40	65	100	125	150	175	200	225	250
68	...	−198	689	310	427	207	207	207	207	207	207	207	204	202
69	...	−198	586	241	427	161	161	161	*161*	*161*	*161*	**154**	**149**	**144**
70	...	−198	586	241	427	161	161	161	*161*	*161*	*161*	**154**	**149**	**144**
71	...	−198	586	241	427	161	161	161	*161*	*161*	*161*	**154**	**149**	**144**
72	...	−198	689	310	427	207	207	207	207	207	207	207	207	206
73	...	−198	689	310	427	207	207	207	207	207	207	207	207	206
74	...	−198	689	310	427	207	207	207	207	207	207	207	207	206
75	...	−198	689	310	427	207	207	207	207	207	207	207	**207**	**200**
76	...	−198	689	310	427	207	207	207	207	207	207	207	**207**	**200**
77	...	−198	689	310	427	207	207	207	207	207	207	207	**207**	**200**
78	...	−198	725	310	427	207	207	207	207	207	207	204	202	199
79	...	−198	725	310	427	207	207	207	207	207	207	204	202	199
80	...	−198	725	310	427	207	207	207	207	207	207	204	202	199
81	...	−198	689	310	427	207	207	207	207	207	207	207	207	207
82	...	−198	689	310	427	207	207	207	207	207	207	207	207	207
83	...	−198	758	352	427	234	234	234	234	234	234	234	234	234
84	...	−198	758	352	427	234	234	234	234	234	234	234	234	234
85	...	−198	758	352	427	234	234	234	234	234	234	234	234	234
86	...	−198	758	352	427	234	234	234	234	234	234	234	234	234
87	...	−198	758	352	427	234	234	234	234	234	234	234	234	234
88	(64) (70)	−198	827	414	649	276	276	276	*274*	*273*	*272*	*270*	*269*	*267*
89	(64) (70)	−198	827	414	649	276	276	276	*274*	*273*	*272*	*270*	*269*	*267*
90	...	−198	758	310	899	207	207	207	207	207	207	207	207	207
91	...	−198	758	310	899	207	207	207	207	207	207	207	207	207
92	...	−198	758	310	899	207	207	207	207	207	207	207	207	207
93	...	−198	750	380	427	250	231	209	200	193	187	181	176	172
94	...	−198	750	380	427	250	231	209	200	193	187	181	176	172
95	...	−198	750	380	427	250	231	209	200	193	187	181	176	172
96	...	−198	345	83	649	55.2	53.8	52.8	52.3	51.9	51.7	51.6	51.6	51.6
97	...	−198	345	83	649	55.2	53.8	52.8	52.3	51.9	51.7	51.6	51.6	51.6
98	...	−198	379	103	316	68.9	68.9	68.9	68.9	68.9	68.9	68.9	68.9	68.9
99	...	−198	379	138	316	91.9	91.9	91.9	91.9	91.9	91.9	91.9	91.9	91.9
100	...	−198	448	172	899	115	115	115	115	115	115	115	115	115
101	...	−198	448	172	899	115	115	115	115	115	115	115	115	115
102	...	−198	517	193	427	129	129	129	129	129	129	129	129	129
103	...	−198	483	193	482	129	119	112	108	105	103	102	101	101
104	...	−198	586	207	538	138	138	138	138	138	138	138	138	138

Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

Line No.	Basic Allowable Stress, *S*, MPa, at Metal Temperature, °C [Notes (1) and (4b)]												
	275	300	325	350	375	400	425	450	475	500	525	550	575
68	197	193	189	185	182	180	177	177	...	...	...	...	...
69	**140**	**137**	**135**	**133**	**132**	**131**	**129**	**128**	...	...	...	...	...
70	**140**	**137**	**135**	**133**	**132**	**131**	**129**	**128**	...	...	...	...	...
71	**140**	**137**	**135**	**133**	**132**	**131**	**129**	**128**	...	...	...	...	...
72	202	197	192	188	184	180	176	176	...	...	...	...	...
73	202	197	192	188	184	180	176	176	...	...	...	...	...
74	202	197	192	188	184	180	176	176	...	...	...	...	...
75	**194**	**188**	**184**	**180**	**177**	**175**	**174**	**173**	...	...	...	...	...
76	**194**	**188**	**184**	**180**	**177**	**175**	**174**	**173**	...	...	...	...	...
77	**194**	**188**	**184**	**180**	**177**	**175**	**174**	**173**	...	...	...	...	...
78	197	193	190	188	186	184	182	180	...	...	...	...	...
79	197	193	190	188	186	184	182	180	...	...	...	...	...
80	197	193	190	188	186	184	182	180	...	...	...	...	...
81	207	207	207	207	207	207	206	206	...	...	...	...	...
82	207	207	207	207	207	207	206	206	...	...	...	...	...
83	234	234	234	234	234	234	234	234	...	...	...	...	...
84	234	234	234	234	234	234	234	234	...	...	...	...	...
85	234	234	234	234	234	**233**	**231**	**230**	...	...	...	...	...
86	234	234	234	234	234	**233**	**231**	**230**	...	...	...	...	...
87	234	234	234	234	234	**233**	**231**	**230**	...	...	...	...	...
88	*265*	*262*	*260*	*257*	*255*	*252*	*251*	*249*	*247*	*245*	*242*	**215**	**194**
89	*265*	*262*	*260*	*257*	*255*	*252*	*251*	*249*	*247*	*245*	*242*	**215**	**194**
90	207	207	203	199	197	196	195	195	195	195	195	195	183
91	207	207	203	199	197	196	195	195	195	195	195	195	183
92	207	207	203	199	197	196	195	195	195	195	195	195	183
93	169	165	163	161	159	157	156	155	...	...	...	...	...
94	169	165	163	161	159	157	156	155	...	...	...	...	...
95	169	165	163	161	159	157	156	155	...	...	...	...	...
96	51.6	51.6	51.6	51.5	51.2	50.7	49.9	**41.4**	**33.1**	**27.4**	**22.8**	**18.7**	**15.6**
97	51.6	51.6	51.6	51.5	51.2	50.7	49.9	**41.4**	**33.1**	**27.4**	**22.8**	**18.7**	**15.6**
98	68.9	68.9	68.9	...	...	...	...	...	...	...	...	...	...
99	91.9	91.9	91.9	...	...	...	...	...	...	...	...	...	...
100	115	115	113	110	108	105	104	102	100	98.6	97.1	95.9	**91.8**
101	115	115	113	110	108	105	104	102	100	98.6	97.1	96.1	**94.1**
102	129	129	127	125	122	121	119	119	...	...	...	...	...
103	101	101	101	101	100	99.6	98.6	**79.7**	**59.9**	**55.2**	...	...	...
104	138	135	134	132	131	130	129	128	128	127	127	126	...

Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

	Basic Allowable Stress, *S*, MPa, at Metal Temperature, °C [Notes (1) and (4b)]												
Line No.	600	625	650	675	700	725	750	775	800	825	850	875	900
68	...	...	...	...	...	...	...	...	...	...	...	...	...
69	...	...	...	...	...	...	...	...	...	...	...	...	...
70	...	...	...	...	...	...	...	...	...	...	...	...	...
71	...	...	...	...	...	...	...	...	...	...	...	...	...
72	...	...	...	...	...	...	...	...	...	...	...	...	...
73	...	...	...	...	...	...	...	...	...	...	...	...	...
74	...	...	...	...	...	...	...	...	...	...	...	...	...
75	...	...	...	...	...	...	...	...	...	...	...	...	...
76	...	...	...	...	...	...	...	...	...	...	...	...	...
77	...	...	...	...	...	...	...	...	...	...	...	...	...
78	...	...	...	...	...	...	...	...	...	...	...	...	...
79	...	...	...	...	...	...	...	...	...	...	...	...	...
80	...	...	...	...	...	...	...	...	...	...	...	...	...
81	...	...	...	...	...	...	...	...	...	...	...	...	...
82	...	...	...	...	...	...	...	...	...	...	...	...	...
83	...	...	...	...	...	...	...	...	...	...	...	...	...
84	...	...	...	...	...	...	...	...	...	...	...	...	...
85	...	...	...	...	...	...	...	...	...	...	...	...	...
86	...	...	...	...	...	...	...	...	...	...	...	...	...
87	...	...	...	...	...	...	...	...	...	...	...	...	...
88	**156**	**136**	**91.0**	...	...	...	...	...	...	...	...	...	...
89	**156**	**136**	**91.0**	...	...	...	...	...	...	...	...	...	...
90	**153**	**128**	**107**	**89.7**	**74.7**	**61.9**	**50.8**	**41.1**	**32.6**	**25.2**	**18.9**	**13.8**	**10.2**
91	**153**	**128**	**107**	**89.7**	**74.7**	**61.9**	**50.8**	**41.1**	**32.6**	**25.2**	**18.9**	**13.8**	**10.2**
92	**153**	**128**	**107**	**89.7**	**74.7**	**61.9**	**50.8**	**41.1**	**32.6**	**25.2**	**18.9**	**13.8**	**10.2**
93	...	...	...	...	...	...	...	...	...	...	...	...	...
94	...	...	...	...	...	...	...	...	...	...	...	...	...
95	...	...	...	...	...	...	...	...	...	...	...	...	...
96	**12.9**	**10.0**	**8.27**	...	...	...	...	...	...	...	...	...	...
97	**12.9**	**10.0**	**8.27**	...	...	...	...	...	...	...	...	...	...
98	...	...	...	...	...	...	...	...	...	...	...	...	...
99	...	...	...	...	...	...	...	...	...	...	...	...	...
100	**75.7**	**62.6**	**50.6**	**41.2**	**33.6**	**27.7**	**22.6**	**18.3**	**15.0**	**11.9**	**9.03**	**7.35**	**5.86**
101	**85.5**	**69.3**	**56.8**	**46.8**	**38.6**	**31.5**	**25.5**	**20.6**	**17.1**	**13.8**	**10.7**	**7.98**	**6.20**
102	...	...	...	...	...	...	...	...	...	...	...	...	...
103	...	...	...	...	...	...	...	...	...	...	...	...	...
104	...	...	...	...	...	...	...	...	...	...	...	...	...

Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

Line No.	Nominal Composition	Product Form	Spec. No.	Type/ Grade	UNS No.	Class/ Condition/ Temper	Size, mm	P-No. (5)
105	33Ni–42Fe–21Cr	Pl. & sht.	B409	...	N08800	Annealed	All	45
106	31Ni–31Fe–29Cr–Mo	Pl. & sht.	B709	...	N08028	Sol. ann.	All	45
107	42Ni–21.5Cr–3Mo–2.3Cu	Plate	B424	...	N08825	Annealed	...	45
108	35Ni–35Fe–20Cr–Cb	Pl. & sht.	B463	...	N08020	Annealed	All	45
109	40Ni–29Cr–15Fe–5Mo	Pl. & sht.	B582	...	N06030	Sol. ann.	All	45
110	47Ni–22Cr–19Fe–6Mo	Pl. & sht.	B582	...	N06007	Sol. ann.	≤19	45
111	47Ni–22Cr–9Mo–18Fe	Pl. & sht.	B435	...	N06002	H.R sol. ann.	All	43
112	72Ni–15Cr–8Fe	Plate	B168	...	N06600	H.R. ann.	...	43
113	72Ni–15Cr–8Fe	Plate	B168	...	N06600	H.R. as R.	...	43
114	58Ni–29Cr–9Fe	Plate	B168	...	N06690	Annealed	≥5	43
115	58Ni–29Cr–9Fe	Sheet	B168	...	N06690	H.R. ann. or C.R. ann.	0.5 to 6	43
116	67Ni–30Cu	Plate	B127	...	N04400	H.R. as R.	...	42
117	37Ni–33Fe–25Cr	Pl. & sht.	B409	...	N08120	Sol. ann.	All	45
118	31Ni–33Fe–27Cr–6.5Mo–Cu–N	Pl. & sht.	B625	...	N08031	Annealed	All	45
119	61Ni–16Mo–16Cr	Pl. & sht.	B575	...	N06455	Sol. ann.	All	43
120	54Ni–16Mo–15Cr	Pl. & sht.	B575	...	N10276	Sol. ann.	All	43
121	60Ni–22Cr–9Mo–3.5Cb	Plate	B443	1	N06625	Annealed	All	43
122	57Ni–22Cr–14W–2Mo–La	Pl. & sht.	B435	...	N06230	Sol. ann.	All	43
123	55Ni–21Cr–13.5Mo	Sheet	B575	...	N06022	Sol. ann.	<5	43
124	58Ni–33Cr–8Mo	Pl. & sht.	B575	...	N06035	Sol. ann.	All	43
125	46Fe–24Ni–21Cr–6Mo–Cu–N	Pl. & sht.	B688	...	N08367	Annealed	>5	45
126	46Fe–24Ni–21Cr–6Mo–Cu–N	Pl. & sht.	B688	...	N08367	Annealed	≤5	45
127	59Ni–23Cr–16Mo	Pl. & sht.	B575	...	N06059	Sol. ann.	All	43
128	59Ni–23Cr–16Mo–1.6Cu	Pl. & sht.	B575	...	N06200	Sol. ann.	All	43
129	62Ni–22Mo–15Cr	Pl. & sht.	B575	...	N10362	Sol. ann.	All	43
130	62Ni–28Mo–5Fe	Plate	B333	...	N10001	Sol. ann.	≥5, ≤64	44
131	62Ni–28Mo–5Fe	Sheet	B333	...	N10001	Sol. ann.	≤5	44
132	65Ni–28Mo–2Fe	Pl. & sht.	B333	...	N10665	Sol. ann.	All	44
133	65Ni–29.5Mo–2Fe–2Cr	Pl. & sht.	B333	...	N10675	Sol. ann.	All	44
134	33Cr–31Ni–32Fe–1.5Mo–0.6Cu–N	Pl. & sht.	B625	...	R20033	Sol. ann.	...	45
135	99.0Ni–Low C	Forg. & ftg.	B160	...	N02201	Annealed	All	41
136	99.0Ni–Low C	Forg. & ftg.	B366	...	N02201	Annealed	All	41
137	99.0Ni	Forg. & ftg.	B366	...	N02200	Annealed	All	41
138	99.0Ni	Forg. & ftg.	B564	...	N02200	Annealed	All	41

Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

						Basic Allowable Stress, *S*, MPa, at Metal Temperature, °C [Notes (1) and (4b)]								
Line No.	Notes	Min. Temp., °C (6)	Min. Tensile Str., MPa	Min. Yield Str., MPa	Max. Use Temp., °C	Min. Temp. to 40	65	100	125	150	175	200	225	250
105	...	−198	517	207	816	138	138	138	138	138	138	138	138	138
106	...	−198	505	215	454	143	*143*	*143*	*143*	*143*	*143*	*143*	*143*	*143*
107	(9)	−198	585	240	538	161	161	161	161	161	161	161	161	161
108	...	−198	552	241	427	161	161	161	161	161	161	161	161	161
109	...	−198	586	241	427	161	*161*	*161*	*161*	*161*	*161*	*161*	**157**	**154**
110	...	−198	621	241	538	161	161	161	161	161	161	161	161	161
111	...	−198	655	241	427	161	161	161	161	161	161	161	161	156
112	...	−198	552	241	649	161	161	161	161	161	161	161	161	161
113	...	−198	586	241	649	161	161	161	161	161	161	161	161	161
114	...	−198	586	240	482	160	160	160	160	160	160	160	160	160
115	...	−198	586	240	482	160	160	160	160	160	160	160	160	160
116	...	−198	517	276	482	*172*	*172*	*172*	*171*	*170*	168	165	164	162
117	...	−198	621	276	899	184	184	184	184	184	184	184	180	175
118	...	−198	648	276	427	184	184	184	184	184	177	171	166	162
119	...	−198	689	276	427	184	184	184	184	184	184	184	184	184
120	...	−198	689	283	677	188	188	188	188	188	188	188	188	187
121	(64) (70)	−198	758	379	649	253	253	253	*251*	*250*	*249*	*248*	*247*	*245*
122	...	−198	758	310	899	207	207	207	207	207	207	207	207	207
123	...	−198	689	310	427	207	207	207	207	207	207	207	204	202
124	...	−198	586	241	427	161	161	161	*161*	*161*	*161*	**154**	**149**	**144**
125	...	−198	655	310	427	207	207	207	207	*206*	*202*	*198*	*195*	*192*
126	...	−198	689	310	427	207	207	207	207	207	207	206	199	193
127	...	−198	689	310	427	207	207	207	207	207	207	207	207	206
128	...	−198	689	310	427	207	207	207	207	207	207	207	**207**	**200**
129	...	−198	725	310	427	207	207	207	207	207	207	204	202	199
130	...	−198	689	310	427	207	207	207	207	207	207	207	207	207
131	...	−198	793	345	427	230	230	230	230	230	230	230	230	230
132	...	−198	758	352	427	234	234	234	234	234	234	234	234	234
133	...	−198	758	352	427	234	*234*	*234*	*234*	*234*	*234*	*234*	*234*	*234*
134	...	−198	750	380	427	250	231	209	200	193	187	181	176	172
135	(9) (9a)	−198	345	69	649	46.0	44.7	43.9	43.6	43.3	43.2	43.2	43.2	43.2
136	(32) (74)	−198	345	69	649	46.0	44.7	43.9	43.6	43.3	43.2	43.2	43.2	43.2
137	(32) (74)	−198	380	105	260	70.0	70.0	70.0	70.0	70.0	70.0	70.0	70.0	70.0
138	(9)	−198	379	103	316	68.9	68.9	68.9	68.9	68.9	68.9	68.9	68.9	68.9

Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

Line No.	Basic Allowable Stress, *S*, MPa, at Metal Temperature, °C [Notes (1) and (4b)]												
	275	300	325	350	375	400	425	450	475	500	525	550	575
105	138	138	138	138	138	138	138	138	138	138	138	136	**107**
106	**140**	**137**	**133**	**130**	**125**	**122**	**119**	**116**	**113**	...	...	...	...
107	161	161	161	161	161	160	159	158	157	156	155	153	...
108	161	161	161	161	161	160	157	156	...	...	...	...	...
109	**151**	**148**	**146**	**143**	**141**	**138**	**136**	**136**	...	...	...	...	...
110	160	158	156	154	153	152	151	150	149	**136**	**132**	**130**	...
111	152	148	145	142	140	138	137	137	...	...	...	...	...
112	161	161	161	161	161	161	161	161	161	**84.8**	**58.4**	**39.7**	**27.0**
113	161	161	161	161	161	161	161	161	161	**84.8**	**58.4**	**39.7**	**27.0**
114	160	160	160	160	160	160	160	160	160	160	...	...	...
115	160	160	160	160	160	160	160	160	160	160	...	...	...
116	161	160	159	158	156	**136**	**102**	**63.8**	**33.5**	**27.6**	...	...	...
117	170	166	163	160	158	156	154	153	153	152	151	151	151
118	158	155	152	149	146	144	141	140	...	...	...	...	...
119	184	184	184	184	182	180	178	176	...	...	...	...	...
120	183	177	172	169	165	162	159	157	156	155	154	**143**	**118**
121	*243*	*241*	*238*	*236*	*233*	*231*	*230*	*228*	*227*	*225*	*222*	**215**	**194**
122	207	207	203	199	197	196	195	195	195	195	195	195	183
123	197	193	189	185	182	180	177	177	...	...	...	...	...
124	**140**	**137**	**135**	**133**	**132**	**131**	**129**	**128**	...	...	...	...	...
125	188	183	179	176	173	170	168	167	...	...	...	...	...
126	188	183	179	176	173	170	168	167	...	...	...	...	...
127	202	197	192	188	184	180	176	176	...	...	...	...	...
128	**194**	**188**	**184**	**180**	**177**	**175**	**174**	**173**	...	...	...	...	...
129	197	193	190	188	186	184	182	180	...	...	...	...	...
130	207	207	207	207	207	207	206	206	...	...	...	...	...
131	230	230	230	230	230	230	229	229	...	...	...	...	...
132	234	234	234	234	234	234	234	234	...	...	...	...	...
133	*234*	*234*	*234*	*234*	*234*	**233**	**231**	**230**	...	...	...	...	...
134	169	165	163	161	159	157	156	155	...	...	...	...	...
135	43.2	43.2	43.1	42.9	42.6	42.1	41.5	40.7	**33.1**	**27.4**	**22.8**	**18.7**	**15.6**
136	43.2	43.2	43.1	42.9	42.6	42.1	41.5	40.7	**33.1**	**27.4**	**22.8**	**18.7**	**15.6**
137	70.0	...	...	...	...	...	...	...	...	...	...	...	...
138	68.9	68.9	68.9	...	...	...	...	...	...	...	...	...	...

Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

	Basic Allowable Stress, *S*, MPa, at Metal Temperature, °C [Notes (1) and (4b)]												
Line No.	600	625	650	675	700	725	750	775	800	825	850	875	900
105	83.8	63.9	44.7	29.8	15.5	11.7	8.68	7.20	6.25	5.11	...	...	...
106	...	...	...	...	...	...	...	...	...	...	...	...	...
107	...	...	...	...	...	...	...	...	...	...	...	...	...
108	...	...	...	...	...	...	...	...	...	...	...	...	...
109	...	...	...	...	...	...	...	...	...	...	...	...	...
110	...	...	...	...	...	...	...	...	...	...	...	...	...
111	...	...	...	...	...	...	...	...	...	...	...	...	...
112	19.2	15.0	13.8	...	...	...	...	...	...	...	...	...	...
113	19.2	15.0	13.8	...	...	...	...	...	...	...	...	...	...
114	...	...	...	...	...	...	...	...	...	...	...	...	...
115	...	...	...	...	...	...	...	...	...	...	...	...	...
116	...	...	...	...	...	...	...	...	...	...	...	...	...
117	117	96.2	79.3	65.6	54.4	45.0	37.2	30.6	25.1	20.5	16.5	13.0	9.8
118	...	...	...	...	...	...	...	...	...	...	...	...	...
119	...	...	...	...	...	...	...	...	...	...	...	...	...
120	99.1	81.6	67.0	54.6	42.2	...	...	...	...	...	...	...	...
121	156	136	91.0	...	...	...	...	...	...	...	...	...	...
122	153	128	107	89.7	74.7	61.9	50.8	41.1	32.6	25.2	18.9	13.8	10.2
123	...	...	...	...	...	...	...	...	...	...	...	...	...
124	...	...	...	...	...	...	...	...	...	...	...	...	...
125	...	...	...	...	...	...	...	...	...	...	...	...	...
126	...	...	...	...	...	...	...	...	...	...	...	...	...
127	...	...	...	...	...	...	...	...	...	...	...	...	...
128	...	...	...	...	...	...	...	...	...	...	...	...	...
129	...	...	...	...	...	...	...	...	...	...	...	...	...
130	...	...	...	...	...	...	...	...	...	...	...	...	...
131	...	...	...	...	...	...	...	...	...	...	...	...	...
132	...	...	...	...	...	...	...	...	...	...	...	...	...
133	...	...	...	...	...	...	...	...	...	...	...	...	...
134	...	...	...	...	...	...	...	...	...	...	...	...	...
135	12.9	10.0	8.27	...	...	...	...	...	...	...	...	...	...
136	12.9	10.0	8.27	...	...	...	...	...	...	...	...	...	...
137	...	...	...	...	...	...	...	...	...	...	...	...	...
138	...	...	...	...	...	...	...	...	...	...	...	...	...

Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

Line No.	Nominal Composition	Product Form	Spec. No.	Type/ Grade	UNS No.	Class/ Condition/ Temper	Size, mm	P-No. (5)
139	33Ni–42Fe–21Cr	Forg. & ftg.	B564	...	N08810	Annealed	...	45
140	33Ni–42Fe–21Cr–Al–Ti	Forg. & ftg.	B564	...	N08811	Annealed	...	45
141	33Ni–42Fe–21Cr	Fittings	B366	...	N08810	Annealed	All	45
142	33Ni–42Fe–21Cr–Al–Ti	Fittings	B366	...	N08811	Annealed	All	45
143	67Ni–30Cu	Forg. & ftg.	B564	...	N04400	Annealed	...	42
144	67Ni–30Cu	Forg. & ftg.	B366	...	N04400	Annealed	All	42
145	72Ni–15Cr–8Fe	Forg. & ftg.	B366	...	N06600	Annealed	All	43
146	40Ni–29Cr–15Fe–5Mo	Forg. & ftg.	B366	...	N06030	Sol. ann.	All	45
147	40Ni–29Cr–15Fe–5Mo	Forg. & ftg.	B462	...	N06030	Sol. ann.	All	45
148	33Ni–42Fe–21Cr	Forg. & ftg.	B366	...	N08800	C.D. ann.	All	45
149	33Ni–42Fe–21Cr	Forg. & ftg.	B564	...	N08800	Annealed	...	45
150	35Ni–35Fe–20Cr–Cb	Forg. & ftg.	B366	...	N08020	Annealed	All	45
151	35Ni–35Fe–20Cr–Cb	Forg. & ftg.	B462	...	N08020	Annealed	...	45
152	72Ni–15Cr–8Fe	Forg. & ftg.	B564	...	N06600	Annealed	All	43
153	42Ni–21.5Cr–3Mo–2.3Cu	Fittings	B366	...	N08825	C.D. ann.	All	45
154	42Ni–21.5Cr–3Mo–2.3Cu	Forgings	B564	...	N08825	Annealed	...	45
155	58Ni–29Cr–9Fe	Forgings	B564	...	N06690	Annealed	All	43
156	37Ni–33Fe–25Cr	Fittings	B366	...	N08120	Sol. ann.	All	45
157	37Ni–33Fe–25Cr	Forgings	B564	...	N08120	Sol. ann.	All	45
158	47Ni–22Cr–9Mo–18Fe	Forg. & ftg.	B366	...	N06002	Sol. ann.	All	43
159	31Ni–33Fe–27Cr–6.5Mo–Cu–N	Forg. & ftg.	B366	...	N08031	Sol. ann.	All	45
160	31Ni–33Fe–27Cr–6.5Mo–Cu–N	Forg. & ftg.	B564	...	N08031	Annealed H.W.	All	45
161	54Ni–16Mo–15Cr	Forg. & ftg.	B366	...	N10276	Sol. ann.	All	43
162	54Ni–16Mo–15Cr	Forg. & ftg.	B462	...	N10276	Sol. ann.	All	43
163	54Ni–16Mo–15Cr	Forg. & ftg.	B564	...	N10276	Sol. ann.	All	43
164	62Ni–28Mo–5Fe	Forg. & ftg.	B366	...	N10001	Sol. ann.	All	44
165	55Ni–21Cr–13.5Mo	Forg. & ftg.	B366	...	N06022	Sol. ann.	All	43
166	55Ni–21Cr–13.5Mo	Forg. & ftg.	B462	...	N06022	Sol. ann.	All	43
167	55Ni–21Cr–13.5Mo	Forg. & ftg.	B564	...	N06022	Sol. ann.	All	43
168	58Ni–33Cr–8Mo	Forg. & ftg.	B366	...	N06035	Sol. ann.	All	43
169	58Ni–33Cr–8Mo	Forg. & ftg.	B462	...	N06035	Sol. ann.	All	43
170	58Ni–33Cr–8Mo	Forg. & ftg.	B564	...	N06035	Sol. ann.	All	43
171	59Ni–23Cr–16Mo	Forg. & ftg.	B366	...	N06059	Sol. ann.	All	43
172	59Ni–23Cr–16Mo	Forg. & ftg.	B564	...	N06059	H.W. sol. ann.	All	43
173	59Ni–23Cr–16Mo–1.6Cu	Forg. & ftg.	B366	...	N06200	Sol. ann.	All	43
174	59Ni–23Cr–16Mo–1.6Cu	Forg. & ftg.	B462	...	N06200	Sol. ann.	All	43

Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

Line No.	Notes	Min. Temp., °C (6)	Min. Tensile Str., MPa	Min. Yield Str., MPa	Max. Use Temp., °C	Basic Allowable Stress, S, MPa, at Metal Temperature, °C [Notes (1) and (4b)] Min. Temp. to 40	65	100	125	150	175	200	225	250
139	(9)	−198	448	172	899	115	115	115	115	115	115	115	115	115
140	(9)	−198	448	172	899	115	115	115	115	115	115	115	115	115
141	(9) (74)	−198	450	170	899	115	115	115	115	115	115	115	115	115
142	(9) (74)	−198	450	170	899	115	115	115	115	115	115	115	115	115
143	(9)	−198	483	172	482	115	106	99.7	96.2	93.6	91.9	90.9	90.4	90.4
144	(32) (74)	−198	483	172	482	115	106	99.7	96.2	93.6	91.9	90.9	90.4	90.4
145	(32) (74)	−198	517	172	649	115	115	115	115	115	115	115	115	115
146	(74)	−198	586	241	427	161	*161*	*161*	*161*	*161*	*161*	*161*	**157**	**154**
147	...	−198	586	241	427	161	*161*	*161*	*161*	*161*	*161*	*161*	**157**	**154**
148	(74)	−198	517	207	816	138	138	138	138	138	138	138	138	138
149	(9)	−198	517	207	816	138	138	138	138	138	138	138	138	138
150	(74)	−198	552	241	427	161	161	161	161	161	161	161	161	161
151	(9)	−198	552	241	427	161	161	161	161	161	161	161	161	161
152	(9)	−198	552	241	649	161	161	161	161	161	161	161	161	161
153	(9) (74)	−198	585	240	538	161	161	161	161	161	161	161	161	161
154	(9)	−198	585	240	538	160	160	160	160	160	160	160	160	160
155	(9)	−198	586	241	482	160	160	160	160	160	160	160	160	160
156	...	−198	621	276	899	184	184	184	184	184	184	184	180	175
157	...	−198	621	276	899	184	184	184	184	184	184	184	180	175
158	(32)	−198	689	276	816	184	184	184	184	184	184	184	184	178
159	(74)	−198	648	276	427	184	184	184	184	184	177	171	166	162
160	...	−198	648	276	427	184	184	184	184	184	177	171	166	162
161	(74)	−198	689	283	677	188	188	188	188	188	188	188	188	187
162	(9)	−198	689	283	677	188	188	188	188	188	188	188	188	187
163	(9)	−198	689	283	677	188	188	188	188	188	188	188	188	187
164	(32)	−198	689	310	427	207	207	207	207	207	207	207	207	207
165	(32) (74)	−198	689	310	427	207	207	207	207	207	207	207	204	202
166	(9)	−198	689	310	427	207	207	207	207	207	207	207	204	202
167	(9)	−198	689	310	427	207	207	207	207	207	207	207	204	202
168	(32) (74)	−198	586	241	427	161	161	161	*161*	*161*	*161*	**154**	**149**	**144**
169	(9)	−198	586	241	427	161	161	161	*161*	*161*	*161*	**154**	**149**	**144**
170	(9)	−198	586	241	427	161	161	161	*161*	*161*	*161*	**154**	**149**	**144**
171	(74)	−198	689	310	427	207	207	207	207	207	207	207	207	206
172	...	−198	689	310	427	207	207	207	207	207	207	207	207	206
173	(74)	−198	689	310	427	207	207	207	207	207	207	207	**207**	**200**
174	...	−198	689	310	427	207	207	207	207	207	207	207	**207**	**200**

Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

Line No.	Basic Allowable Stress, *S*, MPa, at Metal Temperature, °C [Notes (1) and (4b)]												
	275	300	325	350	375	400	425	450	475	500	525	550	575
139	115	115	113	110	108	105	104	102	100	98.6	97.1	95.9	91.8
140	115	115	113	110	108	105	104	102	100	98.7	97.1	96.1	94.1
141	115	115	113	110	108	105	104	102	100	98.6	97.1	95.9	91.8
142	115	115	113	110	108	105	104	102	100	98.7	97.1	96.1	94.1
143	90.4	90.4	90.4	90.4	89.8	89.0	88.0	**79.7**	**59.9**	**55.2**	...	...	...
144	90.4	90.4	90.4	90.4	89.8	89.0	88.0	**79.7**	**59.9**	**55.2**	...	...	...
145	115	115	115	115	115	115	115	115	115	**84.8**	**58.4**	**39.7**	**27.0**
146	**151**	**148**	**146**	**143**	**141**	**138**	**136**	**136**	...	...	...	...	...
147	**151**	**148**	**146**	**143**	**141**	**138**	**136**	**136**	...	...	...	...	...
148	138	138	138	138	138	138	138	138	138	138	138	136	**107**
149	138	138	138	138	138	138	138	138	138	138	138	136	**107**
150	161	161	161	161	161	160	157	156	...	...	...	...	...
151	161	161	161	161	161	160	157	156	...	...	...	...	...
152	161	161	161	161	161	161	161	161	161	**84.8**	**58.4**	**39.7**	**27.0**
153	161	161	161	161	161	160	159	158	157	156	155	153	...
154	160	160	160	160	160	159	158	157	156	156	154	151	...
155	160	160	160	160	160	160	160	160	160	160	...	...	...
156	170	166	163	160	158	156	154	153	153	152	151	151	151
157	170	166	163	160	158	156	154	153	153	152	151	151	151
158	173	169	165	162	160	158	157	155	154	**135**	**134**	**133**	**129**
159	158	155	152	149	146	144	141	141	...	...	...	...	...
160	158	155	152	149	146	144	141	141	...	...	...	...	...
161	183	177	172	169	165	162	159	157	156	155	154	**143**	**118**
162	183	177	172	169	165	162	159	157	156	155	154	**143**	**118**
163	183	177	172	169	165	162	159	157	156	155	154	**143**	**118**
164	207	207	207	207	207	207	206	206	...	...	...	...	...
165	197	193	189	185	182	180	177	177	...	...	...	...	...
166	197	193	189	185	182	180	177	177	...	...	...	...	...
167	197	193	189	185	182	180	177	177	...	...	...	...	...
168	**140**	**137**	**135**	**133**	**132**	**131**	**129**	**128**	...	...	...	...	...
169	**140**	**137**	**135**	**133**	**132**	**131**	**129**	**128**	...	...	...	...	...
170	**140**	**137**	**135**	**133**	**132**	**131**	**129**	**128**	...	...	...	...	...
171	202	197	192	188	184	180	176	176	...	...	...	...	...
172	202	197	192	188	184	180	176	176	...	...	...	...	...
173	**194**	**188**	**184**	**180**	**177**	**175**	**174**	**173**	...	...	...	...	...
174	**194**	**188**	**184**	**180**	**177**	**175**	**174**	**173**	...	...	...	...	...

Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

Line No.	Basic Allowable Stress, *S*, MPa, at Metal Temperature, °C [Notes (1) and (4b)]												
	600	625	650	675	700	725	750	775	800	825	850	875	900
139	75.7	62.6	50.6	41.2	33.6	27.7	22.6	18.3	15.0	11.9	9.03	7.35	5.86
140	85.5	69.3	56.8	46.8	38.6	31.5	25.5	20.6	17.1	13.8	10.2	7.98	6.20
141	75.7	62.6	50.6	41.2	33.6	27.7	22.6	18.3	15.0	11.9	9.03	7.35	5.86
142	85.5	69.3	56.8	46.8	38.6	31.5	25.5	20.6	17.1	13.8	10.2	7.98	6.20
143	...	...	...	...	...	...	...	...	...	...	...	...	...
144	...	...	...	...	...	...	...	...	...	...	...	...	...
145	19.2	15.0	13.8	...	...	...	...	...	...	...	...	...	...
146	...	...	...	...	...	...	...	...	...	...	...	...	...
147	...	...	...	...	...	...	...	...	...	...	...	...	...
148	83.8	63.9	44.7	29.8	15.5	11.7	8.68	7.20	6.25	5.11	...	...	...
149	83.8	63.9	44.7	29.8	15.5	11.7	8.68	7.20	6.25	5.11	...	...	...
150	...	...	...	...	...	...	...	...	...	...	...	...	...
151	...	...	...	...	...	...	...	...	...	...	...	...	...
152	19.2	15.0	13.8	...	...	...	...	...	...	...	...	...	...
153	...	...	...	...	...	...	...	...	...	...	...	...	...
154	...	...	...	...	...	...	...	...	...	...	...	...	...
155	...	...	...	...	...	...	...	...	...	...	...	...	...
156	117	96.2	79.3	65.6	54.4	45.0	37.2	30.6	25.1	20.5	16.5	13.0	9.8
157	117	96.2	79.3	65.6	54.4	45.0	37.2	30.6	25.1	20.5	16.5	13.0	9.8
158	115	94.2	77.3	64.9	54.7	44.7	36.1	29.2	23.6	19.1	...	...	...
159	...	...	...	...	...	...	...	...	...	...	...	...	...
160	...	...	...	...	...	...	...	...	...	...	...	...	...
161	99.1	81.6	67.0	54.6	42.2	...	...	...	...	...	...	...	...
162	99.1	81.6	67.0	54.6	42.2	...	...	...	...	...	...	...	...
163	99.1	81.6	67.0	54.6	42.2	...	...	...	...	...	...	...	...
164	...	...	...	...	...	...	...	...	...	...	...	...	...
165	...	...	...	...	...	...	...	...	...	...	...	...	...
166	...	...	...	...	...	...	...	...	...	...	...	...	...
167	...	...	...	...	...	...	...	...	...	...	...	...	...
168	...	...	...	...	...	...	...	...	...	...	...	...	...
169	...	...	...	...	...	...	...	...	...	...	...	...	...
170	...	...	...	...	...	...	...	...	...	...	...	...	...
171	...	...	...	...	...	...	...	...	...	...	...	...	...
172	...	...	...	...	...	...	...	...	...	...	...	...	...
173	...	...	...	...	...	...	...	...	...	...	...	...	...
174	...	...	...	...	...	...	...	...	...	...	...	...	...

Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

Line No.	Nominal Composition	Product Form	Spec. No.	Type/ Grade	UNS No.	Class/ Condition/ Temper	Size, mm	P-No. (5)
175	59Ni–23Cr–16Mo–1.6Cu	Forg. & ftg.	B564	...	N06200	Sol. ann.	All	43
176	62Ni–22Mo–15Cr	Fittings	B366	...	N10362	Sol. ann.	All	43
177	62Ni–22Mo–15Cr	Forgings	B462	...	N10362	Sol. ann.	All	43
178	62Ni–22Mo–15Cr	Forgings	B564	...	N10362	Sol. ann.	All	43
179	60Ni–22Cr–9Mo–3.5Cb	Forg. & ftg.	B564	...	N06625	Annealed	≤100	43
180	65Ni–28Mo–2Fe	Forg. & ftg.	B366	...	N10665	Sol. ann.	All	44
181	65Ni–29.5Mo–2Fe–2Cr	Forg. & ftg.	B366	...	N10675	Sol. ann.	All	44
182	65Ni–29.5Mo–2Fe–2Cr	Forg. & ftg.	B462	...	N10675	Sol. ann.	All	44
183	65Ni–29.5Mo–2Fe–2Cr	Forg. & ftg.	B564	...	N10675	Sol. ann.	All	44
184	57Ni–22Cr–14W–2Mo–La	Forg. & ftg.	B564	...	N06230	Sol. ann.	All	43
185	57Ni–22Cr–14W–2Mo–La	Forg. & ftg.	B366	...	N06230	Sol. ann.	All	43
186	33Cr–31Ni–32Fe–1.5Mo–0.6Cu–N	Fittings	B366	...	R20033	Sol. ann.	...	45
187	33Cr–31Ni–32Fe–1.5Mo–0.6Cu–N	Fittings	B462	...	R20033	Sol. ann.	...	45
188	33Cr–31Ni–32Fe–1.5Mo–0.6Cu–N	Forgings	B564	...	R20033	Sol. ann.	...	45
189	99.0Ni	Rod & bar	B160	...	N02200	H.W.	All	41
190	99.0Ni	Rod & bar	B160	...	N02200	Annealed	All	41
191	67Ni–30Cu	Rod & bar	B164	...	N04400	Ann. forg.	All	42
192	33Ni–42Fe–21Cr	Rod & bar	B408	...	N08810	Sol. trt. or ann.	...	45
193	33Ni–42Fe–21Cr–Al–Ti	Rod & bar	B408	...	N08811	Annealed	...	45
194	33Ni–42Fe–21Cr	Rod & bar	B408	...	N08800	Annealed	...	45
195	26Ni–22Cr–5Mo–Ti	Rod & bar	B621	...	N08320	Sol. ann.	All	45
196	47Ni–22Cr–19Fe–6Mo	Rod & bar	B581	...	N06007	Sol. ann.	>19	45
197	42Ni–21.5Cr–3Mo–2.3Cu	Rod & bar	B425	...	N08825	Annealed	...	45
198	58Ni–29Cr–9Fe	Rod & bar	B166	...	N06690	H.R.	>75	43
199	58Ni–29Cr–9Fe	Rod & bar	B166	...	N06690	H.R. ann. or C.D. ann.	All	43
200	47Ni–22Cr–19Fe–6Mo	Rod & bar	B581	...	N06007	Sol. ann.	≤19	45
201	40Ni–29Cr–15Fe–5Mo	Rod & bar	B581	...	N06030	Sol. ann.	All	45
202	31Ni–33Fe–27Cr–6.5Mo–Cu–N	Rod & bar	B649	...	N08031	Annealed	All	45
203	67Ni–30Cu	Rod & bar	B164	...	N04400	H.W.	All except hex >54	42
204	58Ni–33Cr–8Mo	Rod & bar	B574	...	N06035	Sol. ann.	All	43
205	37Ni–33Fe–25Cr	Rod & bar	B408	...	N08120	Sol. ann.	All	45

Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

						Basic Allowable Stress, *S*, MPa, at Metal Temperature, °C [Notes (1) and (4b)]								
Line No.	Notes	Min. Temp., °C (6)	Min. Tensile Str., MPa	Min. Yield Str., MPa	Max. Use Temp., °C	Min. Temp. to 40	65	100	125	150	175	200	225	250
175	...	−198	689	310	427	207	207	207	207	207	207	207	**207**	**200**
176	...	−198	725	310	427	207	207	207	207	207	207	204	202	199
177	...	−198	725	310	427	207	207	207	207	207	207	204	202	199
178	...	−198	725	310	427	207	207	207	207	207	207	204	202	199
179	(9) (64)	−198	827	414	649	276	276	276	*274*	*273*	*272*	*270*	*269*	*267*
180	(74)	−198	758	352	427	234	234	234	234	234	234	234	234	234
181	(74)	−198	758	352	427	234	*234*	*234*	*234*	*234*	*234*	*234*	*234*	*234*
182	...	−198	758	352	427	234	*234*	*234*	*234*	*234*	*234*	*234*	*234*	*234*
183	...	−198	758	352	427	234	*234*	*234*	*234*	*234*	*234*	*234*	*234*	*234*
184	...	−198	758	310	899	207	207	207	207	207	207	207	207	207
185	(74)	−198	758	310	899	207	207	207	207	207	207	207	207	207
186	...	−198	750	380	427	250	231	209	200	193	187	181	176	172
187	...	−198	750	380	427	250	231	209	200	193	187	181	176	172
188	...	−198	750	380	427	250	231	209	200	193	187	181	176	172
189	(9)	−198	414	103	316	68.9	68.9	68.9	68.9	68.9	68.9	68.9	68.9	68.9
190	(9)	−198	379	103	316	68.9	68.9	68.9	68.9	68.9	68.9	68.9	68.9	68.9
191	(13)	−198	483	172	482	115	106	99.7	96.2	93.6	91.9	90.9	90.4	90.4
192	(9)	−198	450	170	899	115	115	115	115	115	115	115	115	115
193	(9)	−198	450	170	899	115	115	115	115	115	115	115	115	115
194	(9)	−198	515	205	816	138	138	138	138	138	138	138	138	138
195	...	−198	517	193	427	129	129	129	129	129	129	129	129	129
196	...	−198	586	207	538	138	138	138	138	138	138	138	138	138
197	(9)	−198	585	240	538	161	161	161	161	161	161	161	161	161
198	...	−198	585	240	482	160	160	160	160	160	160	160	160	160
199	...	−198	586	240	482	160	160	160	160	160	160	160	160	160
200	...	−198	621	241	538	161	161	161	161	161	161	161	161	161
201	...	−198	586	241	427	161	*161*	*161*	*161*	*161*	*161*	*161*	**157**	**154**
202	...	−198	648	276	427	184	184	184	184	184	177	171	166	162
203	...	−198	552	276	510	184	182	177	174	171	168	165	164	162
204	(9)	−198	586	241	427	161	161	161	*161*	*161*	*161*	**154**	**149**	**144**
205	...	−198	621	276	899	184	184	184	184	184	184	184	180	175

Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

Line No.	Basic Allowable Stress, *S*, MPa, at Metal Temperature, °C [Notes (1) and (4b)]												
	275	300	325	350	375	400	425	450	475	500	525	550	575
175	**194**	**188**	**184**	**180**	**177**	**175**	**174**	**173**	...	...	...	...	...
176	197	193	190	188	186	184	182	180	...	...	...	...	...
177	197	193	190	188	186	184	182	180	...	...	...	...	...
178	197	193	190	188	186	184	182	180	...	...	...	...	...
179	*265*	*262*	*260*	*257*	*255*	*252*	*251*	*249*	*247*	*245*	*242*	**215**	**194**
180	234	234	234	234	234	234	234	234	...	...	...	...	...
181	*234*	*234*	*234*	*234*	*234*	**233**	**231**	**230**	...	...	...	...	...
182	*234*	*234*	*234*	*234*	*234*	**233**	**231**	**230**	...	...	...	...	...
183	*234*	*234*	*234*	*234*	*234*	**233**	**231**	**230**	...	...	...	...	...
184	207	207	203	199	197	196	195	195	195	195	195	195	183
185	207	207	203	199	197	196	195	195	195	195	195	195	183
186	169	165	163	161	159	157	156	155	...	...	...	...	...
187	169	165	163	161	159	157	156	155	...	...	...	...	...
188	169	165	163	161	159	157	156	155	...	...	...	...	...
189	68.9	68.9	68.9	...	...	...	...	...	...	...	...	...	...
190	68.9	68.9	68.9	...	...	...	...	...	...	...	...	...	...
191	90.4	90.4	90.4	90.4	89.8	89.0	88.0	**79.7**	**59.9**	**55.2**	...	...	...
192	115	115	113	110	108	105	104	102	100	98.6	97.1	95.9	91.8
193	115	115	113	110	108	105	104	102	100	98.7	97.1	96.1	94.1
194	138	138	138	138	138	138	138	138	138	138	137	131	**108**
195	129	129	127	125	122	121	119	119	...	...	...	...	...
196	138	135	134	132	131	130	129	128	128	127	127	126	...
197	161	161	161	161	161	160	159	158	157	156	155	153	...
198	160	160	160	160	160	160	160	160	160	160	...	...	...
199	160	160	160	160	160	160	160	160	160	160	...	...	...
200	160	158	156	154	153	152	151	150	149	**136**	**132**	**130**	...
201	**151**	**148**	**146**	**143**	**141**	**138**	**136**	**136**	...	...	...	...	...
202	158	155	152	149	146	144	141	141	...	...	...	...	...
203	161	160	159	158	156	**136**	**102**	**63.8**	**33.5**	**17.0**	**13.0**	...	...
204	**140**	**137**	**135**	**133**	**132**	**131**	**129**	**128**	...	...	...	...	...
205	170	166	163	160	158	156	154	153	153	152	151	151	151

Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

	Basic Allowable Stress, *S*, MPa, at Metal Temperature, °C [Notes (1) and (4b)]												
Line No.	600	625	650	675	700	725	750	775	800	825	850	875	900
175	...	...	...	...	...	...	...	...	...	...	...	...	...
176	...	...	...	...	...	...	...	...	...	...	...	...	...
177	...	...	...	...	...	...	...	...	...	...	...	...	...
178	...	...	...	...	...	...	...	...	...	...	...	...	...
179	**156**	**136**	**91.0**	...	...	...	...	...	...	...	...	...	...
180	...	...	...	...	...	...	...	...	...	...	...	...	...
181	...	...	...	...	...	...	...	...	...	...	...	...	...
182	...	...	...	...	...	...	...	...	...	...	...	...	...
183	...	...	...	...	...	...	...	...	...	...	...	...	...
184	**153**	**128**	**107**	**89.7**	**74.7**	**61.9**	**50.8**	**41.1**	**32.6**	**25.2**	**18.9**	**13.8**	**10.2**
185	**153**	**128**	**107**	**89.7**	**74.7**	**61.9**	**50.8**	**41.1**	**32.6**	**25.2**	**18.9**	**13.8**	**10.2**
186	...	...	...	...	...	...	...	...	...	...	...	...	...
187	...	...	...	...	...	...	...	...	...	...	...	...	...
188	...	...	...	...	...	...	...	...	...	...	...	...	...
189	...	...	...	...	...	...	...	...	...	...	...	...	...
190	...	...	...	...	...	...	...	...	...	...	...	...	...
191	...	...	...	...	...	...	...	...	...	...	...	...	...
192	**75.7**	**62.6**	**50.6**	**41.2**	**33.6**	**27.7**	**22.6**	**18.3**	**15.0**	**11.9**	**9.03**	**7.35**	**5.86**
193	**85.5**	**69.3**	**56.8**	**46.8**	**38.6**	**31.5**	**25.5**	**20.6**	**17.1**	**13.8**	**10.2**	**7.98**	**6.20**
194	**85.0**	**64.4**	**44.8**	**30.0**	**15.5**	**11.3**	**8.82**	**6.98**	**6.43**	**5.00**	...	...	...
195	...	...	...	...	...	...	...	...	...	...	...	...	...
196	...	...	...	...	...	...	...	...	...	...	...	...	...
197	...	...	...	...	...	...	...	...	...	...	...	...	...
198	...	...	...	...	...	...	...	...	...	...	...	...	...
199	...	...	...	...	...	...	...	...	...	...	...	...	...
200	...	...	...	...	...	...	...	...	...	...	...	...	...
201	...	...	...	...	...	...	...	...	...	...	...	...	...
202	...	...	...	...	...	...	...	...	...	...	...	...	...
203	...	...	...	...	...	...	...	...	...	...	...	...	...
204	...	...	...	...	...	...	...	...	...	...	...	...	...
205	**117**	**96.2**	**79.3**	**65.6**	**54.4**	**45.0**	**37.2**	**30.6**	**25.1**	**20.5**	**16.5**	**13.0**	**9.8**

Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

Line No.	Nominal Composition	Product Form	Spec. No.	Type/ Grade	UNS No.	Class/ Condition/ Temper	Size, mm	P-No. (5)
206	61Ni–16Mo–16Cr	Rod & bar	B574	...	N06455	Sol. ann.	All	43
207	54Ni–16Mo–15Cr	Rod & bar	B574	...	N10276	Sol. ann.	All	43
208	62Ni–22Mo–15Cr	Rod & bar	B574	...	N10362	Sol. ann.	All	43
209	60Ni–22Cr–9Mo–3.5Cb	Rod & bar	B446	1	N06625	Annealed	>100, ≤250	43
210	60Ni–22Cr–9Mo–3.5Cb	Rod & bar	B446	1	N06625	Annealed	≤100	43
211	57Ni–22Cr–14W–2Mo–La	Rod & bar	B572	...	N06230	Sol. ann.	All	43
212	59Ni–23Cr–16Mo	Rod & bar	B574	...	N06059	Sol. ann.	All	43
213	59Ni–23Cr–16Mo–1.6Cu	Rod & bar	B574	...	N06200	Sol. ann.	All	43
214	65Ni–29.5Mo–2Fe–2Cr	Rod & bar	B335	...	N10675	Sol. ann.	All	44
215	33Cr–31Ni–32Fe–1.5Mo–0.6Cu–N	Rod	B649	...	R20033	Sol. ann.	...	45
216	59Ni–22Cr–14Mo–4Fe–3W	Castings	A494	CX2MW	N26022	...	...	43
217	53Ni–17Mo–16Cr–6Fe–5W	Castings	A494	CW12MW	N30002	...	...	a
218	56Ni–19Mo–18Cr–2Fe	Castings	A494	CW6M	N30107	...	...	44

Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

Line No.	Notes	Min. Temp., °C (6)	Min. Tensile Str., MPa	Min. Yield Str., MPa	Max. Use Temp., °C	Basic Allowable Stress, S, MPa, at Metal Temperature, °C [Notes (1) and (4b)] Min. Temp. to 40	65	100	125	150	175	200	225	250
206	(9)	−198	689	276	427	184	184	184	184	184	184	184	184	184
207	...	−198	689	283	677	188	188	188	188	188	188	188	188	187
208	...	−198	725	310	427	207	207	207	207	207	207	204	202	199
209	(9) (64) (70)	−198	758	345	649	230	230	230	230	230	230	230	230	230
210	(9) (64) (70)	−198	827	414	649	276	276	276	*274*	*273*	*272*	*270*	*269*	*267*
211	...	−198	758	310	899	207	207	207	207	207	207	207	207	207
212	...	−198	689	310	427	207	207	207	207	207	207	207	207	206
213	...	−198	689	310	427	207	207	207	207	207	207	207	**207**	**200**
214	...	−198	758	352	427	234	*234*	*234*	*234*	*234*	*234*	*234*	*234*	*234*
215	...	−198	750	380	427	250	231	209	200	193	187	181	176	172
216	(7) (9)	−198	550	310	260	*184*	*184*	*184*	*184*	*184*	*184*	*184*	*184*	*184*
217	(7) (9)	−198	495	275	538	*165*	*165*	*165*	*165*	*165*	*165*	*165*	*165*	*165*
218	(7) (9)	−198	495	275	538	*165*	*165*	*165*	*165*	*165*	*165*	*165*	*165*	*165*

Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

	Basic Allowable Stress, *S*, MPa, at Metal Temperature, °C [Notes (1) and (4b)]												
Line No.	**275**	**300**	**325**	**350**	**375**	**400**	**425**	**450**	**475**	**500**	**525**	**550**	**575**
206	184	184	184	184	182	180	178	178	...	...	...	...	...
207	183	177	172	169	165	162	159	157	156	155	154	**143**	**118**
208	197	193	190	188	186	184	182	180	...	...	...	...	...
209	230	230	230	230	230	230	*230*	*228*	*227*	*225*	*222*	**215**	**194**
210	*265*	*262*	*260*	*257*	*255*	*252*	*251*	*249*	*247*	*245*	*242*	**215**	**194**
211	207	207	203	199	197	196	195	195	195	195	195	195	183
212	202	197	192	188	184	180	176	176	...	...	...	...	...
213	**194**	**188**	**184**	**180**	**177**	**175**	**174**	**173**	...	...	...	...	...
214	*234*	*234*	*234*	*234*	*234*	**233**	**231**	**230**	...	...	...	...	...
215	169	165	163	161	159	157	156	155	...	...	...	...	...
216	*184*	...	...	...	...	...	...	...	...	...	...	...	...
217	*165*	*165*	*165*	*165*	*165*	*165*	*165*	*165*	*165*	*165*	*165*	*157*	...
218	*165*	*165*	*165*	*165*	*165*	*165*	*165*	*165*	*165*	*165*	*165*	*157*	...

Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

	Basic Allowable Stress, *S*, MPa, at Metal Temperature, °C [Notes (1) and (4b)]												
Line No.	600	625	650	675	700	725	750	775	800	825	850	875	900
206	...	...	...	...	...	...	...	...	...	...	...	...	...
207	99.1	81.6	67.0	54.6	42.2	...	...	...	...	...	...	...	...
208	...	...	...	...	...	...	...	...	...	...	...	...	...
209	156	136	91.0	...	...	...	...	...	...	...	...	...	...
210	156	136	91.0	...	...	...	...	...	...	...	...	...	...
211	153	128	107	89.7	74.7	61.9	50.8	41.1	32.6	25.2	18.9	13.8	10.2
212	...	...	...	...	...	...	...	...	...	...	...	...	...
213	...	...	...	...	...	...	...	...	...	...	...	...	...
214	...	...	...	...	...	...	...	...	...	...	...	...	...
215	...	...	...	...	...	...	...	...	...	...	...	...	...
216	...	...	...	...	...	...	...	...	...	...	...	...	...
217	...	...	...	...	...	...	...	...	...	...	...	...	...
218	...	...	...	...	...	...	...	...	...	...	...	...	...

Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

Line No.	Nominal Composition	Product Form	Spec. No.	Type/ Grade	UNS No.	Class/ Condition/ Temper	P-No. (5)	Notes	Min. Temp., °C (6)	Min. Tensile Strength, MPa	Min. Yield Strength, MPa
1	Ti	Smls. & wld. tube	B338	1	R50250	Annealed	51	...	−59	240	138
2	Ti	Smls. pipe	B861	1	R50250	Annealed	51	...	−59	240	138
3	Ti	Wld. pipe	B862	1	R50250	Annealed	51	...	−59	240	138
4	Ti	Smls. & wld. tube	B338	2	R50400	Annealed	51	...	−59	345	275
5	Ti	Smls. pipe	B861	2	R50400	Annealed	51	...	−59	345	275
6	Ti	Wld. pipe	B862	2	R50400	Annealed	51	...	−59	345	275
7	Ti	Smls. & wld. tube	B338	3	R50550	Annealed	52	...	−59	450	380
8	Ti	Smls. pipe	B861	3	R50550	Annealed	52	...	−59	450	380
9	Ti	Wld. pipe	B862	3	R50550	Annealed	52	...	−59	450	380
10	Ti–Pd	Smls. & wld. tube	B338	7	R52400	Annealed	51	...	−59	345	275
11	Ti–Pd	Smls. pipe	B861	7	R52400	Annealed	51	...	−59	345	275
12	Ti–Pd	Wld. pipe	B862	7	R52400	Annealed	51	...	−59	345	275
13	Ti–0.3Mo–0.8Ni	Smls. & wld. tube	B338	12	R53400	Annealed	52	...	−59	485	345
14	Ti–0.3Mo–0.8Ni	Smls. pipe	B861	12	R53400	Annealed	52	...	−59	485	345
15	Ti–0.3Mo–0.8Ni	Wld. pipe	B862	12	R53400	Annealed	52	...	−59	485	345
16	Ti	Plate, sheet, strip	B265	1	R50250	Annealed	51	...	−59	240	138
17	Ti	Plate, sheet, strip	B265	2	R50400	Annealed	51	...	−59	345	275
18	Ti	Plate, sheet, strip	B265	3	R50550	Annealed	52	...	−59	450	380
19	Ti–Pd	Plate, sheet, strip	B265	7	R52400	Annealed	51	...	−59	345	275
20	Ti–0.3Mo–0.8Ni	Plate, sheet, strip	B265	12	R53400	Annealed	52	...	−59	485	345
21	Ti	Fittings	B363	WPT1	R50250	Annealed	51	...	−59	240	138
22	Ti	Forgings	B381	F-1	R50250	Annealed	51	...	−59	240	138
23	Ti	Fittings	B363	WPT2	R50400	Annealed	51	...	−59	345	275
24	Ti	Forgings	B381	F-2	R50400	Annealed	51	...	−59	345	275
25	Ti	Fittings	B363	WPT3	R50550	Annealed	52	...	−59	450	380
26	Ti	Forgings	B381	F-3	R50550	Annealed	52	...	−59	450	380
27	Ti–Pd	Fittings	B363	WPT7	R52400	Annealed	51	...	−59	345	275
28	Ti–Pd	Forgings	B381	F-7	R52400	Annealed	51	...	−59	345	275
29	Ti–0.3Mo–0.8Ni	Fittings	B363	WPT12	R53400	Annealed	52	...	−59	485	345
30	Ti–0.3Mo–0.8Ni	Forgings	B381	F-12	R53400	Annealed	52	...	−59	485	345
31	Ti	Bar	B348	1	R50250	Annealed	51	...	−59	240	138
32	Ti	Bar	B348	2	R50400	Annealed	51	...	−59	345	275
33	Ti	Bar	B348	3	R50550	Annealed	52	...	−59	450	380
34	Ti–Pd	Bar	B348	7	R52400	Annealed	51	...	−59	345	275
35	Ti–0.3Mo–0.8Ni	Bar	B348	12	R53400	Annealed	52	...	−59	485	345
36	Ti	Castings	B367	C-2	R52550	...	51	(14) (44)	−59	345	275
37	Ti	Castings	B367	C-3	R52550	...	52	(14) (44)	−59	450	380
38	Ti–Pd	Castings	B367	C-7	R52700	...	51	(14) (44)	−59	345	275

Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

Line No.	Max. Use Temp., °C	Basic Allowable Stress, *S*, MPa, at Metal Temperature, °C [Notes (1) and (4b)]											
		Min. Temp. to 40	65	100	125	150	175	200	225	250	275	300	325
1	316	*80.3*	*73.8*	62.4	55.5	49.4	43.4	38.3	33.9	30.2	27.3	25.2	23.7
2	316	*80.3*	*73.8*	62.4	55.5	49.4	43.4	38.3	33.9	30.2	27.3	25.2	23.7
3	316	*80.3*	*73.8*	62.4	55.5	49.4	43.4	38.3	33.9	30.2	27.3	25.2	23.7
4	316	*115*	*108*	*98.3*	*90.7*	*83.0*	*77.5*	*72.0*	*67.3*	*62.7*	*58.7*	*54.7*	50.7
5	316	*115*	*108*	*98.3*	*90.7*	*83.0*	*77.5*	*72.0*	*67.3*	*62.7*	*58.7*	*54.7*	50.7
6	316	*115*	*108*	*98.3*	*90.7*	*83.0*	*77.5*	*72.0*	*67.3*	*62.7*	*58.7*	*54.7*	50.7
7	316	*149*	*139*	*124*	*113*	*102*	*93.3*	*84.7*	*77.7*	*70.7*	*66.2*	*61.7*	*57.7*
8	316	*149*	*139*	*124*	*113*	*102*	*93.3*	*84.7*	*77.7*	*70.7*	*66.2*	*61.7*	*57.7*
9	316	*149*	*139*	*124*	*113*	*102*	*93.3*	*84.7*	*77.7*	*70.7*	*66.2*	*61.7*	*57.7*
10	316	*115*	*108*	*98.3*	*90.7*	*83.0*	*77.5*	*72.0*	*67.3*	*62.7*	*58.7*	*54.7*	50.7
11	316	*115*	*108*	*98.3*	*90.7*	*83.0*	*77.5*	*72.0*	*67.3*	*62.7*	*58.7*	*54.7*	50.7
12	316	*115*	*108*	*98.3*	*90.7*	*83.0*	*77.5*	*72.0*	*67.3*	*62.7*	*58.7*	*54.7*	50.7
13	316	*161*	*156*	*148*	*139*	*130*	*123*	*116*	*111*	*106*	*104*	*101*	*98.3*
14	316	*161*	*156*	*148*	*139*	*130*	*123*	*116*	*111*	*106*	*104*	*101*	*98.3*
15	316	*161*	*156*	*148*	*139*	*130*	*123*	*116*	*111*	*106*	*104*	*101*	*98.3*
16	316	*80.3*	*73.8*	62.4	55.5	49.4	43.4	38.3	33.9	30.2	27.3	25.2	23.7
17	316	*115*	*108*	*98.3*	*90.7*	*83.0*	*77.5*	*72.0*	*67.3*	*62.7*	*58.7*	*54.7*	50.7
18	316	*149*	*139*	*124*	*113*	*102*	*93.3*	*84.7*	*77.7*	*70.7*	*66.2*	*61.7*	*57.7*
19	316	*115*	*108*	*98.3*	*90.7*	*83.0*	*77.5*	*72.0*	*67.3*	*62.7*	*58.7*	*54.7*	50.7
20	316	*161*	*156*	*148*	*139*	*130*	*123*	*116*	*111*	*106*	*104*	*101*	*98.3*
21	316	*80.3*	*73.8*	62.4	55.5	49.4	43.4	38.3	33.9	30.2	27.3	25.2	23.7
22	316	*80.3*	*73.8*	62.4	55.5	49.4	43.4	38.3	33.9	30.2	27.3	25.2	23.7
23	316	*115*	*108*	*98.3*	*90.7*	*83.0*	*77.5*	*72.0*	*67.3*	*62.7*	*58.7*	*54.7*	50.7
24	316	*115*	*108*	*98.3*	*90.7*	*83.0*	*77.5*	*72.0*	*67.3*	*62.7*	*58.7*	*54.7*	50.7
25	316	*149*	*139*	*124*	*113*	*102*	*93.3*	*84.7*	*77.7*	*70.7*	*66.2*	*61.7*	*57.7*
26	316	*149*	*139*	*124*	*113*	*102*	*93.3*	*84.7*	*77.7*	*70.7*	*66.2*	*61.7*	*57.7*
27	316	*115*	*108*	*98.3*	*90.7*	*83.0*	*77.5*	*72.0*	*67.3*	*62.7*	*58.7*	*54.7*	50.7
28	316	*115*	*108*	*98.3*	*90.7*	*83.0*	*77.5*	*72.0*	*67.3*	*62.7*	*58.7*	*54.7*	50.7
29	316	*161*	*156*	*148*	*139*	*130*	*123*	*116*	*111*	*106*	*104*	*101*	*98.3*
30	316	*161*	*156*	*148*	*139*	*130*	*123*	*116*	*111*	*106*	*104*	*101*	*98.3*
31	316	*80.3*	*73.8*	62.4	55.5	49.4	43.4	38.3	33.9	30.2	27.3	25.2	23.7
32	316	*115*	*108*	*98.3*	*90.7*	*83.0*	*77.5*	*72.0*	*67.3*	*62.7*	*58.7*	*54.7*	50.7
33	316	*149*	*139*	*124*	*113*	*102*	*93.3*	*84.7*	*77.7*	*70.7*	*66.2*	*61.7*	*57.7*
34	316	*115*	*108*	*98.3*	*90.7*	*83.0*	*77.5*	*72.0*	*67.3*	*62.7*	*58.7*	*54.7*	50.7
35	316	*161*	*156*	*148*	*139*	*130*	*123*	*116*	*111*	*106*	*104*	*101*	*98.3*
36	260	*115*	*106*	*92.7*	*85.3*	*78.0*	*72.2*	*66.3*	*61.5*	*56.7*	*52.0*	...	...
37	260	*149*	*139*	*124*	*113*	*102*	*93.3*	*84.7*	*77.7*	*70.7*	*65.3*	...	...
38	260	*115*	*106*	*92.7*	*85.3*	*78.0*	*72.2*	*66.3*	*61.5*	*56.7*	*52.0*	...	...

Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

Line No.	Nominal Composition	Product Form	Spec. No.	UNS No.	P-No. (5)	Notes	Min. Temp., °C (6)	Min. Tensile Strength, MPa	Min. Yield Strength, MPa	Max. Use Temp., °C
1	99.2Zr	Smls & wld. tube	B523	R60702	61	...	−59	380	205	371
2	99.2Zr	Smls. & wld. pipe	B658	R60702	61	...	−59	380	205	371
3	95.5Zr + 2.5Nb	Smls. & wld. pipe	B658	R60705	62	(73)	−59	550	380	371
4	99.2Zr	Plate, sheet, strip	B551	R60702	61	...	−59	380	205	371
5	95.5Zr + 2.5Nb	Plate, sheet, strip	B551	R60705	62	(73)	−59	550	380	371
6	99.2Zr	Forgings	B493	R60702	61	...	−59	380	205	371
7	99.2Zr	Bar, wire	B550	R60702	61	...	−59	380	205	371
8	95.5Zr + 2.5Nb	Forgings	B493	R60705	62	(73)	−59	485	380	380
9	95.5Zr + 2.5Nb	Bar, wire	B550	R60705	62	(73)	−59	550	380	371

Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

	Basic Allowable Stress, *S*, MPa, at Metal Temperature, °C [Notes (1) and (4b)]													
Line No.	**Min. Temp. to 40**	**65**	**100**	**125**	**150**	**175**	**200**	**225**	**250**	**275**	**300**	**325**	**350**	**375**
1	*126*	119	103	92.4	82.5	73.6	65.7	58.8	52.8	47.8	43.7	40.4	37.8	36.1
2	*126*	119	103	92.4	82.5	73.6	65.7	58.8	52.8	47.8	43.7	40.4	37.8	36.1
3	*184*	*169*	*149*	*139*	*130*	*123*	*116*	*111*	*106*	*101*	*97.6*	*94.6*	*92.4*	*91.0*
4	*126*	119	103	92.4	82.5	73.6	65.7	58.8	52.8	47.8	43.7	40.4	37.8	36.1
5	*184*	*169*	*149*	*139*	*130*	*123*	*116*	*111*	*106*	*101*	*97.6*	*94.6*	*92.4*	*91.0*
6	*126*	119	103	92.4	82.5	73.6	65.7	58.8	52.8	47.8	43.7	40.4	37.8	36.1
7	*126*	119	103	92.4	82.5	73.6	65.7	58.8	52.8	47.8	43.7	40.4	37.8	36.1
8	*161*	*148*	*130*	*122*	*114*	*108*	*101*	*97.1*	*92.7*	*88.4*	*85.4*	*82.8*	*80.8*	*79.6*
9	*184*	*169*	*149*	*139*	*130*	*123*	*116*	*111*	*106*	*101*	*97.6*	*94.6*	*92.4*	*91.0*

Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

Line No.	Nominal Composition	Product Form	Spec. No.	Type/ Grade	UNS No.	Class/ Condition/ Temper	Size, mm	P-No. (5)
1	Al–Mn–Cu	Smls. pipe & tube	B210	Alclad 3003	A83003	O	...	21
2	Al–Mn–Cu	Smls. pipe & tube	B210	Alclad 3003	A83003	H112	...	21
3	Al–Mn–Cu	Smls. pipe & tube	B241	Alclad 3003	A83003	O	...	21
4	Al–Mn–Cu	Smls. pipe & tube	B241	Alclad 3003	A83003	H112	...	21
5	Al–Mn–Cu	Smls. pipe & tube	B210	Alclad 3003	A83003	H14	...	21
6	Al–Mn–Cu	Smls. pipe & tube	B210	Alclad 3003	A83003	H18	...	21
7	99.60Al	Smls. pipe & tube	B210	1060	A91060	O	...	21
8	99.60Al	Smls. pipe & tube	B210	1060	A91060	H112	...	21
9	99.60Al	Smls. pipe & tube	B210	1060	A91060	H113	...	21
10	99.60Al	Smls. pipe & tube	B241	1060	A91060	O	...	21
11	99.60Al	Smls. pipe & tube	B241	1060	A91060	H112	...	21
12	99.60Al	Smls. pipe & tube	B241	1060	A91060	H113	...	21
13	99.60Al	Smls. pipe & tube	B210	1060	A91060	H14	...	21
14	99.0Al–Cu	Smls. pipe & tube	B241	1100	A91100	O	...	21
15	99.0Al–Cu	Smls. pipe & tube	B241	1100	A91100	H112	...	21
16	99.0Al–Cu	Smls. pipe & tube	B210	1100	A91100	H113	...	21
17	99.0Al–Cu	Smls. pipe & tube	B210	1100	A91100	H14	...	21
18	Al–Mn–Cu	Smls. pipe & tube	B210	3003	A93003	O	...	21
19	Al–Mn–Cu	Smls. pipe & tube	B210	3003	A93003	H112	...	21
20	Al–Mn–Cu	Smls. pipe & tube	B241	3003	A93003	O	...	21
21	Al–Mn–Cu	Smls. pipe & tube	B241	3003	A93003	H112	...	21
22	Al–Mn–Cu	Smls. pipe & tube	B491	3003	A93003	O	...	21
23	Al–Mn–Cu	Smls. pipe & tube	B491	3003	A93003	H112	...	21
24	Al–Mn–Cu	Smls. pipe & tube	B210	3003	A93003	H14	...	21
25	Al–Mn–Cu	Smls. pipe & tube	B210	3003	A93003	H18	...	21
26	Al–Mn–Cu	Smls. pipe & tube	B241	3003	A93003	H18	...	21
27	Al–2.5Mg	Smls. pipe & tube	B210	5052	A95052	O	...	22
28	Al–2.5Mg	Smls. pipe & tube	B241	5052	A95052	O	...	22
29	Al–2.5Mg	Smls. pipe & tube	B210	5052	A95052	H32	...	22
30	Al–2.5Mg	Smls. pipe & tube	B210	5052	A95052	H34	...	22
31	Al–4.4Mg–Mn	Smls. pipe & tube	B210	5083	A95083	O	...	25
32	Al–4.4Mg–Mn	Smls. pipe & tube	B210	5083	A95083	H112	...	25
33	Al–4.4Mg–Mn	Smls. pipe & tube	B241	5083	A95083	O	...	25
34	Al–4.4Mg–Mn	Smls. pipe & tube	B241	5083	A95083	H112	...	25
35	Al–4.0Mg–Mn	Smls. pipe & tube	B210	5086	A95086	O	...	25
36	Al–4.0Mg–Mn	Smls. pipe & tube	B210	5086	A95086	H112	...	25
37	Al–4.0Mg–Mn	Smls. pipe & tube	B241	5086	A95086	O	...	25
38	Al–4.0Mg–Mn	Smls. pipe & tube	B241	5086	A95086	H112	...	25

Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

Line No.	Notes	Min. Temp., °C (6)	Min. Tensile Strength, MPa	Min. Yield Strength, MPa	Max. Use Temp., °C	Basic Allowable Stress, *S*, MPa, at Metal Temperature, °C [Notes (1) and (4b)]							
						Min. Temp. to 40	65	100	125	150	175	200	225
1	(14) (33)	−269	90	31	204	20.7	19.9	19.3	18.4	17.3	**13.6**	**10.9**	**10.5**
2	(14) (33)	−269	90	31	204	20.7	19.9	19.3	18.4	17.3	**13.6**	**10.9**	**10.5**
3	(14) (33)	−269	90	31	204	20.7	19.9	19.3	18.4	17.3	**13.6**	**10.9**	**10.5**
4	(14) (33)	−269	90	31	204	20.7	19.9	19.3	18.4	17.3	**13.6**	**10.9**	**10.5**
5	(14) (33)	−269	131	110	204	*43.7*	*43.7*	*43.7*	*41.7*	**29.0**	**21.1**	**16.7**	**16.1**
6	(14) (33)	−269	179	159	204	*59.8*	*59.8*	*59.8*	*57.0*	**29.0**	**21.1**	**16.7**	**16.1**
7	(14) (33)	−269	59	17	204	11.5	11.5	10.9	9.8	8.8	**7.5**	**5.8**	**5.5**
8	(14) (33)	−269	59	17	204	11.5	11.5	10.9	9.8	8.8	**7.5**	**5.8**	**5.5**
9	(14) (33)	−269	59	17	204	11.5	11.5	10.9	9.8	8.8	**7.5**	**5.8**	**5.5**
10	(14) (33)	−269	59	17	204	11.5	11.5	10.9	9.8	8.8	**7.5**	**5.8**	**5.5**
11	(14) (33)	−269	59	17	204	11.5	11.5	10.9	9.8	8.8	**7.5**	**5.8**	**5.5**
12	(14) (33)	−269	59	17	204	11.5	11.5	10.9	9.8	8.8	**7.5**	**5.8**	**5.5**
13	(14) (33)	−269	83	69	204	*27.6*	*27.6*	*27.6*	*26.6*	**18.1**	**12.7**	**8.4**	**7.8**
14	(14) (33)	−269	76	21	204	13.8	13.8	13.7	13.2	**11.8**	**9.3**	**7.2**	**6.9**
15	(14) (33)	−269	76	21	204	13.8	13.8	13.7	13.2	**11.8**	**9.3**	**7.2**	**6.9**
16	(14) (33)	−269	76	24	204	16.1	16.1	16.0	15.6	**11.8**	**9.3**	**7.2**	**6.9**
17	(14) (33)	−269	110	97	204	*36.8*	*36.8*	*36.1*	*33.1*	**19.0**	**13.6**	**8.5**	**7.8**
18	(14) (33)	−269	97	34	204	23.0	22.1	21.4	20.5	**18.2**	**13.6**	**10.9**	**10.5**
19	(14) (33)	−269	97	34	204	23.0	22.1	21.4	20.5	**18.2**	**13.6**	**10.9**	**10.5**
20	(14) (33)	−269	97	34	204	23.0	22.1	21.4	20.5	**18.2**	**13.6**	**10.9**	**10.5**
21	(14) (33)	−269	97	34	204	23.0	22.1	21.4	20.5	**18.2**	**13.6**	**10.9**	**10.5**
22	(14) (33)	−269	97	34	204	23.0	22.1	21.4	20.5	**18.2**	**13.6**	**10.9**	**10.5**
23	(14) (33)	−269	97	34	204	23.0	22.1	21.4	20.5	**18.2**	**13.6**	**10.9**	**10.5**
24	(14) (33)	−269	138	117	204	*46.0*	*46.0*	*46.0*	*43.9*	**29.0**	**21.1**	**16.7**	**16.1**
25	(14) (33)	−269	186	165	204	*62.1*	*62.1*	*60.3*	**52.1**	**36.1**	**24.5**	**18.0**	**17.0**
26	(14) (33)	−269	186	165	204	*62.1*	*62.1*	*60.3*	**52.1**	**36.1**	**24.5**	**18.0**	**17.0**
27	(14)	−269	172	69	204	46.0	46.0	46.0	45.9	**41.6**	**28.8**	**17.6**	**16.1**
28	(14)	−269	172	69	204	46.0	46.0	46.0	45.9	**41.6**	**28.8**	**17.6**	**16.1**
29	(14) (33)	−269	214	159	204	*71.2*	*71.2*	*71.2*	*71.0*	**41.6**	**28.8**	**17.6**	**16.1**
30	(14) (33)	−269	234	179	204	*78.1*	*78.1*	*78.1*	*78.1*	**41.6**	**28.8**	**17.6**	**16.1**
31	(33)	−269	269	110	65	73.5	73.5	...	...	...	...	...	...
32	(33)	−269	269	110	65	73.5	73.5	...	...	...	...	...	...
33	(33)	−269	269	110	65	73.5	73.5	...	...	...	...	...	...
34	(33)	−269	269	110	65	73.5	73.5	...	...	...	...	...	...
35	(33)	−269	241	97	65	64.4	64.4	...	...	...	...	...	...
36	(33)	−269	241	97	65	64.4	64.4	...	...	...	...	...	...
37	(33)	−269	241	97	65	64.4	64.4	...	...	...	...	...	...
38	(33)	−269	241	97	65	64.4	64.4	...	...	...	...	...	...

Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

Line No.	Nominal Composition	Product Form	Spec. No.	Type/ Grade	UNS No.	Class/ Condition/ Temper	Size, mm	P-No. (5)
39	Al–4.0Mg–Mn	Smls. pipe & tube	B210	5086	A95086	H32	...	25
40	Al–4.0Mg–Mn	Smls. pipe & tube	B210	5086	A95086	H34	...	25
41	Al–3.5Mg	Smls. pipe & tube	B210	5154	A95154	O	...	22
42	Al–3.5Mg	Smls. pipe & tube	B210	5154	A95154	H34	...	22
43	Al–2.7Mg–Mn	Smls. pipe & tube	B241	5454	A95454	O	...	22
44	Al–2.7Mg–Mn	Smls. pipe & tube	B241	5454	A95454	H112	...	22
45	Al–5.1Mg–Mn	Smls. pipe & tube	B210	5456	A95456	O	...	25
46	Al–5.1Mg–Mn	Smls. pipe & tube	B210	5456	A95456	H112	...	25
47	Al–5.1Mg–Mn	Smls. pipe & tube	B241	5456	A95456	O	...	25
48	Al–5.1Mg–Mn	Smls. pipe & tube	B241	5456	A95456	H112	...	25
49	Al–Mg–Si–Cu	Smls. pipe & tube	B210	6061	A96061	T4 wld.	...	23
50	Al–Mg–Si–Cu	Smls. pipe & tube	B210	6061	A96061	T6 wld.	...	23
51	Al–Mg–Si–Cu	Smls. pipe & tube	B241	6061	A96061	T4 wld.	...	23
52	Al–Mg–Si–Cu	Smls. pipe & tube	B241	6061	A96061	T6 wld.	...	23
53	Al–Mg–Si–Cu	Smls. pipe & tube	B241	6061	A96061	T4	...	23
54	Al–Mg–Si–Cu	Smls. pipe & tube	B210	6061	A96061	T4	...	23
55	Al–Mg–Si–Cu	Smls. pipe & tube	B241	6061	A96061	T6	...	23
56	Al–Mg–Si–Cu	Smls. pipe & tube	B210	6061	A96061	T6	...	23
57	Al–Mg–Si	Smls. pipe & tube	B210	6063	A96063	T4 wld.	...	23
58	Al–Mg–Si	Smls. pipe & tube	B210	6063	A96063	T5 wld.	...	23
59	Al–Mg–Si	Smls. pipe & tube	B210	6063	A96063	T6 wld.	...	23
60	Al–Mg–Si	Smls. pipe & tube	B241	6063	A96063	T4 wld.	...	23
61	Al–Mg–Si	Smls. pipe & tube	B241	6063	A96063	T5 wld.	...	23
62	Al–Mg–Si	Smls. pipe & tube	B241	6063	A96063	T6 wld.	...	23
63	Al–Mg–Si	Smls. pipe & tube	B241	6063	A96063	T4	≤13	23
64	Al–Mg–Si	Smls. pipe & tube	B210	6063	A96063	T4	...	23
65	Al–Mg–Si	Smls. pipe & tube	B241	6063	A96063	T5	≤13	23
66	Al–Mg–Si	Smls. pipe & tube	B241	6063	A96063	T6	...	23
67	Al–Mg–Si	Smls. pipe & tube	B210	6063	A96063	T6	...	23
68	Al–Mn–Cu	Structural tube	B221	Alclad 3003	A83003	O	...	21
69	Al–Mn–Cu	Structural tube	B221	Alclad 3003	A83003	H112	...	21
70	99.0Al	Structural tube	B221	1060	A91060	O	...	21
71	99.0Al	Structural tube	B221	1060	A91060	H112	...	21
72	99.0Al–Cu	Structural tube	B221	1100	A91100	O	...	21
73	99.0Al–Cu	Structural tube	B221	1100	A91100	H112	...	21
74	Al–Mn–Cu	Structural tube	B221	3003	A93003	O	...	21
75	Al–Mn–Cu	Structural tube	B221	3003	A93003	H112	...	21

Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

Line No.	Notes	Min. Temp., °C (6)	Min. Tensile Strength, MPa	Min. Yield Strength, MPa	Max. Use Temp., °C	Basic Allowable Stress, S, MPa, at Metal Temperature, °C [Notes (1) and (4b)] Min. Temp. to 40	65	100	125	150	175	200	225
39	(33)	−269	276	193	65	*91.9*	*91.9*	...	...	...	...	...	...
40	(33)	−269	303	234	65	*101.1*	*101.1*	...	...	...	...	...	...
41	...	−269	207	76	65	50.6	50.6	...	...	...	...	...	...
42	(33)	−269	269	200	65	*89.6*	*89.6*	...	...	...	...	...	...
43	(33)	−269	214	83	204	55.2	55.2	55.2	**48.9**	**37.5**	**28.6**	**21.7**	**20.7**
44	(33)	−269	214	83	204	55.2	55.2	55.2	**48.9**	**37.5**	**28.6**	**21.7**	**20.7**
45	(33)	−269	283	131	65	87.3	87.3	...	...	...	...	...	...
46	(33)	−269	283	131	65	87.3	87.3	...	...	...	...	...	...
47	(33)	−269	283	131	65	87.3	87.3	...	...	...	...	...	...
48	(33)	−269	283	131	65	87.3	87.3	...	...	...	...	...	...
49	(22) (63)	−269	165	...	204	*55.2*	*55.2*	*55.2*	*54.3*	*52.0*	*46.3*	*35.3*	*34.8*
50	(22) (63)	−269	165	...	204	*55.2*	*55.2*	*55.2*	*54.3*	*52.0*	*46.3*	*35.3*	*34.8*
51	(22) (63)	−269	165	...	204	*55.2*	*55.2*	*55.2*	*54.3*	*52.0*	*46.3*	*35.3*	*34.8*
52	(22) (63)	−269	165	...	204	*55.2*	*55.2*	*55.2*	*54.3*	*52.0*	*46.3*	*35.3*	*34.8*
53	(33) (63)	−269	179	110	204	*59.8*	*59.8*	*59.8*	*58.9*	*56.3*	*50.2*	*38.3*	*35.9*
54	(33)	−269	207	110	204	*68.9*	*68.9*	*68.9*	*67.8*	*64.8*	*57.9*	**40.2**	**35.9**
55	(33) (63)	−269	262	241	204	*87.3*	*87.3*	*87.3*	*83.6*	*72.3*	*57.2*	**40.2**	**35.9**
56	(33)	−269	290	241	204	*96.5*	*96.5*	*96.5*	*92.5*	*79.9*	*63.1*	**40.2**	**35.9**
57	...	−269	117	...	204	*39.1*	*39.1*	*37.9*	*35.9*	*32.1*	*25.7*	*17.6*	*13.8*
58	...	−269	117	...	204	*39.1*	*39.1*	*37.9*	*35.9*	*32.1*	*25.7*	*17.6*	*13.8*
59	...	−269	117	...	204	*39.1*	*39.1*	*37.9*	*35.9*	*32.1*	*25.7*	*17.6*	*13.8*
60	...	−269	117	...	204	*39.1*	*39.1*	*37.9*	*35.9*	*32.1*	*25.7*	*17.6*	*13.8*
61	...	−269	117	...	204	*39.1*	*39.1*	*37.9*	*35.9*	*32.1*	*25.7*	*17.6*	*13.8*
62	...	−269	117	...	204	*39.1*	*39.1*	*37.9*	*35.9*	*32.1*	*25.7*	*17.6*	*13.8*
63	(33)	−269	131	69	204	*43.7*	*43.7*	*43.7*	*43.7*	*43.7*	*35.8*	*23.9*	*10.3*
64	(33)	−269	152	69	204	46.0	45.8	45.8	45.5	45.5	*41.5*	*27.7*	*12.0*
65	(33)	−269	152	110	204	*50.6*	*50.6*	*48.7*	*46.6*	*41.4*	**27.5**	**15.3**	**13.8**
66	(33)	−269	207	172	204	*68.9*	*68.9*	*67.7*	*59.0*	*45.9*	**27.5**	**15.3**	**49.3**
67	(33)	−269	228	193	204	*75.8*	*75.8*	*74.8*	**64.0**	**49.2**	**27.5**	**15.3**	**13.8**
68	(33) (69)	−269	90	31	204	20.7	19.9	19.3	18.4	17.3	**13.6**	**10.9**	**10.5**
69	(33) (69)	−269	90	31	204	20.7	19.9	19.3	18.4	17.3	**13.6**	**10.9**	**10.5**
70	(33) (69)	−269	59	17	204	11.5	11.5	10.9	9.8	8.8	**7.5**	**5.8**	**5.5**
71	(33) (69)	−269	59	17	204	11.5	11.5	10.9	9.8	8.8	**7.5**	**5.8**	**5.5**
72	(33) (69)	−269	76	21	204	13.8	13.8	13.7	13.2	**11.8**	**9.3**	**7.2**	**6.9**
73	(33) (69)	−269	76	21	204	13.8	13.8	13.7	13.2	**11.8**	**9.3**	**7.2**	**6.9**
74	(33) (69)	−269	97	34	204	23.0	22.1	21.4	20.5	**18.2**	**13.6**	**10.9**	**10.5**
75	(33) (69)	−269	97	34	204	23.0	22.1	21.4	20.5	**18.2**	**13.6**	**10.9**	**10.5**

Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

Line No.	Nominal Composition	Product Form	Spec. No.	Type/ Grade	UNS No.	Class/ Condition/ Temper	Size, mm	P-No. (5)
76	Al–2.5Mg	Structural tube	B221	5052	A95052	O	...	22
77	Al–4.4Mg–Mn	Structural tube	B221	5083	A95083	O	...	25
78	Al–4.0Mg–Mn	Structural tube	B221	5086	A95086	O	...	25
79	Al–3.5Mg	Structural tube	B221	5154	A95154	O	...	22
80	Al–2.7Mg–Mn	Structural tube	B221	5454	A95454	O	...	22
81	Al–5.1Mg–Mn	Structural tube	B221	5456	A95456	O	...	25
82	Al–Mg–Si–Cu	Structural tube	B221	6061	A96061	T4 wld.	...	23
83	Al–Mg–Si–Cu	Structural tube	B221	6061	A96061	T6 wld.	...	23
84	Al–Mg–Si–Cu	Structural tube	B221	6061	A96061	T4	...	23
85	Al–Mg–Si–Cu	Structural tube	B221	6061	A96061	T6	...	23
86	Al–Mg–Si	Structural tube	B221	6063	A96063	T4 wld.	...	23
87	Al–Mg–Si	Structural tube	B221	6063	A96063	T5 wld.	...	23
88	Al–Mg–Si	Structural tube	B221	6063	A96063	T6 wld.	...	23
89	Al–Mg–Si	Structural tube	B221	6063	A96063	T4	≤13	23
90	Al–Mg–Si	Structural tube	B221	6063	A96063	T5	≤13	23
91	Al–Mg–Si	Structural tube	B221	6063	A96063	T6	...	23
92	Al–Mn–Cu	Plate & sheet	B209	Alclad 3003	A83003	O	≥0.15, <13	21
93	Al–Mn–Cu	Plate & sheet	B209	Alclad 3003	A83003	O	≥13, ≤75	21
94	Al–Mn–Cu	Plate & sheet	B209	Alclad 3003	A83003	H112	≥13, ≤50	21
95	Al–Mn–Cu	Plate & sheet	B209	Alclad 3003	A83003	H12	≥0.43, <13	21
96	Al–Mn–Cu	Plate & sheet	B209	Alclad 3003	A83003	H12	≥13, ≤50	21
97	Al–Mn–Cu	Plate & sheet	B209	Alclad 3003	A83003	H14	≥0.23, <13	21
98	Al–Mn–Cu	Plate & sheet	B209	Alclad 3003	A83003	H14	≥13, ≤25	21
99	Al–Mn–Mg	Plate & sheet	B209	Alclad 3004	A83004	O	≥0.15, <13	22
100	Al–Mn–Mg	Plate & sheet	B209	Alclad 3004	A83004	O	≥13, ≤75	22
101	Al–Mn–Mg	Plate & sheet	B209	Alclad 3004	A83004	H112	≥6, <13	22
102	Al–Mn–Mg	Plate & sheet	B209	Alclad 3004	A83004	H112	≥13, ≤75	22
103	Al–Mn–Mg	Plate & sheet	B209	Alclad 3004	A83004	H32	≥0.43, <13	22
104	Al–Mn–Mg	Plate & sheet	B209	Alclad 3004	A83004	H32	≥13, ≤50	22
105	Al–Mn–Mg	Plate & sheet	B209	Alclad 3004	A83004	H34	≥0.23, <13	22
106	Al–Mn–Mg	Plate & sheet	B209	Alclad 3004	A83004	H34	≥13, ≤25	22
107	Al–Mg–Si–Cu	Plate & sheet	B209	Alclad 6061	A86061	T4 wld.	...	23
108	Al–Mg–Si–Cu	Plate & sheet	B209	Alclad 6061	A86061	T6 wld.	...	23
109	Al–Mg–Si–Cu	Plate & sheet	B209	Alclad 6061	A86061	T4	...	23
110	Al–Mg–Si–Cu	Plate & sheet	B209	Alclad 6061	A86061	T451	≥6, <13	23
111	Al–Mg–Si–Cu	Plate & sheet	B209	Alclad 6061	A86061	T451	≥13, ≤75	23
112	Al–Mg–Si–Cu	Plate & sheet	B209	Alclad 6061	A86061	T6	...	23
113	Al–Mg–Si–Cu	Plate & sheet	B209	Alclad 6061	A86061	T651	≥6, <13	23

Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

Line No.	Notes	Min. Temp., °C (6)	Min. Tensile Strength, MPa	Min. Yield Strength, MPa	Max. Use Temp., °C	Basic Allowable Stress, *S*, MPa, at Metal Temperature, °C [Notes (1) and (4b)]							
						Min. Temp. to 40	65	100	125	150	175	200	225
76	(69)	−269	172	69	204	46.0	46.0	46.0	45.9	**41.6**	**28.8**	**17.6**	**16.1**
77	(69)	−269	269	110	65	73.5	73.5	...	...	...	...	...	...
78	(69)	−269	241	97	65	64.4	64.4	...	...	...	...	...	...
79	(69)	−269	207	76	65	50.6	50.6	...	...	...	...	...	...
80	(69)	−269	214	83	204	55.2	55.2	55.2	**48.9**	**37.5**	**28.6**	**21.7**	**20.7**
81	(69)	−269	283	131	65	87.3	87.3	...	...	...	...	...	...
82	(22) (63) (69)	−269	165	...	204	*55.2*	*55.2*	*55.2*	*54.3*	*52.0*	*46.3*	*35.3*	*34.8*
83	(22) (63) (69)	−269	165	...	204	*55.2*	*55.2*	*55.2*	*54.3*	*52.0*	*46.3*	*35.3*	*34.8*
84	(33) (63) (69)	−269	179	110	204	*59.8*	*59.8*	*59.8*	*58.9*	*56.3*	*50.2*	*38.3*	*35.9*
85	(33) (63) (69)	−269	262	241	204	*87.3*	*87.3*	*87.3*	*83.6*	*72.3*	*57.2*	**40.2**	**35.9**
86	(69)	−269	117	...	204	*39.1*	*39.1*	*37.9*	*35.9*	*32.1*	*25.7*	*17.6*	*13.8*
87	(69)	−269	117	...	204	*39.1*	*39.1*	*37.9*	*35.9*	*32.1*	*25.7*	*17.6*	*13.8*
88	(69)	−269	117	...	204	*39.1*	*39.1*	*37.9*	*35.9*	*32.1*	*25.7*	*17.6*	*13.8*
89	(13) (33) (69)	−269	131	69	204	*43.7*	*43.7*	*43.7*	*43.7*	*43.7*	*35.8*	*23.9*	*10.3*
90	(13) (33) (69)	−269	152	110	204	*50.6*	*50.6*	*48.7*	*46.6*	*41.4*	**27.5**	**15.3**	**13.8**
91	(33) (69)	−269	207	172	204	*68.9*	*68.9*	*67.7*	*59.0*	*45.9*	**27.5**	**15.3**	**49.3**
92	(66)	−269	90	31	204	20.7	19.9	19.3	18.4	17.3	**13.6**	**10.9**	**10.5**
93	(68)	−269	97	34	204	23.0	22.2	21.3	20.4	***18.2***	**13.6**	**10.9**	**10.5**
94	(33) (66)	−269	103	41	204	27.6	26.6	25.6	24.4	***18.2***	**13.6**	**10.9**	**10.5**
95	(33) (66)	−269	110	76	204	*36.8*	*36.8*	*35.9*	*33.7*	***29.0***	**21.1**	**16.7**	**16.1**
96	(33) (68)	−269	117	83	204	*39.1*	*39.1*	*39.1*	*39.1*	***29.0***	**21.1**	**16.7**	**16.1**
97	(33) (66)	−269	131	110	204	*43.7*	*43.7*	*43.7*	*41.7*	***29.0***	**21.1**	**16.7**	**16.1**
98	(33) (68)	−269	138	117	204	*46.0*	*46.0*	*46.0*	*43.9*	***29.0***	**21.1**	**16.7**	**16.1**
99	(66)	−269	145	55	204	36.8	36.8	36.8	36.8	36.8	**26.9**	**17.4**	**16.1**
100	(68)	−269	152	59	204	39.1	39.1	39.1	39.1	**38.9**	**26.9**	**17.4**	**16.1**
101	(33) (66)	−269	152	59	204	39.1	39.1	39.1	39.1	**38.9**	**26.9**	**17.4**	**16.1**
102	(33) (68)	−269	159	62	204	41.4	41.4	41.4	41.4	**38.9**	**26.9**	**17.4**	**16.1**
103	(33) (66)	−269	186	138	204	*62.1*	*62.1*	*62.1*	**60.4**	**38.9**	**26.9**	**17.4**	**16.1**
104	(33) (68)	−269	193	145	204	*64.4*	*64.4*	*64.4*	**60.4**	**38.9**	**26.9**	**17.4**	**16.1**
105	(33) (66)	−269	214	165	204	*71.2*	*71.2*	*71.2*	*71.2*	**38.9**	**26.9**	**17.4**	**16.1**
106	(33) (68)	−269	221	172	204	*73.5*	*73.5*	*73.5*	*73.5*	**38.9**	**26.9**	**17.4**	**16.1**
107	(22) (63)	−269	165	...	204	*55.2*	*55.2*	*55.2*	*54.3*	*52.0*	*46.3*	*35.3*	*34.8*
108	(22) (63)	−269	165	...	204	*55.2*	*55.2*	*55.2*	*54.3*	*52.0*	*46.3*	*35.3*	*34.8*
109	(33) (66)	−269	186	97	204	*62.1*	*62.1*	*62.1*	*61.0*	*58.3*	*52.1*	*39.7*	*35.9*
110	(33) (66)	−269	186	97	204	*62.1*	*62.1*	*62.1*	*61.0*	*58.3*	*52.1*	*39.7*	*35.9*
111	(33) (68)	−269	207	110	204	*68.9*	*68.9*	*68.9*	*67.8*	*64.8*	*57.9*	**40.2**	**35.9**
112	(33) (66)	−269	262	221	204	*87.3*	*87.3*	*87.3*	*83.8*	*72.3*	*57.2*	**40.2**	**35.9**
113	(33) (66)	−269	262	221	204	*87.3*	*87.3*	*87.3*	*83.8*	*72.3*	*57.2*	**40.2**	**35.9**

Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

Line No.	Nominal Composition	Product Form	Spec. No.	Type/ Grade	UNS No.	Class/ Condition/ Temper	Size, mm	P-No. (5)
114	Al–Mg–Si–Cu	Plate & sheet	B209	Alclad 6061	A86061	T651	≥13, ≤100	23
115	99.60Al	Plate & sheet	B209	1060	A91060	O	...	21
116	99.60Al	Plate & sheet	B209	1060	A91060	H112	≥13, ≤25	21
117	99.60Al	Plate & sheet	B209	1060	A91060	H12	...	21
118	99.60Al	Plate & sheet	B209	1060	A91060	H14	...	21
119	99.0Al–Cu	Plate & sheet	B209	1100	A91100	O	...	21
120	99.0Al–Cu	Plate & sheet	B209	1100	A91100	H112	≥13, ≤50	21
121	99.0Al–Cu	Plate & sheet	B209	1100	A91100	H12	...	21
122	99.0Al–Cu	Plate & sheet	B209	1100	A91100	H14	...	21
123	Al–Mn–Cu	Plate & sheet	B209	3003	A93003	O	...	21
124	Al–Mn–Cu	Plate & sheet	B209	3003	A93003	H112	≥13, ≤50	21
125	Al–Mn–Cu	Plate & sheet	B209	3003	A93003	H12	...	21
126	Al–Mn–Cu	Plate & sheet	B209	3003	A93003	H14	...	21
127	Al–Mn–Mg	Plate & sheet	B209	3004	A93004	O	...	22
128	Al–Mn–Mg	Plate & sheet	B209	3004	A93004	H112	...	22
129	Al–Mn–Mg	Plate & sheet	B209	3004	A93004	H32	...	22
130	Al–Mn–Mg	Plate & sheet	B209	3004	A93004	H34	...	22
131	Al–1.5Mg	Plate & sheet	B209	5050	A95050	O	...	21
132	Al–1.5Mg	Plate & sheet	B209	5050	A95050	H112	...	21
133	Al–1.5Mg	Plate & sheet	B209	5050	A95050	H32	...	21
134	Al–1.5Mg	Plate & sheet	B209	5050	A95050	H34	...	21
135	Al–2.5Mg	Plate & sheet	B209	5052	A95052	O	...	22
136	Al–2.5Mg	Plate & sheet	B209	5052	A95052	H112	≥13, ≤75	22
137	Al–2.5Mg	Plate & sheet	B209	5052	A95052	H32	...	22
138	Al–2.5Mg	Plate & sheet	B209	5052	A95052	H34	...	22
139	Al–4.4Mg–Mn	Plate & sheet	B209	5083	A95083	O	≥1.3, ≤38	25
140	Al–4.4Mg–Mn	Plate & sheet	B209	5083	A95083	H32	≥5, ≤38	25
141	Al–4.0Mg–Mn	Plate & sheet	B209	5086	A95086	O	...	25
142	Al–4.0Mg–Mn	Plate & sheet	B209	5086	A95086	H112	≥13, ≤25	25
143	Al–4.0Mg–Mn	Plate & sheet	B209	5086	A95086	H32	...	25
144	Al–4.0Mg–Mn	Plate & sheet	B209	5086	A95086	H34	...	25
145	Al–3.5Mg	Plate & sheet	B209	5154	A95154	O	...	22
146	Al–3.5Mg	Plate & sheet	B209	5154	A95154	H112	≥13, ≤75	22
147	Al–3.5Mg	Plate & sheet	B209	5154	A95154	H32	...	22
148	Al–3.5Mg	Plate & sheet	B209	5154	A95154	H34	...	22
149	Al–3.5Mg	Plate & sheet	B209	5254	A95254	O	...	22

Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

Line No.	Notes	Min. Temp., °C (6)	Min. Tensile Strength, MPa	Min. Yield Strength, MPa	Max. Use Temp., °C	Basic Allowable Stress, *S*, MPa, at Metal Temperature, °C [Notes (1) and (4b)]							
						Min. Temp. to 40	65	100	125	150	175	200	225
114	(33) (68)	−269	290	241	204	*96.5*	*96.5*	*96.5*	*92.5*	*79.9*	*63.1*	**40.2**	**35.9**
115	...	−269	55	17	204	11.5	11.5	10.9	9.8	8.8	**7.5**	**5.8**	**5.5**
116	(13) (33)	−269	69	34	204	*23.0*	*21.8*	*19.1*	*17.0*	*15.0*	**11.8**	**7.5**	**5.9**
117	(33)	−269	76	62	204	*25.3*	*25.3*	*23.1*	*21.0*	**18.1**	**12.7**	**8.4**	**7.8**
118	(33)	−269	83	69	204	*27.6*	*27.6*	*27.6*	*26.6*	**18.1**	**12.7**	**8.4**	**7.8**
119	...	−269	76	24	204	16.1	16.1	16.0	15.6	**11.8**	**9.3**	**7.2**	**6.9**
120	(13) (33)	−269	83	34	204	23.0	23.0	22.7	**21.6**	**16.3**	**11.8**	**7.5**	**6.9**
121	(33)	−269	97	76	204	*32.2*	*32.2*	*31.3*	**25.2**	**19.0**	**13.6**	**8.5**	**7.8**
122	(33)	−269	110	97	204	*36.8*	*36.8*	*36.1*	*33.1*	**19.0**	**13.6**	**8.5**	**7.8**
123	...	−269	97	34	204	23.0	22.1	21.4	20.5	**18.2**	**13.6**	**10.9**	**10.5**
124	(13) (33)	−269	103	41	204	27.6	26.6	25.6	24.4	**18.2**	**13.6**	**10.9**	**10.5**
125	(33)	−269	117	83	204	*39.1*	*39.1*	*38.1*	*35.8*	**29.0**	**21.1**	**16.7**	**16.1**
126	(33)	−269	138	117	204	*46.0*	*46.0*	*46.0*	*43.9*	**29.0**	**21.1**	**16.7**	**16.1**
127	...	−269	152	59	204	39.1	39.1	39.1	39.0	***38.9***	**26.9**	**17.4**	**16.1**
128	(33)	−269	159	62	204	41.4	41.4	41.4	41.4	***38.9***	**26.9**	**17.4**	**16.1**
129	(33)	−269	193	145	204	*64.4*	*64.4*	*64.4*	**60.4**	**38.9**	**26.9**	**17.4**	**16.1**
130	(33)	−269	221	172	204	*73.5*	*73.5*	*73.5*	*73.5*	**38.9**	**26.9**	**17.4**	**16.1**
131	...	−269	124	41	204	27.6	27.6	27.5	27.5	27.5	**20.1**	**10.8**	**9.7**
132	(33)	−269	138	55	204	36.8	36.7	36.7	36.6	**35.8**	**20.1**	**10.8**	**9.7**
133	(33)	−269	152	110	204	*50.6*	*50.6*	*50.6*	*50.6*	**35.8**	**20.1**	**10.8**	**9.7**
134	(33)	−269	172	138	204	*57.5*	*57.5*	*57.5*	*57.5*	**35.8**	**20.1**	**10.8**	**9.7**
135	...	−269	172	65	204	43.7	43.7	43.7	43.6	**41.6**	**28.8**	**17.6**	**16.1**
136	(13) (33)	−269	172	65	204	43.7	43.7	43.7	43.6	**41.6**	**28.8**	**17.6**	**16.1**
137	(33)	−269	214	159	204	*71.2*	*71.2*	*71.2*	*71.0*	**41.6**	**28.8**	**17.6**	**16.1**
138	(33)	−269	234	179	204	*78.1*	*78.1*	*78.1*	*78.1*	**41.6**	**28.8**	**17.6**	**16.1**
139	(13)	−269	276	124	65	82.7	82.7	...	...	...	...	...	...
140	(13) (33)	−269	303	214	65	*101.1*	*101.1*	...	...	...	...	...	...
141	...	−269	241	97	65	64.4	64.4	...	...	...	...	...	...
142	(13) (33)	−269	241	110	65	73.5	73.5	...	...	...	...	...	...
143	(33)	−269	276	193	65	*91.9*	*91.9*	...	...	...	...	...	...
144	(33)	−269	303	234	65	*101.1*	*101.1*	...	...	...	...	...	...
145	...	−269	207	76	65	50.6	50.4	...	...	...	...	...	...
146	(13) (33)	−269	207	76	65	50.6	50.4	...	...	...	...	...	...
147	(33)	−269	248	179	65	*82.7*	*82.7*	...	...	...	...	...	...
148	(33)	−269	269	200	65	*89.6*	*89.6*	...	...	...	...	...	...
149	...	−269	207	76	65	50.6	50.4	...	...	...	...	...	...

Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

Line No.	Nominal Composition	Product Form	Spec. No.	Type/ Grade	UNS No.	Class/ Condition/ Temper	Size, mm	P-No. (5)
150	Al–3.5Mg	Plate & sheet	B209	5254	A95254	H112	≥13, ≤75	22
151	Al–3.5Mg	Plate & sheet	B209	5254	A95254	H32	...	22
152	Al–3.5Mg	Plate & sheet	B209	5254	A95254	H34	...	22
153	Al–2.7Mg–Mn	Plate & sheet	B209	5454	A95454	O	...	22
154	Al–2.7Mg–Mn	Plate & sheet	B209	5454	A95454	H112	≥13, ≤75	22
155	Al–2.7Mg–Mn	Plate & sheet	B209	5454	A95454	H32	...	22
156	Al–2.7Mg–Mn	Plate & sheet	B209	5454	A95454	H34	...	22
157	Al–5.1Mg–Mn	Plate & sheet	B209	5456	A95456	O	≥1.3, ≤38	25
158	Al–5.1Mg–Mn	Plate & sheet	B209	5456	A95456	H32	≥5, <13	25
159	Al–2.5Mg	Plate & sheet	B209	5652	A95652	O	...	22
160	Al–2.5Mg	Plate & sheet	B209	5652	A95652	H112	≥13, ≤75	22
161	Al–2.5Mg	Plate & sheet	B209	5652	A95652	H32	...	22
162	Al–2.5Mg	Plate & sheet	B209	5652	A95652	H34	...	22
163	Al–Mg–Si–Cu	Plate & sheet	B209	6061	A96061	T4 wld.	...	23
164	Al–Mg–Si–Cu	Plate & sheet	B209	6061	A96061	T6 wld.	...	23
165	Al–Mg–Si–Cu	Plate & sheet	B209	6061	A96061	T4	...	23
166	Al–Mg–Si–Cu	Plate & sheet	B209	6061	A96061	T6	...	23
167	Al–Mg–Si–Cu	Plate & sheet	B209	6061	A96061	T651	≥6, ≤100	23
168	Al–Mn–Cu	Forgings & fittings	B361	WP Alclad 3003	A83003	O	...	21
169	Al–Mn–Cu	Forgings & fittings	B361	WP Alclad 3003	A83003	H112	...	21
170	99.60Al	Forgings & fittings	B361	WP1060	A91060	O	...	21
171	99.60Al	Forgings & fittings	B361	WP1060	A91060	H112	...	21
172	99.0Al–Cu	Forgings & fittings	B361	WP1100	A91100	O	...	21
173	99.0Al–Cu	Forgings & fittings	B361	WP1100	A91100	H112	...	21
174	Al–Mn–Cu	Forgings & fittings	B247	3003	A93003	H112	...	21
175	Al–Mn–Cu	Forgings & fittings	B247	3003	A93003	H112 wld.	...	21
176	Al–Mn–Cu	Forgings & fittings	B361	WP3003	A93003	O	...	21
177	Al–Mn–Cu	Forgings & fittings	B361	WP3003	A93003	H112	...	21
178	Al–Mn–Cu	Forgings & fittings	B247	5083	A95083	O	...	25
179	Al–Mn–Cu	Forgings & fittings	B247	5083	A95083	H112	...	25
180	Al–Mn–Cu	Forgings & fittings	B247	5083	A95083	H112 wld.	...	25
181	Al–4.4Mg–Mn	Forgings & fittings	B361	WP5083	A95083	O	...	25

Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

Line No.	Notes	Min. Temp., °C (6)	Min. Tensile Strength, MPa	Min. Yield Strength, MPa	Max. Use Temp., °C	Basic Allowable Stress, *S*, MPa, at Metal Temperature, °C [Notes (1) and (4b)] — Min. Temp. to 40	65	100	125	150	175	200	225
150	(13) (33)	−269	207	76	65	50.6	50.4	...	...	...	...	...	...
151	(33)	−269	248	179	65	*82.7*	*82.7*	...	...	...	...	...	...
152	(33)	−269	269	200	65	*89.6*	*89.6*	...	...	...	...	...	...
153	...	−269	214	83	204	55.2	55.2	55.2	**48.9**	**37.5**	**28.6**	**21.7**	**20.7**
154	(13) (33)	−269	214	83	204	55.2	55.2	55.2	**48.9**	**37.5**	**28.6**	**21.7**	**20.7**
155	(33)	−269	248	179	204	*82.7*	*82.7*	*82.7*	**49.5**	**37.5**	**28.6**	**21.7**	**20.7**
156	(33)	−269	269	200	204	*89.6*	*89.6*	*89.6*	**49.5**	**37.5**	**28.6**	**21.7**	**20.7**
157	(13)	−269	290	131	65	87.3	87.3	...	...	...	...	...	...
158	(13) (33)	−269	317	228	65	*105.7*	*105.7*	...	...	...	...	...	...
159	...	−269	172	65	204	43.7	43.7	43.7	43.6	**41.6**	**28.8**	**17.6**	**16.1**
160	(13) (33)	−269	172	65	204	43.7	43.7	43.7	43.6	**41.6**	**28.8**	**17.6**	**16.1**
161	(33)	−269	214	159	204	*71.2*	*71.2*	*71.2*	*71.0*	**41.6**	**28.8**	**17.6**	**16.1**
162	(33)	−269	234	179	204	*78.1*	*78.1*	*78.1*	*78.1*	**41.6**	**28.8**	**17.6**	**16.1**
163	(22) (63)	−269	165	...	204	*55.2*	*55.2*	*55.2*	*54.3*	*52.0*	*46.3*	*35.3*	*34.8*
164	(22) (63)	−269	165	...	204	*55.2*	*55.2*	*55.2*	*54.3*	*52.0*	*46.3*	*35.3*	*34.8*
165	(33) (63)	−269	207	110	204	*68.9*	*68.9*	*68.9*	*67.8*	*64.8*	*57.9*	**40.2**	**35.9**
166	(33)	−269	290	241	204	*96.5*	*96.5*	*96.5*	*92.5*	*79.9*	*63.1*	**40.2**	**35.9**
167	(13) (33)	−269	290	241	204	*96.5*	*96.5*	*96.5*	*92.5*	*79.9*	*63.1*	**40.2**	**35.9**
168	(13) (14) (32) (33) (66)	−269	90	31	204	20.7	19.9	19.3	18.4	17.3	**13.6**	**10.9**	**10.5**
169	(13) (14) (32) (33) (66)	−269	90	31	204	20.7	19.9	19.3	18.4	17.3	**13.6**	**10.9**	**10.5**
170	(13) (14) (32) (33)	−269	55	17	204	11.5	11.5	10.9	9.8	8.8	**7.5**	**5.8**	**5.5**
171	(13) (14) (32) (33)	−269	55	17	204	11.5	11.5	10.9	9.8	8.8	**7.5**	**5.8**	**5.5**
172	(13) (14) (32) (33)	−269	76	21	204	13.8	13.8	13.7	13.2	**11.8**	**9.3**	**7.2**	**6.9**
173	(13) (14) (32) (33)	−269	76	21	204	13.8	13.8	13.7	13.2	**11.8**	**9.3**	**7.2**	**6.9**
174	(9) (45)	−269	97	34	204	23.0	22.1	21.4	20.5	**18.2**	**13.6**	**10.9**	**10.5**
175	(9) (45)	−269	97	34	204	23.0	22.1	21.4	20.5	**18.2**	**13.6**	**10.9**	**10.5**
176	(13) (14) (32) (33)	−269	97	34	204	23.0	22.1	21.4	20.5	**18.2**	**13.6**	**10.9**	**10.5**
177	(13) (14) (32) (33)	−269	97	34	204	23.0	22.1	21.4	20.5	**18.2**	**13.6**	**10.9**	**10.5**
178	(9) (32) (33)	−269	268	110	65	73.5	73.5	...	...	...	...	...	...
179	(9) (32) (33)	−269	268	110	65	73.5	73.5	...	...	...	...	...	...
180	(9) (32) (33)	−269	268	110	65	73.5	73.5	...	...	...	...	...	...
181	(13) (32) (33)	−269	269	110	65	73.5	73.5	...	...	...	...	...	...

Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

Line No.	Nominal Composition	Product Form	Spec. No.	Type/ Grade	UNS No.	Class/ Condition/ Temper	Size, mm	P-No. (5)
182	Al–4.4Mg–Mn	Forgings & fittings	B361	WP5083	A95083	H112	...	25
183	Al–3.5Mg	Forgings & fittings	B361	WP5154	A95154	O	...	22
184	Al–3.5Mg	Forgings & fittings	B361	WP5154	A95154	H112	...	22
185	Al–Mg–Si–Cu	Forgings & fittings	B247	6061	A96061	T6 wld.	...	23
186	Al–Mg–Si–Cu	Forgings & fittings	B361	WP6061	A96061	T4 wld.	...	23
187	Al–Mg–Si–Cu	Forgings & fittings	B361	WP6061	A96061	T6 wld.	...	23
188	Al–Mg–Si–Cu	Forgings & fittings	B361	WP6061	A96061	T4	...	23
189	Al–Mg–Si–Cu	Forgings & fittings	B247	6061	A96061	T6	...	23
190	Al–Mg–Si–Cu	Forgings & fittings	B361	WP6061	A96061	T6	...	23
191	Al–Mg–Si	Forgings & fittings	B361	WP6063	A96063	T4 wld.	...	23
192	Al–Mg–Si	Forgings & fittings	B361	WP6063	A96063	T6 wld.	...	23
193	Al–Mg–Si	Forgings & fittings	B361	WP6063	A96063	T4	...	23
194	Al–Mg–Si	Forgings & fittings	B361	WP6063	A96063	T6	...	23
195	Al–Si–Mg	Castings	B26	356.0	A03560	T71	...	26
196	Al–Si–Mg	Castings	B26	356.0	A03560	T6	...	26
197	Al–Si	Castings	B26	443.0	A04430	F	...	...

Table A-1M Basic Allowable Stresses in Tension for Metals (SI Units) (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

Line No.	Notes	Min. Temp., °C (6)	Min. Tensile Strength, MPa	Min. Yield Strength, MPa	Max. Use Temp., °C	Basic Allowable Stress, *S*, MPa, at Metal Temperature, °C [Notes (1) and (4b)] Min. Temp. to 40	65	100	125	150	175	200	225
182	(13) (32) (33)	−269	269	110	65	73.5	73.5	...	...	...	...	...	...
183	(32) (33)	−269	207	76	65	50.6	50.6	...	...	...	...	...	...
184	(32) (33)	−269	207	76	65	50.6	50.6	...	...	...	...	...	...
185	(9) (22)	−269	165	...	204	*55.2*	*55.2*	*55.2*	*54.3*	*52.0*	*46.3*	*35.3*	*34.8*
186	(22) (32) (63)	−269	165	...	204	*55.2*	*55.2*	*55.2*	*54.3*	*52.0*	*46.3*	*35.3*	*34.8*
187	(22) (32) (63)	−269	165	...	204	*55.2*	*55.2*	*55.2*	*54.3*	*52.0*	*46.3*	*35.3*	*34.8*
188	(13) (32) (33) (63)	−269	179	110	204	*59.8*	*59.8*	*59.8*	*58.9*	*56.3*	*50.2*	*38.3*	*35.9*
189	(9) (33)	−269	262	241	204	*87.3*	*87.3*	*87.3*	*83.6*	*72.3*	*57.2*	**40.2**	**35.9**
190	(13) (32) (33) (63)	−269	262	241	204	*87.3*	*87.3*	*87.3*	*83.6*	*72.3*	*57.2*	**40.2**	**35.9**
191	(32)	−269	117	...	204	*39.1*	*39.1*	*37.6*	*36.0*	*32.0*	*24.7*	**15.3**	**13.8**
192	(32)	−269	117	...	204	*39.1*	*39.1*	*37.6*	*36.0*	*32.0*	*24.7*	**15.3**	**13.8**
193	(13) (32) (33)	−269	124	62	204	*41.4*	41.3	*41.3*	41.0	*41.0*	*33.9*	*22.6*	*9.8*
194	(13) (32) (33)	−269	207	172	204	*68.9*	*68.9*	*67.7*	*59.0*	*45.9*	**27.5**	**15.3**	**13.8**
195	(9) (43)	−269	172	124	204	*57.5*	*57.5*	*57.5*	**55.0**	**49.8**	**38.6**	**18.9**	**16.5**
196	(9) (43)	−269	207	138	121	*68.9*	*68.9*	*68.9*	*57.9*	...	...	...	...
197	(9) (43)	−269	117	48	204	32.0	32.0	32.0	32.0	32.0	32.0	32.0	24.1

Table A-1A Basic Casting Quality Factors, E_c

These quality factors are determined in accordance with para. 302.3.3(b). See also para. 302.3.3(c) and Table 302.3.3C for increased quality factors applicable in special cases. Specifications are ASTM.

Spec. No.	Description	E_c [Note (2)]	Appendix A Notes
Iron			
A47	Malleable iron castings	1.00	(9)
A48	Gray iron castings	1.00	(9)
A126	Gray iron castings	1.00	(9)
A197	Cupola malleable iron castings	1.00	(9)
A278	Gray iron castings	1.00	(9)
A395	Ductile and ferritic ductile iron castings	0.80	(9), (40)
A536	Ductile iron castings	0.80	(9), (40)
A571	Austenitic ductile iron castings	0.80	(9), (40)
Carbon Steel			
A216	Carbon steel castings	0.80	(9), (40)
A352	Ferritic steel castings	0.80	(9), (40)
Low and Intermediate Alloy Steel			
A217	Martensitic stainless and alloy castings	0.80	(9), (40)
A352	Ferritic steel castings	0.80	(9), (40)
A426	Centrifugally cast pipe	1.00	(10)
Stainless Steel			
A351	Austenitic steel castings	0.80	(9), (40)
A451	Centrifugally cast pipe	0.90	(10), (40)
A487	Steel castings	0.80	(9), (40)
Copper and Copper Alloy			
B61	Steam bronze castings	0.80	(9), (40)
B62	Composition bronze castings	0.80	(9), (40)
B148	Al–bronze and Si–Al–bronze castings	0.80	(9), (40)
B584	Copper alloy castings	0.80	(9), (40)
Nickel and Nickel Alloy			
A494	Nickel and nickel alloy castings	0.80	(9), (40)
Aluminum Alloy			
B26, Temper F	Aluminum alloy castings	1.00	(9), (10)
B26, Temper T6, T71	Aluminum alloy castings	0.80	(9), (40)
Titanium and Titanium Alloy			
B367	Titanium and titanium alloy castings	0.80	(9), (40)

Table A-1B Basic Quality Factors for Longitudinal Weld Joints in Pipes and Tubes, E_j (20)

These quality factors are determined in accordance with para. 302.3.4(a). See also para. 302.3.4(b) and Table 302.3.4 for increased quality factors applicable in special cases. Specifications, except API, are ASTM.

Spec. No.	Class (or Type)	Description	E_j [Note (2)]	Appendix A Notes
Carbon Steel				
API 5L	...	Seamless pipe	1.00	...
		Electric fusion welded pipe, 100% radiographed	1.00	...
		Electric resistance welded pipe	0.85	...
		Electric fusion welded pipe, double butt seam	0.95	...
		Continuous welded (furnace butt welded) pipe	0.60	...
A53	Type S	Seamless pipe	1.00	...
	Type E	Electric resistance welded pipe	0.85	...
	Type F	Furnace butt welded pipe	0.60	...
A106	...	Seamless pipe	1.00	...
A134	...	Electric fusion welded pipe, single butt, straight or spiral (helical) seam	0.80	...
A135	...	Electric resistance welded pipe	0.85	...
A139	...	Electric fusion welded pipe, straight or spiral (helical) seam	0.80	...
A179	...	Seamless tube	1.00	...
A333	...	Seamless pipe	1.00	...
		Electric resistance welded pipe	0.85	...
A334	...	Seamless tube	1.00	...
A369	...	Seamless pipe	1.00	...
A381	...	Electric fusion welded pipe, 100% radiographed	1.00	...
		Electric fusion welded pipe, spot radiographed	0.90	(19)
		Electric fusion welded pipe, as manufactured	0.85	...
A524	...	Seamless pipe	1.00	...
A587	...	Electric resistance welded pipe	0.85	...
A671	12, 22, 32, 42, 52	Electric fusion welded pipe, 100% radiographed	1.00	...
	13, 23, 33, 43, 53	Electric fusion welded pipe, double butt seam	0.85	...
A672	12, 22, 32, 42, 52	Electric fusion welded pipe, 100% radiographed	1.00	...
	13, 23, 33, 43, 53	Electric fusion welded pipe, double butt seam	0.85	...
A691	12, 22, 32, 42, 52	Electric fusion welded pipe, 100% radiographed	1.00	...
	13, 23, 33, 43, 53	Electric fusion welded pipe, double butt seam	0.85	...
Low and Intermediate Alloy Steel				
A333	...	Seamless pipe	1.00	...
		Electric resistance welded pipe	0.85	(78)
A334	...	Seamless tube	1.00	...
A335	...	Seamless pipe	1.00	...
A369	...	Seamless pipe	1.00	...
A671	12, 22, 32, 42, 52	Electric fusion welded pipe, 100% radiographed	1.00	...
	13, 23, 33, 43, 53	Electric fusion welded pipe, double butt seam	0.85	(78)
A672	12, 22, 32, 42, 52	Electric fusion welded pipe, 100% radiographed	1.00	...
	13, 23, 33, 43, 53	Electric fusion welded pipe, double butt seam	0.85	(78)
A691	12, 22, 32, 42, 52	Electric fusion welded pipe, 100% radiographed	1.00	...
	13, 23, 33, 43, 53	Electric fusion welded pipe, double butt seam	0.85	(78)

Table A-1B Basic Quality Factors for Longitudinal Weld Joints in Pipes and Tubes, E_j (Cont'd)

These quality factors are determined in accordance with para. 302.3.4(a). See also para. 302.3.4(b) and Table 302.3.4 for increased quality factors applicable in special cases. Specifications, except API, are ASTM.

Spec. No.	Class (or Type)	Description	E_j [Note (2)]	Appendix A Notes
Stainless Steel				
A249	...	Electric fusion welded tube, single butt seam	0.80	...
A268	...	Seamless tube	1.00	...
		Electric fusion welded tube, double butt seam	0.85	...
		Electric fusion welded tube, single butt seam	0.80	...
A269	...	Seamless tube	1.00	...
		Electric fusion welded tube, double butt seam	0.85	...
		Electric fusion welded tube, single butt seam	0.80	...
A270	...	Seamless tube	1.00	...
		Electric fusion welded tube, double butt seam	0.85	...
		Electric fusion welded tube, single butt seam	0.80	...
A312	...	Seamless pipe	1.00	...
		Electric fusion welded pipe, double butt seam	0.85	...
		Electric fusion welded pipe, single butt seam	0.80	...
		Electric fusion welded pipe, 100% radiographed	1.00	(46)
A358	1, 3, 4	Electric fusion welded pipe, 100% radiographed	1.00	...
	5	Electric fusion welded pipe, spot radiographed	0.90	...
	2	Electric fusion welded pipe, double butt seam	0.85	...
A376	...	Seamless pipe	1.00	...
A409	...	Electric fusion welded pipe, double butt seam	0.85	...
		Electric fusion welded pipe, single butt seam	0.80	...
A789	...	Seamless tube	1.00	...
		Electric fusion welded tube, 100% radiographed	1.00	...
		Electric fusion welded tube, double butt	0.85	...
		Electric fusion welded tube, single butt	0.80	...
A790	...	Seamless pipe	1.00	...
		Electric fusion welded pipe, 100% radiographed	1.00	...
		Electric fusion welded pipe, double butt	0.85	...
		Electric fusion welded pipe, single butt	0.80	...
A813	DW	Electric fusion welded pipe, double butt	0.85	...
	SW	Electric fusion welded pipe, single butt	0.80	...
A814	DW	Electric fusion welded pipe, double butt	0.85	...
	SW	Electric fusion welded pipe, single butt	0.80	...
A928	1, 3, 4	Electric fusion welded pipe, 100% radiographed	1.00	...
	5	Electric fusion welded pipe, spot radiographed	0.90	...
	2	Electric fusion welded pipe, double butt seam	0.85	...
Copper and Copper Alloy				
B42	...	Seamless pipe	1.00	...
B43	...	Seamless pipe	1.00	...
B68	...	Seamless tube	1.00	...
B75	...	Seamless tube	1.00	...
B88	...	Seamless water tube	1.00	...

Table A-1B Basic Quality Factors for Longitudinal Weld Joints in Pipes and Tubes, E_j (Cont'd)

These quality factors are determined in accordance with para. 302.3.4(a). See also para. 302.3.4(b) and Table 302.3.4 for increased quality factors applicable in special cases. Specifications, except API, are ASTM.

Spec. No.	Class (or Type)	Description	E_j [Note (2)]	Appendix A Notes
Copper and Copper Alloy (Cont'd)				
B280	...	Seamless tube	1.00	...
B466	...	Seamless pipe and tube	1.00	...
B467	...	Electric resistance welded pipe	0.85	...
		Electric fusion welded pipe, double butt seam	0.85	...
		Electric fusion welded pipe, single butt seam	0.80	...
Nickel and Nickel Alloy				
B161	...	Seamless pipe and tube	1.00	...
B163	...	Seamless tube	1.00	...
B165	...	Seamless pipe and tube	1.00	...
B167	...	Seamless pipe and tube	1.00	...
B407	...	Seamless pipe and tube	1.00	...
B444	...	Seamless pipe and tube	1.00	...
B464	...	Welded pipe	0.80	...
B474	1, 3, 4	Welded pipe, 100% radiographed	1.00	...
	2	Electric fusion welded pipe, double butt seam	0.85	...
B514	...	Welded pipe	0.80	...
B515	...	Welded tube	0.80	...
B619	...	Electric resistance welded pipe	0.85	...
		Electric fusion welded pipe, double butt seam	0.85	...
		Electric fusion welded pipe, single butt seam	0.80	...
B622	...	Seamless pipe and tube	1.00	...
B626	All	Electric resistance welded tube	0.85	...
		Electric fusion welded tube, double butt seam	0.85	...
		Electric fusion welded tube, single butt seam	0.80	...
B668	All	Seamless pipe and tube	1.00	...
B675	All	Welded pipe	0.80	...
B690	...	Seamless pipe and tube	1.00	...
B704	...	Welded tube	0.80	...
B705	...	Welded pipe	0.80	...
B725	...	Electric fusion welded pipe, double butt seam	0.85	...
		Electric fusion welded pipe, single butt seam	0.80	...
B729	...	Seamless pipe and tube	1.00	...
B804	1, 3, 5	Welded pipe, 100% radiographed	1.00	...
	2, 4	Welded pipe, double fusion welded	0.85	...
	6	Welded pipe, single fusion welded	0.80	...
Titanium and Titanium Alloy				
B338	...	Seamless tube	1.00	...
		Electric fusion welded tube, 100% radiographed	1.00	...

Table A-1B Basic Quality Factors for Longitudinal Weld Joints in Pipes and Tubes, E_j (Cont'd)

These quality factors are determined in accordance with para. 302.3.4(a). See also para. 302.3.4(b) and Table 302.3.4 for increased quality factors applicable in special cases. Specifications, except API, are ASTM.

Spec. No.	Class (or Type)	Description	E_j [Note (2)]	Appendix A Notes
Titanium and Titanium Alloy (Cont'd)				
		Electric fusion welded tube, double butt seam	0.85	...
		Electric fusion welded tube, single butt seam	0.80	...
B861	...	Seamless pipe	1.00	...
B862	...	Electric fusion welded pipe, 100% radiographed	1.00	...
		Electric fusion welded pipe, double butt seam	0.85	...
		Electric fusion welded pipe, single butt seam	0.80	...
Zirconium and Zirconium Alloy				
B523	...	Seamless tube	1.00	...
		Electric fusion welded tube	0.80	...
B658	...	Seamless pipe	1.00	...
		Electric fusion welded pipe	0.80	...
Aluminum Alloy				
B210	...	Seamless tube	1.00	...
B241	...	Seamless pipe and tube	1.00	...

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Table A-2 Design Stress Values for Bolting Materials

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM

Nominal Composition	Product Form	Spec. No.	Type/ Grade	UNS No.	Class/ Condition/ Temper	Size Range, Dia., in.	Notes	Min. Temp., °F (6)	Specified Min. Strength, ksi: Tensile	Specified Min. Strength, ksi: Yield	Design Stress, ksi, at Metal Temperature, °F [Note (1)]: Min. Temp. to 100	200	300	400	500
...	Bolts	A675	45	D40450	...	...	(8f) (8g)	−20	45	22.5	11.3	11.3	11.3	11.3	11.3
...	Bolts	A675	50	D40500	...	...	(8f) (8g)	−20	50	25	12.5	12.5	12.5	12.5	12.5
...	Bolts	A675	55	D40550	...	...	(8f) (8g)	−20	55	27.5	13.8	13.8	13.8	13.8	13.8
...	Bolts	A307	B	...	...	...	(8f) (8g)	−20	60	...	15.0	15.0	15.0	15.0	15.0
...	Bolts	A675	60	D40600	...	...	(8f) (8g)	−20	60	30	15.0	15.0	15.0	15.0	15.0
...	Bolts	A675	65	D40650	...	...	(8g)	−20	65	32.5	16.3	16.3	16.3	16.3	16.3
...	Bolts	A675	70	D40700	...	...	(8g)	−20	70	35	17.5	17.5	17.5	17.5	17.5
...	Bolts	A675	80	D40800	...	...	(8g)	−20	80	40	20.0	20.0	20.0	20.0	20.0
...	Bolts	F3125	A325	K02706	...	...	(8g)	−20	120	92	23.0	23.0	23.0	23.0	23.0
...	Nuts	A194	1	K01503	...	...	(42)	−20	...	...	...	...	...	...	...
...	Nuts	A194	2	K04002	...	...	(42)	−55	...	...	...	...	...	...	...
...	Nuts	A194	2H	K04002	...	...	(42)	−55	...	...	...	...	...	...	...
...	Nuts	A194	2HM	K04002	...	...	(42)	−55	...	...	...	...	...	...	...
...	Nuts, hvy. hex	A563	A	K05802	...	...	(42b)	−20	...	...	...	...	...	...	...
Alloy Steel															
Cr–$\frac{1}{5}$Mo	Bolts	A193	B7M	G41400	...	≤4	...	−55	100	80	20.0	20.0	20.0	20.0	20.0
Cr–$\frac{1}{5}$Mo	Bolts	A320	L7M	G41400	...	≤2$\frac{1}{2}$	...	−100	100	80	20.0	20.0	20.0	20.0	20.0
5Cr	Bolts	A193	B5	S50100	...	≤4	(15)	−20	100	80	20.0	20.0	20.0	20.0	20.0
Cr–Mo–V	Bolts	A193	B16	K14072	...	>2$\frac{1}{2}$, ≤4	(15)	−20	110	95	22.0	22.0	22.0	22.0	22.0
Alloy steel	Bolts	A354	BC	K04100	...	>2$\frac{1}{2}$, ≤4	(15)	0	115	99	23.0	23.0	23.0	23.0	23.0
Cr–Mo	Bolts	A193	B7	G41400	...	>2$\frac{1}{2}$, ≤4	(15)	−40	115	95	23.0	23.0	23.0	23.0	23.0
Ni–Cr–Mo	Bolts	A320	L43	G43400	...	≤4	(15)	−150	125	105	25.0	25.0	25.0	25.0	25.0
Cr–Mo	Bolts	A320	L7	G41400	...	≤2$\frac{1}{2}$	(15)	−150	125	105	25.0	25.0	25.0	25.0	25.0
Cr–Mo	Bolts	A320	L7A	G40370	...	≤2$\frac{1}{2}$	(15)	−150	125	105	25.0	25.0	25.0	25.0	25.0
Cr–Mo	Bolts	A320	L7B	G41370	...	≤2$\frac{1}{2}$	(15)	−150	125	105	25.0	25.0	25.0	25.0	25.0
Cr–Mo	Bolts	A320	L7C	G87400	...	≤2$\frac{1}{2}$	(15)	−150	125	105	25.0	25.0	25.0	25.0	25.0
Cr–Mo	Bolts	A193	B7	G41400	...	≤2$\frac{1}{2}$	...	−55	125	105	25.0	25.0	25.0	25.0	25.0
Cr–Mo–V	Bolts	A193	B16	K14072	...	≤2$\frac{1}{2}$	(15)	−20	125	105	25.0	25.0	25.0	25.0	25.0
Alloy steel	Bolts	A354	BC	K04100	...	≤2$\frac{1}{2}$	(15)	0	125	109	25.0	25.0	25.0	25.0	25.0
Alloy steel	Bolts	A354	BD	K04100	...	≤4	(15)	−20	150	130	30.0	30.0	30.0	30.0	30.0
5Cr	Nuts	A194	3	S50100	...	...	(42)	−20	...	...	...	...	...	...	...
Cr–Mo	Nuts	A194	7	G41400	...	...	(42)	−55	...	...	...	...	...	...	...
Cr–Mo	Nuts	A194	7L	G41400	...	...	(42)	−150	...	...	...	...	...	...	...
Cr–Mo	Nuts	A194	7M	G41400	...	...	(42)	−55	...	...	...	...	...	...	...
Cr–Mo	Nuts	A194	7ML	G41400	...	...	(42)	−100	...	...	...	...	...	...	...
Stainless Steel															
16Cr–12Ni–2Mo	Bolts	A193	B8M	S31600	2	>1$\frac{1}{4}$, ≤1$\frac{1}{2}$	(15) (60)	−325	90	50	18.8	17.3	15.6	14.3	13.3
16Cr–12Ni–2Mo	Bolts	A320	B8M	S31600	2	>1$\frac{1}{4}$, ≤1$\frac{1}{2}$	(15) (60)	−325	90	50	18.8	17.3	15.6	14.3	13.3

Table A-2 Design Stress Values for Bolting Materials

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM

Design Stress, ksi, at Metal Temperature, °F [Note (1)]																				
600	650	700	750	800	850	900	950	1,000	1,050	1,100	1,150	1,200	1,250	1,300	1,350	1,400	1,450	1,500	Type/ Grade	Spec. No.
11.3	11.1	10.7	10.4	9.2	7.9	5.9	4.0	...	...	...	...	...	...	...	...	...	...	...	45	A675
12.5	12.4	11.9	10.7	9.2	7.9	5.9	4.0	...	...	...	...	...	...	...	...	...	...	...	50	A675
13.8	13.6	13.1	12.7	10.8	8.7	5.9	4.0	...	...	...	...	...	...	...	...	...	...	...	55	A675
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	B	A307
15.0	14.8	14.3	13.8	11.4	8.7	5.9	4.0	...	...	...	...	...	...	...	...	...	...	...	60	A675
16.3	16.1	15.5	13.9	11.4	9.0	6.3	4.0	...	...	...	...	...	...	...	...	...	...	...	65	A675
17.5	17.3	16.7	14.8	12.0	9.3	6.7	4.0	...	...	...	...	...	...	...	...	...	...	...	70	A675
20.0	19.8	19.1	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	80	A675
23.0	23.0	23.0	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	A325	F3125
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	1	A194
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	2	A194
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	2H	A194
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	2HM	A194
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	A	A563
																				Alloy Steel
20.0	20.0	20.0	20.0	18.5	16.3	12.5	8.5	4.5	2.4	...	...	...	...	...	...	...	...	...	B7M	A193
20.0	20.0	20.0	20.0	18.5	16.3	12.5	8.5	4.5	2.4	...	...	...	...	...	...	...	...	...	L7M	A320
20.0	20.0	20.0	20.0	20.0	14.3	10.9	8.0	5.8	4.2	2.9	1.8	1.0	0.6	...	...	...	...	...	B5	A193
22.0	22.0	22.0	22.0	22.0	21.0	18.5	15.3	11.0	6.3	2.8	1.2	...	...	...	...	...	...	...	B16	A193
23.0	23.0	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	BC	A354
23.0	23.0	23.0	23.0	20.0	16.3	12.5	8.5	4.5	2.4	...	...	...	...	...	...	...	...	...	B7	A193
25.0	25.0	25.0	25.0	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	L43	A320
25.0	25.0	25.0	25.0	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	L7	A320
25.0	25.0	25.0	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	L7A	A320
25.0	25.0	25.0	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	L7B	A320
25.0	25.0	25.0	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	L7C	A320
25.0	25.0	25.0	25.0	25.0	21.0	17.0	12.5	8.5	4.5	2.4	...	...	...	...	...	...	...	...	B7	A193
25.0	25.0	25.0	25.0	25.0	23.5	20.5	16.0	11.0	6.3	2.8	1.2	...	...	...	...	...	...	...	B16	A193
25.0	25.0	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	BC	A354
30.0	30.0	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	BD	A354
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	3	A194
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	7	A194
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	7L	A194
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	7M	A194
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	7ML	A194
																				Stainless Steel
12.6	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	...	...	...	...	...	...	...	...	...	B8M Cl. 2	A193
12.6	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	...	...	...	...	...	...	...	...	...	B8M Cl. 2	A320

Table A-2 Design Stress Values for Bolting Materials (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM

Nominal Composition	Product Form	Spec. No.	Type/ Grade	UNS No.	Class/ Condition/ Temper	Size Range, Dia., in.	Notes	Min. Temp., °F (6)	Specified Min. Strength, ksi: Tensile	Specified Min. Strength, ksi: Yield	Design Stress, ksi, at Metal Temperature, °F [Note (1)]: Min. Temp. to 100	200	300	400	500
Stainless Steel															
18Cr–8Ni	Bolts	A193	B8	S30400	2	>1¼, ≤1½	(15) (60)	−325	100	50	18.8	16.7	15.0	13.8	12.9
18Cr–8Ni	Bolts	A320	B8	S30400	2	>1¼, ≤1½	(15) (60)	−325	100	50	18.8	16.7	15.0	13.8	12.9
18Cr–10Ni–Cb	Bolts	A193	B8C	...	2	>1¼, ≤1½	(15) (60)	−325	100	50	18.8	17.9	16.5	15.5	15.0
18Cr–10Ni–Cb	Bolts	A320	B8C	S34700	2	>1¼, ≤1½	(15) (60)	−325	100	50	18.8	17.9	16.5	15.5	15.0
18Cr–10Ni–Ti	Bolts	A193	B8T	S32100	2	>1¼, ≤1½	(15) (60)	−325	100	50	18.8	17.8	16.5	15.3	14.3
18Cr–10Ni–Ti	Bolts	A320	B8T	S32100	2	>1¼, ≤1½	(15) (60)	−325	100	50	18.8	17.8	16.5	15.3	14.3
18Cr–9Ni	Bolts	A320	B8F	S30300	1	...	(8f) (15) (39)	−325	75	30	18.8	16.7	15.0	13.8	12.9
19Cr–9Ni	Bolts	A453	651B	...	...	>3	(15) (35)	−20	95	50	23.8	23.4	22.1	21.3	20.8
19Cr–9Ni	Bolts	A453	651B	...	...	≤3	(15) (35)	−20	95	60	23.8	23.4	22.1	21.3	20.8
19Cr–9Ni	Bolts	A453	651A	...	...	>3	(15) (35)	−20	100	60	23.8	23.4	22.1	21.3	20.8
19Cr–9Ni	Bolts	A453	651A	...	...	≤3	(15) (35)	−20	100	70	23.8	23.4	22.1	21.3	20.8
16Cr–12Ni–2Mo	Bolts	A193	B8M	S31600	2	>1, ≤1¼	(15) (60)	−325	105	65	18.8	17.3	16.3	16.3	16.3
16Cr–12Ni–2Mo	Bolts	A320	B8M	S31600	2	>1, ≤1¼	(15) (60)	−325	105	65	18.8	17.3	16.3	16.3	16.3
18Cr–10Ni–Cb	Bolts	A193	B8C	...	2	>1, ≤1¼	(15) (60)	−325	105	65	18.8	17.9	16.5	16.3	16.3
18Cr–10Ni–Cb	Bolts	A320	B8C	S34700	2	>1, ≤1¼	(15) (60)	−325	105	65	18.8	17.9	16.5	16.3	16.3
18Cr–8Ni	Bolts	A193	B8	S30400	2	>1, ≤1¼	(15) (60)	−325	105	65	18.8	16.7	16.3	16.3	16.3
18Cr–8Ni	Bolts	A320	B8	S30400	2	>1, ≤1¼	(15) (60)	−325	105	65	18.8	16.7	16.3	16.3	16.3
18Cr–10Ni–Ti	Bolts	A193	B8T	S32100	2	>1, ≤1¼	(15) (60)	−325	105	65	18.8	17.8	16.5	16.3	16.3
18Cr–10Ni–Ti	Bolts	A320	B8T	S32100	2	>1, ≤1¼	(15) (60)	−325	105	65	18.8	17.8	16.5	16.3	16.3
18Cr–10Ni–Ti	Bolts	A193	B8T	S32100	1	...	(8f) (15) (28)	−325	75	30	18.8	17.8	16.5	15.3	14.3
18Cr–8Ni	Bolts	A193	B8	S30400	1	...	(8f) (15) (28)	−425	75	30	18.8	16.7	15.0	13.8	12.9
18Cr–8Ni	Bolts	A320	B8	S30400	1	...	(8f) (15) (28)	−425	75	30	18.8	16.7	15.0	13.8	12.9
18Cr–10Ni–Cb	Bolts	A193	B8C	...	1	...	(8f) (15) (28)	−425	75	30	18.8	17.9	16.5	15.5	15.0
16Cr–12Ni–2Mo	Bolts	A193	B8M	S31600	1	...	(8f) (15) (28)	−325	75	30	18.8	17.3	15.6	14.3	13.3
16Cr–12Ni–2Mo	Bolts	A193	B8M	S31600	2	>¾, ≤1	(15) (60)	−325	100	80	20.0	20.0	20.0	20.0	20.0
16Cr–12Ni–2Mo	Bolts	A320	B8M	S31600	2	>¾, ≤1	(15) (60)	−325	100	80	20.0	20.0	20.0	20.0	20.0
18Cr–10Ni–Cb	Bolts	A193	B8C	...	2	>¾, ≤1	(15) (60)	−325	115	80	20.0	20.0	20.0	20.0	20.0
18Cr–10Ni–Cb	Bolts	A320	B8C	S34700	2	>¾, ≤1	(15) (60)	−325	115	80	20.0	20.0	20.0	20.0	20.0
18Cr–8Ni	Bolts	A193	B8	S30400	2	>¾, ≤1	(15) (60)	−325	115	80	20.0	20.0	20.0	20.0	20.0
18Cr–8Ni	Bolts	A320	B8	S30400	2	>¾, ≤1	(15) (60)	−325	115	80	20.0	20.0	20.0	20.0	20.0
18Cr–10Ni–Ti	Bolts	A193	B8T	S32100	2	>¾, ≤1	(15) (60)	−325	115	80	20.0	20.0	20.0	20.0	20.0
18Cr–10Ni–Ti	Bolts	A320	B8T	S32100	2	>¾, ≤1	(15) (60)	−325	115	80	20.0	20.0	20.0	20.0	20.0
12Cr	Bolts	A437	B4C	S42200	...	...	(35)	−20	115	85	21.3	21.3	21.3	21.3	21.3
13Cr	Bolts	A193	B6	S41000	...	≤4	(15) (35)	−20	110	85	21.3	21.3	21.3	21.3	21.3

Table A-2 Design Stress Values for Bolting Materials (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM

Design Stress, ksi, at Metal Temperature, °F [Note (1)]																				
600	650	700	750	800	850	900	950	1,000	1,050	1,100	1,150	1,200	1,250	1,300	1,350	1,400	1,450	1,500	Type/ Grade	Spec. No.
																			Stainless Steel	**(Cont'd)**
12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	...	...	...	...	...	...	...	...	...	B8 Cl. 2	A193
12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	...	...	...	...	...	...	...	...	...	B8 Cl. 2	A320
14.3	14.0	13.8	13.7	13.6	13.5	13.4	13.4	13.4	12.5	...	...	...	...	...	...	...	...	...	B8C Cl. 2	A193
14.3	14.0	13.8	13.7	13.6	13.5	13.4	13.4	13.4	12.5	...	...	...	...	...	...	...	...	...	B8C Cl. 2	A320
13.5	13.2	13.0	12.7	12.6	12.5	12.5	12.5	12.5	12.5	...	...	...	...	...	...	...	...	...	B8T Cl. 2	A193
13.5	13.2	13.0	12.7	12.6	12.5	12.5	12.5	12.5	12.5	...	...	...	...	...	...	...	...	...	B8T Cl. 2	A320
12.3	12.0	11.7	11.5	11.2	11.0	...	...	...	...	...	...	...	...	...	...	...	...	...	B8F Cl. 1	A320
20.5	20.4	20.3	20.2	20.0	19.7	19.3	18.9	18.2	17.5	...	...	...	...	...	...	...	...	...	651B	A453
20.5	20.4	20.3	20.2	20.0	19.7	19.3	18.9	18.2	17.5	...	...	...	...	...	...	...	...	...	651B	A453
20.5	20.4	20.3	20.2	20.0	19.7	19.3	18.9	18.2	17.5	...	...	...	...	...	...	...	...	...	651A	A453
20.5	20.4	20.3	20.2	20.0	19.7	19.3	18.9	18.2	17.5	...	...	...	...	...	...	...	...	...	651A	A453
16.3	16.3	16.3	16.3	16.3	16.3	16.3	16.3	16.3	16.3	...	...	...	...	...	...	...	...	...	B8M Cl. 2	A193
16.3	16.3	16.3	16.3	16.3	16.3	16.3	16.3	16.3	16.3	...	...	...	...	...	...	...	...	...	B8M Cl. 2	A320
16.3	16.3	16.3	16.3	16.3	16.3	16.3	16.3	16.3	16.3	...	...	...	...	...	...	...	...	...	B8C Cl. 2	A193
16.3	16.3	16.3	16.3	16.3	16.3	16.3	16.3	16.3	16.3	...	...	...	...	...	...	...	...	...	B8C Cl. 2	A320
16.3	16.3	16.3	16.3	16.3	16.3	16.3	16.3	16.3	16.3	...	...	...	...	...	...	...	...	...	B8 Cl. 2	A193
16.3	16.3	16.3	16.3	16.3	16.3	16.3	16.3	16.3	16.3	...	...	...	...	...	...	...	...	...	B8 Cl. 2	A320
16.3	16.3	16.3	16.3	16.3	16.3	16.3	16.3	16.3	16.3	...	...	...	...	...	...	...	...	...	B8T Cl. 2	A193
16.3	16.3	16.3	16.3	16.3	16.3	16.3	16.3	16.3	16.3	...	...	...	...	...	...	...	...	...	B8T Cl. 2	A320
13.5	13.2	13.0	12.7	12.6	12.4	12.3	12.1	12.0	9.6	6.9	5.0	3.6	2.6	1.7	1.1	0.8	0.5	0.3	B8T Cl. 1	A193
12.3	12.0	11.7	11.5	11.2	11.0	10.8	10.6	10.4	10.1	9.8	7.7	6.1	4.7	3.7	2.9	2.3	1.8	1.4	B8 Cl. 1	A193
12.3	12.0	11.7	11.5	11.2	11.0	10.8	10.6	10.4	10.1	9.8	7.7	6.1	4.7	3.7	2.9	2.3	1.8	1.4	B8 Cl. 1	A320
14.3	14.0	13.8	13.7	13.6	13.5	13.4	13.4	13.4	12.1	9.1	6.1	4.4	3.3	2.2	1.5	1.2	0.9	0.8	B8C Cl. 1	A193
12.6	12.3	12.1	11.9	11.8	11.6	11.5	11.4	11.3	11.2	11.1	9.8	7.4	5.6	4.2	3.2	2.4	1.8	1.4	B8M Cl. 1	A193
20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	...	...	...	...	...	...	...	...	...	B8M Cl. 2	A193
20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	...	...	...	...	...	...	...	...	...	B8M Cl. 2	A320
20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	...	...	...	...	...	...	...	...	...	B8C Cl. 2	A193
20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	...	...	...	...	...	...	...	...	...	B8C Cl. 2	A320
20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	...	...	...	...	...	...	...	...	...	B8 Cl. 2	A193
20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	...	...	...	...	...	...	...	...	...	B8 Cl. 2	A320
20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	...	...	...	...	...	...	...	...	...	B8T Cl. 2	A193
20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	...	...	...	...	...	...	...	...	...	B8T Cl. 2	A320
21.3	21.3	21.3	21.3	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	B4C	A437
21.3	21.3	21.3	21.3	21.3	21.3	20.2	18.7	...	...	...	...	...	...	...	...	...	...	...	B6	A193

Table A-2 Design Stress Values for Bolting Materials (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM

Nominal Composition	Product Form	Spec. No.	Type/ Grade	UNS No.	Class/ Condition/ Temper	Size Range, Dia., in.	Notes	Min. Temp., °F (6)	Specified Min. Strength, ksi: Tensile	Specified Min. Strength, ksi: Yield	Design Stress, ksi, at Metal Temperature, °F [Note (1)]: Min. Temp. to 100	200	300	400	500
Stainless Steel															
14Cr–24Ni	Bolts	A453	660	S66286	A	...	(15) (35)	−325	130	85	21.3	21.3	21.3	21.3	21.3
14Cr–24Ni	Bolts	A453	660	S66286	B	...	(15) (35)	−325	130	85	21.3	21.3	21.3	21.3	21.3
16Cr–12Ni–2Mo	Bolts	A193	B8M	S31600	2	≤3/4	(15) (60)	−325	110	95	22.0	22.0	22.0	22.0	22.0
16Cr–12Ni–2Mo	Bolts	A320	B8M	S31600	2	≤3/4	(15) (60)	−325	110	95	22.0	22.0	22.0	22.0	22.0
18Cr–10Ni–Cb	Bolts	A193	B8C	...	2	≤3/4	(15) (60)	−325	125	100	25.0	25.0	25.0	25.0	25.0
18Cr–10Ni–Cb	Bolts	A320	B8C	S34700	2	≤3/4	(15) (60)	−325	125	100	25.0	25.0	25.0	25.0	25.0
18Cr–8Ni	Bolts	A193	B8	S30400	2	≤3/4	(15) (60)	−325	125	100	25.0	25.0	25.0	25.0	25.0
18Cr–8Ni	Bolts	A320	B8	S30400	2	≤3/4	(15) (60)	−325	125	100	25.0	25.0	25.0	25.0	25.0
18Cr–10Ni–Ti	Bolts	A193	B8T	S32100	2	≤3/4	(15) (60)	−325	125	100	25.0	25.0	25.0	25.0	25.0
18Cr–10Ni–Ti	Bolts	A320	B8T	S32100	2	≤3/4	(15) (60)	−325	125	100	25.0	25.0	25.0	25.0	25.0
12Cr	Bolts	A437	B4B	S42225	...	...	(35)	−20	145	105	26.3	26.3	26.3	26.3	26.3
12Cr	Nuts	A194	6	S41000	...	...	(35) (42)	−20	...	...	...	...	...	...	...
18Cr–9Ni	Nuts	A194	8FA	S30300	...	...	(42)	−20	...	...	...	...	...	...	...
16Cr–12Ni–2Mo	Nuts	A194	8MA	S31600	...	...	(42)	−325	...	...	...	...	...	...	...
18Cr–10Ni–Ti	Nuts	A194	8TA	S32100	...	...	(42)	−325	...	...	...	...	...	...	...
18Cr–8Ni	Nuts	A194	8	S30400	...	...	(42)	−425	...	...	...	...	...	...	...
18Cr–8Ni	Nuts	A194	8A	S30400	...	...	(42)	−425	...	...	...	...	...	...	...
18Cr–10Ni–Cb	Nuts	A194	8CA	S34700	...	...	(42)	−425	...	...	...	...	...	...	...

Table A-2 Design Stress Values for Bolting Materials (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM

Design Stress, ksi, at Metal Temperature, °F [Note (1)]																				
600	650	700	750	800	850	900	950	1,000	1,050	1,100	1,150	1,200	1,250	1,300	1,350	1,400	1,450	1,500	Type/ Grade	Spec. No.
																			Stainless Steel	**(Cont'd)**
21.3	21.3	21.3	21.3	21.3	21.3	21.3	21.3	21.3	21.3	...	...	...	...	...	...	...	...	...	660 Cl. A	A453
21.3	21.3	21.3	21.3	21.3	21.3	21.3	21.3	21.3	21.3	...	...	...	...	...	...	...	...	...	660 Cl. B	A453
22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0	...	...	...	...	...	...	...	...	...	B8M Cl. 2	A193
22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0	...	...	...	...	...	...	...	...	...	B8M Cl. 2	A320
24.6	24.5	24.5	24.5	24.5	24.5	24.4	24.2	23.9	23.5	...	...	...	...	...	...	...	...	...	B8C Cl. 2	A193
24.6	24.5	24.5	24.5	24.5	24.5	24.4	24.2	23.9	23.5	...	...	...	...	...	...	...	...	...	B8C Cl. 2	A320
25.0	25.0	25.0	25.0	25.0	25.0	25.0	24.7	23.9	22.9	...	...	...	...	...	...	...	...	...	B8 Cl. 2	A193
25.0	25.0	25.0	25.0	25.0	25.0	25.0	24.7	23.9	22.9	...	...	...	...	...	...	...	...	...	B8 Cl. 2	A320
25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	...	...	...	...	...	...	...	...	...	B8T Cl. 2	A193
25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	...	...	...	...	...	...	...	...	...	B8T Cl. 2	A320
26.3	26.3	26.3	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	B4B	A437
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	6	A194
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	8FA	A194
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	8MA	A194
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	8TA	A194
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	8	A194
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	8A	A194
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	8CA	A194

Table A-2 Design Stress Values for Bolting Materials (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM

Nominal Composition	Product Form	Spec. No.	Type/ Grade	UNS No.	Class/ Condition/ Temper	Size Range, Dia., in.	Notes	Min. Temp., °F (6)	Specified Min. Strength, ksi: Tensile	Specified Min. Strength, ksi: Yield	Design Stress, ksi, at Metal Temperature, °F [Note (1)]: Min. Temp. to 100	200	300
Copper and Copper Alloy													
Naval brass	Bolts	B21	...	C46400	O60	...	(8f)	−325	50	20	12.5	12.5	12.5
Naval brass	Bolts	B21	...	C48200	O60	...	(8f)	−325	50	20	12.5	12.5	12.5
Naval brass	Bolts	B21	...	C48500	O60	...	(8f)	−325	50	20	12.5	12.5	12.5
Cu	Bolts	B187	...	C10200	O60	...	(8f)	−325	30	10	6.7	5.4	5.0
Cu	Bolts	B187	...	C11000	O60	...	(8f)	−325	30	10	6.7	5.4	5.0
Cu	Bolts	B187	...	C12000	O60	...	(8f)	−325	30	10	6.7	5.4	5.0
Cu	Bolts	B187	...	C12200	O60	...	(8f)	−325	30	10	6.7	5.4	5.0
Cu–Si	Bolts	B98	...	C65100	O60	...	(8f) (52)	−325	40	12	8.0	8.0	7.1
Cu–Si	Bolts	B98	...	C65500	O60	...	(8f) (52)	−325	52	15	10.0	10.0	10.0
Cu–Si	Bolts	B98	...	C66100	O60	...	(8f) (52)	−325	52	15	10.0	10.0	10.0
Cu–Si	Bolts	B98	...	C65500	H01	...	(8f)	−325	55	24	10.0	10.0	10.0
Cu–Si	Bolts	B98	...	C66100	H01	...	(8f)	−325	55	24	10.0	10.0	10.0
Cu–Si	Bolts	B98	...	C65500	H02	<2	...	−325	70	38	10.0	10.0	10.0
Cu–Si	Bolts	B98	...	C66100	H02	<2	...	−325	70	38	10.0	10.0	10.0
Cu–Si	Bolts	B98	...	C65100	H06	>1, <1½	...	−325	75	40	10.0	10.0	10.0
Cu–Si	Bolts	B98	...	C65100	H06	>½, ≤1	...	−325	75	45	11.3	11.3	11.3
Cu–Si	Bolts	B98	...	C65100	H06	≤½	...	−325	85	55	13.8	13.8	13.8
Al–Si–bronze	Bolts	B150	...	C64200	HR50	>1, ≤2	...	−325	80	42	16.7	13.9	13.4
Al–Si–bronze	Bolts	B150	...	C64200	HR50	>½, ≤1	...	−325	85	42	16.7	13.9	13.4
Al–Si–bronze	Bolts	B150	...	C64200	HR50	≤½	...	−325	90	42	16.7	13.9	13.4
Al–bronze	Bolts	B150	...	C61400	HR50	>1, ≤2	...	−325	70	32	17.5	17.5	17.5
Al–bronze	Bolts	B150	...	C61400	HR50	>½, ≤1	...	−325	75	35	17.5	17.5	17.5
Al–bronze	Bolts	B150	...	C61400	HR50	≤½	...	−325	80	40	18.0	18.0	18.0
Al–bronze	Bolts	B150	...	C63000	HR50	>2, ≤3	...	−325	85	42.5	21.3	21.3	21.0
Al–bronze	Bolts	B150	...	C63000	M20	>3, ≤4	...	−325	85	42.5	20.0	19.6	19.1
Al–bronze	Bolts	B150	...	C63000	HR50	>1, ≤2	...	−325	90	45	22.5	22.5	22.5
Al–bronze	Bolts	B150	...	C63000	HR50	≥½, ≤1	...	−325	100	50	22.5	22.5	22.5
Nickel and Nickel Alloy													
Low C–Ni	Bolts	B160	...	N02201	Hot fin./ann.	...	(8f)	−325	50	10	6.7	6.4	6.3
Ni	Bolts	B160	...	N02200	Hot fin.	...	(8f)	−325	60	15	10.0	10.0	10.0
Ni	Bolts	B160	...	N02200	Annealed	...	(8f)	−325	55	15	10.0	10.0	10.0
Ni	Bolts	B160	...	N02200	Cold drawn	...	...	−325	65	40	10.0	10.0	10.0
Ni–Cu	Bolts	B164	...	N04400	C.D./str. rel.	...	(54)	−325	84	50	16.7	14.6	13.6
Ni–Cu	Bolts	B164	...	N04405	Cold drawn	...	(54)	−325	85	50	16.7	14.6	13.6
Ni–Cu	Bolts	B164	...	N04400	Cold drawn	...	(54)	−325	85	55	16.7	14.6	13.8
Ni–Cu	Bolts	B164	...	N04400	Annealed	...	(8f)	−325	70	25	16.7	14.6	13.6
Ni–Cu	Bolts	B164	...	N04405	Annealed	...	(8f)	−325	70	25	16.7	14.6	13.6

Table A-2 Design Stress Values for Bolting Materials (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM

Design Stress, ksi, at Metal Temperature, °F [Note (1)]																		
400	500	600	650	700	750	800	850	900	950	1,000	1,050	1,100	1,150	1,200	1,250	1,300	UNS No.	Spec. No.
Copper and Copper Alloy																		
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	C46400	B21
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	C48200	B21
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	C48500	B21
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	C10200	B187
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	C11000	B187
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	C12000	B187
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	C12200	B187
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	C65100	B98
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	C65500	B98
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	C66100	B98
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	C65500	B98
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	C66100	B98
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	C65500	B98
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	C66100	B98
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	C65100	B98
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	C65100	B98
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	C65100	B98
10.8	5.2	1.7	1.2	...	...	...	...	...	...	...	...	...	...	...	...	...	C64200	B150
10.8	5.2	1.7	1.2	...	...	...	...	...	...	...	...	...	...	...	...	...	C64200	B150
10.8	5.2	1.7	1.2	...	...	...	...	...	...	...	...	...	...	...	...	...	C64200	B150
17.2	16.0	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	C61400	B150
17.2	16.0	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	C61400	B150
17.7	16.4	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	C61400	B150
20.7	19.4	12.0	8.6	6.0	4.2	...	...	...	...	...	...	...	...	...	...	...	C63000	B150
18.8	17.6	12.0	8.6	6.0	4.2	...	...	...	...	...	...	...	...	...	...	...	C63000	B150
22.5	21.1	12.0	8.6	6.0	4.2	...	...	...	...	...	...	...	...	...	...	...	C63000	B150
22.5	21.1	12.0	8.6	6.0	4.2	...	...	...	...	...	...	...	...	...	...	...	C63000	B150
Nickel and Nickel Alloy																		
6.2	6.2	6.2	6.2	6.2	6.1	6.0	5.8	4.5	3.7	3.0	2.4	2.0	1.5	1.2	1.0	...	N02201	B160
10.0	10.0	10.0	10.0	...	...	...	...	...	...	...	...	...	...	...	...	...	N02200	B160
10.0	10.0	10.0	10.0	...	...	...	...	...	...	...	...	...	...	...	...	...	N02200	B160
10.0	10.0	10.0	10.0	...	...	...	...	...	...	...	...	...	...	...	...	...	N02200	B160
13.2	13.1	13.1	13.1	...	...	...	...	...	...	...	...	...	...	...	...	...	N04400	B164
13.2	13.1	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	N04405	B164
13.8	13.8	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	N04400	B164
13.2	13.1	13.1	13.1	13.0	12.9	12.7	12.6	12.5	9.2	...	...	...	...	...	...	...	N04400	B164
13.2	13.1	13.1	13.1	13.0	12.9	12.7	12.6	12.5	9.2	...	...	...	...	...	...	...	N04405	B164

Table A-2 Design Stress Values for Bolting Materials (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM

Nominal Composition	Product Form	Spec. No.	Type/ Grade	UNS No.	Class/ Condition/ Temper	Size Range, Dia., in.	Notes	Min. Temp., °F (6)	Specified Min. Strength, ksi: Tensile	Specified Min. Strength, ksi: Yield	Design Stress, ksi, at Metal Temperature, °F [Note (1)]: Min. Temp. to 100	200	300
Nickel and Nickel Alloy													
Ni–Cu	Rod	B164	...	N04405	Hot fin.	≤3	...	−325	75	35	16.7	14.6	13.6
Ni–Cu	Hex	B164	...	N04400	Hot fin.	≥2$^1/_8$, ≤4	(8f)	−325	75	30	16.7	14.6	13.6
Ni–Cu	All except hex	B164	...	N04400	Hot fin.	>2$^1/_8$	...	−325	80	40	16.7	14.6	13.6
Ni–Cr–Fe	Rod	B166	...	N06600	Cold drawn	≤3	(41) (54)	−325	105	80	20.0	20.0	20.0
Ni–Cr–Fe	Rod	B166	...	N06600	Hot fin.	≤3	...	−325	90	40	16.7	15.9	15.2
Ni–Cr–Fe	Bolts	B166	...	N06600	Annealed	...	...	−325	80	35	16.7	15.9	15.2
Ni–Cr–Fe	Rod	B166	...	N06600	Hot fin.	>3	...	−325	85	35	16.7	15.9	15.2
Ni–Mo	Bolts	B335	...	N10001	Annealed	...	...	−325	100	46	25.0	25.0	25.0
Ni–Mo–Cr	Bolts	B574	...	N10276	Sol. ann.	...	...	−325	100	41	25.0	24.9	23.0
Aluminum Alloy													
...	Bolts	B211	6061	6061	T6, T651 wld.	≥$^1/_8$, ≤8	(8f) (43) (63)	−452	24	...	4.8	4.8	4.8
...	Bolts	B211	6061	6061	T6, T651	≥$^1/_8$, ≤8	(43) (63)	−452	42	35	8.4	8.4	8.4
...	Bolts	B211	2024	2024	T4	>6$^1/_2$, ≤8	(43) (63)	−452	58	38	9.5	9.5	9.5
...	Bolts	B211	2024	2024	T4	>4$^1/_2$, ≤6$^1/_2$	(43) (63)	−452	62	40	10.0	10.0	10.0
...	Bolts	B211	2024	2024	T4	≥$^1/_2$, ≤4$^1/_2$	(43) (63)	−452	62	42	10.5	10.5	10.3
...	Bolts	B211	2024	2024	T4	≥$^1/_8$, <$^1/_2$	(43) (63)	−452	62	45	11.3	11.3	10.3
...	Bolts	B211	2014	2014	T6, T651	≥$^1/_8$, ≤8	(43) (63)	−452	65	55	13.0	13.0	12.4

Table A-2 Design Stress Values for Bolting Materials (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM

Design Stress, ksi, at Metal Temperature, °F [Note (1)]																		
400	500	600	650	700	750	800	850	900	950	1,000	1,050	1,100	1,150	1,200	1,250	1,300	UNS No.	Spec. No.
															Nickel and Nickel Alloy			(Cont'd)
13.2	13.1	13.1	13.1	13.0	12.9	12.7	12.6	12.5	9.2	...	...	...	...	...	...	...	N04405	B164
13.2	13.1	13.1	13.1	13.0	12.9	12.7	12.6	12.5	9.2	...	...	...	...	...	...	...	N04400	B164
13.2	13.1	13.1	13.1	13.0	12.9	12.7	12.6	12.5	9.2	...	...	...	...	...	...	...	N04400	B164
20.0	20.0	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	N06600	B166
14.6	14.0	13.5	13.3	13.1	12.9	12.7	12.5	12.4	10.0	7.0	4.5	3.0	2.2	2.0	1.8	...	N06600	B166
14.6	14.0	13.5	13.3	13.1	12.9	12.7	12.5	12.4	9.2	7.0	4.5	3.0	2.2	2.0	1.8	...	N06600	B166
14.6	14.0	13.5	13.3	13.1	12.9	12.7	12.5	12.4	9.2	7.0	4.5	3.0	2.2	2.0	1.8	...	N06600	B166
24.6	24.3	23.6	23.3	23.0	22.8	22.6	22.5	...	...	...	...	...	...	...	...	...	N10001	B335
21.3	19.9	18.7	18.2	17.8	17.4	17.1	16.9	16.7	16.6	16.5	16.5	...	...	...	...	...	N10276	B574
																	Aluminum Alloy	
3.6	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	A96061	B211
4.8	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	A96061	B211
4.2	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	A92024	B211
4.5	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	A92024	B211
4.5	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	A92024	B211
4.5	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	A92024	B211
4.3	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	A92014	B211

(20)

Table A-2M Design Stress Values for Bolting Materials (SI Units)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM

Line No.	Nominal Composition	Product Form	Spec. No.	Type/ Grade	UNS No.	Class/ Condition/ Temper	Size Range, Dia., mm	Notes
1	Carbon steel	Bolts	A675	45	D40450	...	...	(8f) (8g)
2	Carbon steel	Bolts	A675	50	D40500	...	...	(8f) (8g)
3	Carbon steel	Bolts	A675	55	D40550	...	...	(8f) (8g)
4	Carbon steel	Bolts	A307	B	...	...	...	(8f) (8g)
5	Carbon steel	Bolts	A675	60	D40600	...	...	(8f) (8g)
6	Carbon steel	Bolts	A675	65	D40650	...	...	(8g)
7	Carbon steel	Bolts	A675	70	D40700	...	...	(8g)
8	Carbon steel	Bolts	A675	80	D40800	...	...	(8g)
9	Carbon steel	Bolts	F3125	A325	K02706	...	...	(8g)
10	Carbon steel	Nuts	A194	1	K01503	...	...	(42)
11	Carbon steel	Nuts	A194	2, 2H	K04002	...	...	(42)
12	Carbon steel	Nuts	A194	2HM	K04002	...	...	(42)
13	Carbon steel	Nuts	A563	A, hvy. hex	K05802	...	...	(42b)
14	Cr–0.2Mo	Bolts	A193	B7M	G41400	...	≤100	...
15	Cr–0.2Mo	Bolts	A320	L7M	G41400	...	≤64	...
16	5Cr	Bolts	A193	B5	S50100	...	≤100	(15)
17	Cr–Mo–V	Bolts	A193	B16	K14072	...	>64, ≤100	(15)
18	Alloy steel	Bolts	A354	BC	...	...	>64, ≤100	(15)
19	Cr–Mo	Bolts	A193	B7	G41400	...	>64, ≤100	(15)
20	Ni–Cr–Mo	Bolts	A320	L43	G43400	...	≤100	(15)
21	Cr–Mo	Bolts	A320	L7	G41400	...	≤64	(15)
22	Cr–Mo	Bolts	A320	L7A	G40370	...	≤64	(15)
23	Cr–Mo	Bolts	A320	L7B	G41370	...	≤64	(15)
24	Cr–Mo	Bolts	A320	L7C	G87400	...	≤64	(15)
25	Cr–Mo	Bolts	A193	B7	G41400	...	≤64	...
26	Cr–Mo–V	Bolts	A193	B16	K14072	...	≤64	(15)
27	Alloy steel	Bolts	A354	BC	...	...	≤64	(15)
28	Alloy steel	Bolts	A354	BD	...	...	≤100	(15)
29	5Cr	Nuts	A194	3	S50100	...	...	(42)
30	Cr–Mo	Nuts	A194	7	G41400	...	...	(42)
31	Cr–Mo	Nuts	A194	7L	G41400	...	...	(42)
32	Cr–Mo	Nuts	A194	7M	G41400	...	...	(42)
33	Cr–Mo	Nuts	A194	7ML	G41400	...	...	(42)
34	16Cr–12Ni–2Mo	Bolts	A193	B8M	S31600	2	>32, ≤38	(15) (60)
35	16Cr–12Ni–2Mo	Bolts	A320	B8M	S31600	2	>32, ≤38	(15) (60)
36	18Cr–8Ni	Bolts	A193	B8	S30400	2	>32, ≤38	(15) (60)

Table A-2M Design Stress Values for Bolting Materials (SI Units)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM

Line No.	Min. Temp., °C (6)	Min. Tensile Strength, MPa	Min. Yield Strength, MPa	Max. Use Temp., °C	Design Stress, MPa, at Metal Temperature, °C [Note (1)] Min. Temp. to 40	65	100	125	150	175	200	225
1	−29	310	155	482	77.6	77.6	77.6	77.6	77.6	77.6	77.6	77.6
2	−29	345	172	482	86.2	86.2	86.2	86.2	86.2	86.2	86.2	86.2
3	−29	379	190	482	94.8	94.8	94.8	94.8	94.8	94.8	94.8	94.8
4	−29	414	...	260	103	103	103	103	103	103	103	103
5	−29	414	207	482	103	103	103	103	103	103	103	103
6	−29	448	224	538	112	112	112	112	112	112	112	112
7	−29	483	241	538	121	121	121	121	121	121	121	121
8	−29	552	276	343	138	138	138	138	138	138	138	138
9	−29	825	635	343	159	159	159	159	159	159	159	159
10	−29	...	...	40	...	...	...	...	...	...	...	...
11	−48	...	...	40	...	...	...	...	...	...	...	...
12	−48	...	...	40	...	...	...	...	...	...	...	...
13	−29	...	...	40	...	...	...	...	...	...	...	...
14	−48	689	552	538	138	138	138	138	138	138	138	138
15	−73	689	552	538	138	138	138	138	138	138	138	138
16	−29	689	552	649	138	138	138	138	138	138	138	138
17	−29	758	655	593	152	152	152	152	152	152	152	152
18	−18	793	683	343	159	159	159	159	159	159	159	159
19	−40	793	655	538	159	159	159	159	159	159	159	159
20	−101	862	724	371	172	172	172	172	172	172	172	172
21	−101	862	724	371	172	172	172	172	172	172	172	172
22	−101	862	724	343	172	172	172	172	172	172	172	172
23	−101	862	724	343	172	172	172	172	172	172	172	172
24	−101	862	724	343	172	172	172	172	172	172	172	172
25	−48	862	724	538	172	172	172	172	172	172	172	172
26	−29	862	724	593	172	172	172	172	172	172	172	172
27	−18	862	752	343	172	172	172	172	172	172	172	172
28	−29	1034	896	343	207	207	207	207	207	207	207	207
29	−29	...	...	40	...	...	...	...	...	...	...	...
30	−48	...	...	593	...	...	...	...	...	...	...	...
31	−101	...	...	593	...	...	...	...	...	...	...	...
32	−48	...	...	593	...	...	...	...	...	...	...	...
33	−73	...	...	593	...	...	...	...	...	...	...	...
34	−198	621	345	538	129	126	118	112	107	103	99.1	95.8
35	−198	621	345	538	129	126	118	112	107	103	99.1	95.8
36	−198	689	345	538	129	123	113	108	103	99.0	95.6	92.7

Table A-2M Design Stress Values for Bolting Materials (SI Units)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM

Line No.	Design Stress, MPa, at Metal Temperature, °C [Note (1)]											
	250	275	300	325	350	375	400	425	450	475	500	525
1	77.6	77.6	77.6	77.6	76.0	73.7	71.5	64.0	55.8	43.9	31.7	...
2	86.2	86.2	86.2	86.2	84.5	81.9	73.3	64.0	55.8	43.9	31.7	...
3	94.8	94.8	94.8	94.8	92.9	90.1	87.4	75.3	62.1	45.0	31.7	...
4	103	103	...	...	...	...	...	...	...	...	...	...
5	103	103	103	103	101	98.3	95.1	79.5	62.6	45.0	31.7	...
6	112	112	112	112	110	106	95.1	79.5	64.4	47.7	32.5	21.4
7	121	121	121	121	118	115	101	83.8	66.8	50.3	33.2	21.4
8	138	138	138	138	135	...	...	...	...	...	...	...
9	159	159	159	159	159	...	...	...	...	...	...	...
10	...	...	...	...	...	...	...	...	...	...	...	...
11	...	...	...	...	...	...	...	...	...	...	...	...
12	...	...	...	...	...	...	...	...	...	...	...	...
13	...	...	...	...	...	...	...	...	...	...	...	...
14	138	138	138	138	138	138	138	138	115	92.3	67.3	41.6
15	138	138	138	138	138	138	138	138	115	92.3	67.3	41.6
16	138	138	138	138	138	138	138	138	138	80.6	61.7	46.4
17	152	152	152	152	152	152	152	152	148	132	113	88.3
18	159	159	159	159	159	...	...	...	...	...	...	...
19	159	159	159	159	159	159	159	159	116	92.3	67.3	41.6
20	172	172	172	172	172	172	...	...	...	...	...	...
21	172	172	172	172	172	172	...	...	...	...	...	...
22	172	172	172	172	172	...	...	...	...	...	...	...
23	172	172	172	172	172	...	...	...	...	...	...	...
24	172	172	172	172	172	...	...	...	...	...	...	...
25	172	172	172	172	172	172	172	172	121	93.4	67.3	41.6
26	172	172	172	172	172	172	172	172	166	146	121	90.1
27	172	172	172	172	172	...	...	...	...	...	...	...
28	207	207	207	207	207	...	...	...	...	...	...	...
29	...	...	...	...	...	...	...	...	...	...	...	...
30	...	...	...	...	...	...	...	...	...	...	...	...
31	...	...	...	...	...	...	...	...	...	...	...	...
32	...	...	...	...	...	...	...	...	...	...	...	...
33	...	...	...	...	...	...	...	...	...	...	...	...
34	92.8	90.3	88.1	86.2	86.2	86.2	86.2	86.2	86.2	86.2	86.2	86.2
35	92.8	90.3	88.1	86.2	86.2	86.2	86.2	86.2	86.2	86.2	86.2	86.2
36	90.1	87.9	86.2	86.2	86.2	86.2	86.2	86.2	86.2	86.2	86.2	86.2

Table A-2M Design Stress Values for Bolting Materials (SI Units)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM

Line No.	Design Stress, MPa, at Metal Temperature, °C [Note (1)] 550	575	600	625	650	675	700	725	750	775	800	825
1	...	...	...	...	...	...	...	...	...	...	...	...
2	...	...	...	...	...	...	...	...	...	...	...	...
3	...	...	...	...	...	...	...	...	...	...	...	...
4	...	...	...	...	...	...	...	...	...	...	...	...
5	...	...	...	...	...	...	...	...	...	...	...	...
6	14.2	...	...	...	...	...	...	...	...	...	...	...
7	14.2	...	...	...	...	...	...	...	...	...	...	...
8	...	...	...	...	...	...	...	...	...	...	...	...
9	...	...	...	...	...	...	...	...	...	...	...	...
10	...	...	...	...	...	...	...	...	...	...	...	...
11	...	...	...	...	...	...	...	...	...	...	...	...
12	...	...	...	...	...	...	...	...	...	...	...	...
13	...	...	...	...	...	...	...	...	...	...	...	...
14	23.5	...	...	...	...	...	...	...	...	...	...	...
15	23.5	...	...	...	...	...	...	...	...	...	...	...
16	34.7	25.5	17.8	11.4	6.7	...	...	...	...	...	...	...
17	59.3	33.0	15.9	...	...	...	...	...	...	...	...	...
18	...	...	...	...	...	...	...	...	...	...	...	...
19	23.5	...	...	...	...	...	...	...	...	...	...	...
20	...	...	...	...	...	...	...	...	...	...	...	...
21	...	...	...	...	...	...	...	...	...	...	...	...
22	...	...	...	...	...	...	...	...	...	...	...	...
23	...	...	...	...	...	...	...	...	...	...	...	...
24	...	...	...	...	...	...	...	...	...	...	...	...
25	23.5	...	...	...	...	...	...	...	...	...	...	...
26	59.3	33.0	15.9	...	...	...	...	...	...	...	...	...
27	...	...	...	...	...	...	...	...	...	...	...	...
28	...	...	...	...	...	...	...	...	...	...	...	...
29	...	...	...	...	...	...	...	...	...	...	...	...
30	...	...	...	...	...	...	...	...	...	...	...	...
31	...	...	...	...	...	...	...	...	...	...	...	...
32	...	...	...	...	...	...	...	...	...	...	...	...
33	...	...	...	...	...	...	...	...	...	...	...	...
34	86.2	...	...	...	...	...	...	...	...	...	...	...
35	86.2	...	...	...	...	...	...	...	...	...	...	...
36	86.2	...	...	...	...	...	...	...	...	...	...	...

Table A-2M Design Stress Values for Bolting Materials (SI Units) (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM

Line No.	Nominal Composition	Product Form	Spec. No.	Type/ Grade	UNS No.	Class/ Condition/ Temper	Size Range, Dia., mm	Notes
37	18Cr–8Ni	Bolts	A320	B8	S30400	2	>32, ≤38	(15) (60)
38	18Cr–10Ni–Cb	Bolts	A193	B8C	...	2	>32, ≤38	(15) (60)
39	18Cr–10Ni–Cb	Bolts	A320	B8C	S34700	2	>32, ≤38	(15) (60)
40	18Cr–10Ni–Ti	Bolts	A193	B8T	S32100	2	>32, ≤38	(15) (60)
41	18Cr–10Ni–Ti	Bolts	A320	B8T	S32100	2	>32, ≤38	(15) (60)
42	18Cr–9Ni	Bolts	A320	B8F	S30300	1	...	(8f) (15) (39)
43	19Cr–9Ni	Bolts	A453	651B	...	...	>75	(15) (35)
44	19Cr–9Ni	Bolts	A453	651B	...	...	≤75	(15) (35)
45	19Cr–9Ni	Bolts	A453	651A	...	...	>75	(15) (35)
46	19Cr–9Ni	Bolts	A453	651A	...	...	≤75	(15) (35)
47	16Cr–12Ni–2Mo	Bolts	A193	B8M	S31600	2	>25, ≤32	(15) (60)
48	16Cr–12Ni–2Mo	Bolts	A320	B8M	S31600	2	>25, ≤32	(15) (60)
49	18Cr–10Ni–Cb	Bolts	A193	B8C	...	2	>25, ≤32	(15) (60)
50	18Cr–10Ni–Cb	Bolts	A320	B8C	S34700	2	>25, ≤32	(15) (60)
51	18Cr–8Ni	Bolts	A193	B8	S30400	2	>25, ≤32	(15) (60)
52	18Cr–8Ni	Bolts	A320	B8	S30400	2	>25, ≤32	(15) (60)
53	18Cr–10Ni–Ti	Bolts	A193	B8T	S32100	2	>25, ≤32	(15) (60)
54	18Cr–10Ni–Ti	Bolts	A320	B8T	S32100	2	>25, ≤32	(15) (60)
55	18Cr–10Ni–Ti	Bolts	A193	B8T	S32100	1	...	(8f) (15) (28)
56	18Cr–8Ni	Bolts	A193	B8	S30400	1	...	(8f) (15) (28)
57	18Cr–8Ni	Bolts	A320	B8	S30400	1	...	(8f) (15) (28)
58	18Cr–10Ni–Cb	Bolts	A193	B8C	...	1	...	(8f) (15) (28)
59	16Cr–12Ni–2Mo	Bolts	A193	B8M	S31600	1	...	(8f) (15) (28)
60	16Cr–12Ni–2Mo	Bolts	A193	B8M	S31600	2	>19, ≤25	(15) (60)

Table A-2M Design Stress Values for Bolting Materials (SI Units) (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM

Line No.	Min. Temp., °C (6)	Min. Tensile Strength, MPa	Min. Yield Strength, MPa	Max. Use Temp., °C	Design Stress, MPa, at Metal Temperature, °C [Note (1)] Min. Temp. to 40	65	100	125	150	175	200	225
37	−198	689	345	538	129	123	113	108	103	99.0	95.6	92.7
38	−198	689	345	538	129	129	122	117	113	110	108	105
39	−198	689	345	538	129	129	122	117	113	110	108	105
40	−198	689	345	538	129	129	121	118	114	110	106	103
41	−198	689	345	538	129	129	121	118	114	110	106	103
42	−198	517	207	427	129	123	113	108	103	99.0	95.6	92.7
43	−29	655	345	538	164	164	160	156	152	149	147	145
44	−29	655	414	538	164	164	160	156	152	149	147	145
45	−29	689	414	538	164	164	160	156	152	149	147	145
46	−29	689	483	538	164	164	160	156	152	149	147	145
47	−198	724	448	538	129	126	118	112	112	112	112	112
48	−198	724	448	538	129	126	118	112	112	112	112	112
49	−198	724	448	538	129	129	122	117	113	112	112	112
50	−198	724	448	538	129	129	122	117	113	112	112	112
51	−198	724	448	538	129	123	113	112	112	112	112	112
52	−198	724	448	538	129	123	113	112	112	112	112	112
53	−198	724	448	538	129	129	121	118	114	112	112	112
54	−198	724	448	538	129	129	121	118	114	112	112	112
55	−198	517	207	816	129	129	121	118	114	110	106	103
56	−254	517	207	816	129	123	113	108	103	99.0	95.6	92.7
57	−254	517	207	816	129	123	113	108	103	99.0	95.6	92.7
58	−254	517	207	816	129	129	122	117	113	110	108	105
59	−198	517	207	816	129	126	118	112	107	103	99.1	95.8
60	−198	689	552	538	138	138	138	138	138	138	138	138

Table A-2M Design Stress Values for Bolting Materials (SI Units) (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM

	Design Stress, MPa, at Metal Temperature, °C [Note (1)]											
Line No.	250	275	300	325	350	375	400	425	450	475	500	525
37	90.1	87.9	86.2	86.2	86.2	86.2	86.2	86.2	86.2	86.2	86.2	86.2
38	104	102	99.9	98.0	96.4	95.2	94.2	93.5	93.0	92.7	92.6	92.4
39	104	102	99.9	98.0	96.4	95.2	94.2	93.5	93.0	92.7	92.6	92.4
40	100	97.2	94.7	92.6	90.8	89.2	87.8	86.6	86.2	86.2	86.2	86.2
41	100	97.2	94.7	92.6	90.8	89.2	87.8	86.6	86.2	86.2	86.2	86.2
42	90.1	87.9	85.8	84.0	82.3	80.6	79.1	77.6	76.2	...	...	...
43	144	143	142	141	141	140	139	138	136	134	131	128
44	144	143	142	141	141	140	139	138	136	134	131	128
45	144	143	142	141	141	140	139	138	136	134	131	128
46	144	143	142	141	141	140	139	138	136	134	131	128
47	112	112	112	112	112	112	112	112	112	112	112	112
48	112	112	112	112	112	112	112	112	112	112	112	112
49	112	112	112	112	112	112	112	112	112	112	112	112
50	112	112	112	112	112	112	112	112	112	112	112	112
51	112	112	112	112	112	112	112	112	112	112	112	112
52	112	112	112	112	112	112	112	112	112	112	112	112
53	112	112	112	112	112	112	112	112	112	112	112	112
54	112	112	112	112	112	112	112	112	112	112	112	112
55	99.9	97.2	94.7	92.6	90.8	89.2	87.8	86.6	85.6	84.7	84.0	83.2
56	90.1	87.9	85.8	84.0	82.3	80.6	79.1	77.6	76.2	74.8	73.4	72.1
57	90.1	87.9	85.8	84.0	82.3	80.6	79.1	77.6	76.2	74.8	73.4	72.1
58	104	102	99.9	98.0	96.4	95.2	94.2	93.5	93.0	92.7	92.6	92.4
59	92.8	90.3	88.1	86.2	84.6	83.3	82.2	81.2	80.4	79.7	79.0	78.4
60	138	138	138	138	138	138	138	138	138	138	138	138

Table A-2M Design Stress Values for Bolting Materials (SI Units) (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM

	Design Stress, MPa, at Metal Temperature, °C [Note (1)]											
Line No.	550	575	600	625	650	675	700	725	750	775	800	825
37	86.2	...	...	...	...	...	...	...	...	...	...	...
38	92.2	...	...	...	...	...	...	...	...	...	...	...
39	92.2	...	...	...	...	...	...	...	...	...	...	...
40	86.2	...	...	...	...	...	...	...	...	...	...	...
41	86.2	...	...	...	...	...	...	...	...	...	...	...
42	...	...	...	...	...	...	...	...	...	...	...	...
43	124	...	...	...	...	...	...	...	...	...	...	...
44	124	...	...	...	...	...	...	...	...	...	...	...
45	124	...	...	...	...	...	...	...	...	...	...	...
46	124	...	...	...	...	...	...	...	...	...	...	...
47	112	...	...	...	...	...	...	...	...	...	...	...
48	112	...	...	...	...	...	...	...	...	...	...	...
49	112	...	...	...	...	...	...	...	...	...	...	...
50	112	...	...	...	...	...	...	...	...	...	...	...
51	112	...	...	...	...	...	...	...	...	...	...	...
52	112	...	...	...	...	...	...	...	...	...	...	...
53	112	...	...	...	...	...	...	...	...	...	...	...
54	112	...	...	...	...	...	...	...	...	...	...	...
55	82.4	59.2	44.0	32.9	24.5	18.3	12.5	8.5	6.2	4.3	2.8	1.7
56	70.7	69.4	**63.8**	**51.6**	**41.6**	**32.9**	**26**.5	**21.3**	**17.2**	**14.1**	**11.2**	**8.8**
57	70.7	69.4	63.8	51.6	41.6	32.9	26.5	21.3	17.2	14.1	11.2	8.8
58	92.2	75.9	57.2	40.2	30.3	23.2	16.2	11.4	9.0	7.1	5.9	5.3
59	77.7	76.9	75.9	65.0	50.5	39.2	30.4	23.6	18.4	14.3	11.1	8.6
60	138	...	...	...	...	...	...	...	...	...	...	...

Table A-2M Design Stress Values for Bolting Materials (SI Units) (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM

Line No.	Nominal Composition	Product Form	Spec. No.	Type/ Grade	UNS No.	Class/ Condition/ Temper	Size Range, Dia., mm	Notes
61	16Cr–12Ni–2Mo	Bolts	A320	B8M	S31600	2	>19, ≤25	(15) (60)
62	18Cr–10Ni–Cb	Bolts	A193	B8C	...	2	>19, ≤25	(15) (60)
63	18Cr–10Ni–Cb	Bolts	A320	B8C	S34700	2	>19, ≤25	(15) (60)
64	18Cr–8Ni	Bolts	A193	B8	S30400	2	>19, ≤25	(15) (60)
65	18Cr–8Ni	Bolts	A320	B8	S30400	2	>19, ≤25	(15) (60)
66	18Cr–10Ni–Ti	Bolts	A193	B8T	S32100	2	>19, ≤25	(15) (60)
67	18Cr–10Ni–Ti	Bolts	A320	B8T	S32100	2	>19, ≤25	(15) (60)
68	12Cr	Bolts	A437	B4C	S42200	...	...	(35)
69	13Cr	Bolts	A193	B6	S41000	...	≤100	(15) (35)
70	14Cr–24Ni	Bolts	A453	660	S66286	A	...	(15) (35)
71	14Cr–24Ni	Bolts	A453	660	S66286	B	...	(15) (35)
72	16Cr–12Ni–2Mo	Bolts	A193	B8M	S31600	2	≤19	(15) (60)
73	16Cr–12Ni–2Mo	Bolts	A320	B8M	S31600	2	≤19	(15) (60)
74	18Cr–10Ni–Cb	Bolts	A193	B8C	...	2	≤19	(15) (60)
75	18Cr–10Ni–Cb	Bolts	A320	B8C	S34700	2	≤19	(15) (60)
76	18Cr–8Ni	Bolts	A193	B8	S30400	2	≤19	(15) (60)
77	18Cr–8Ni	Bolts	A320	B8	S30400	2	≤19	(15) (60)
78	18Cr–10Ni–Ti	Bolts	A193	B8T	S32100	2	≤19	(15) (60)
79	18Cr–10Ni–Ti	Bolts	A320	B8T	S32100	2	≤19	(15) (60)
80	12Cr	Bolts	A437	B4B	S42225	...	...	(35)
81	12Cr	Nuts	A194	6	S41000	...	...	(35) (42)
82	18Cr–9Ni	Nuts	A194	8FA	S30300	...	...	(42)
83	16Cr–12Ni–2Mo	Nuts	A194	8MA	S31600	...	...	(42)
84	18Cr–10Ni–Ti	Nuts	A194	8TA	S32100	...	...	(42)
85	18Cr–8Ni	Nuts	A194	8	S30400	...	...	(42)
86	18Cr–8Ni	Nuts	A194	8A	S30400	...	...	(42)

Table A-2M Design Stress Values for Bolting Materials (SI Units) (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM

Line No.	Min. Temp., °C (6)	Min. Tensile Strength, MPa	Min. Yield Strength, MPa	Max. Use Temp., °C	Design Stress, MPa, at Metal Temperature, °C [Note (1)] Min. Temp. to 40	65	100	125	150	175	200	225
61	−198	689	552	538	138	138	138	138	138	138	138	138
62	−198	793	552	538	138	138	138	138	138	138	138	138
63	−198	793	552	538	138	138	138	138	138	138	138	138
64	−198	793	552	538	138	138	138	138	138	138	138	138
65	−198	793	552	538	138	138	138	138	138	138	138	138
66	−198	793	552	538	138	138	138	138	138	138	138	138
67	−198	793	552	538	138	138	138	138	138	138	138	138
68	−29	793	586	371	147	147	147	147	147	147	147	147
69	−29	758	586	482	147	147	147	147	147	147	147	147
70	−198	896	586	538	147	147	147	147	147	147	147	147
71	−198	896	586	538	147	147	147	147	147	147	147	147
72	−198	758	655	538	152	152	152	152	152	152	152	152
73	−198	758	655	538	152	152	152	152	152	152	152	152
74	−198	862	689	538	172	172	172	172	172	172	172	172
75	−198	862	689	538	172	172	172	172	172	172	172	172
76	−198	862	689	538	172	172	172	172	172	172	172	172
77	−198	862	689	538	172	172	172	172	172	172	172	172
78	−198	862	689	538	172	172	172	172	172	172	172	172
79	−198	862	689	538	172	172	172	172	172	172	172	172
80	−29	1000	724	343	181	181	181	181	181	181	181	181
81	−29	…	…	40	…	…	…	…	…	…	…	…
82	−29	…	…	40	…	…	…	…	…	…	…	…
83	−198	…	…	40	…	…	…	…	…	…	…	…
84	−198	…	…	40	…	…	…	…	…	…	…	…
85	−254	…	…	40	…	…	…	…	…	…	…	…
86	−254	…	…	40	…	…	…	…	…	…	…	…

Table A-2M Design Stress Values for Bolting Materials (SI Units) (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM

Line No.	Design Stress, MPa, at Metal Temperature, °C [Note (1)]											
	250	275	300	325	350	375	400	425	450	475	500	525
61	138	138	138	138	138	138	138	138	138	138	138	138
62	138	138	138	138	138	138	138	138	138	138	138	138
63	138	138	138	138	138	138	138	138	138	138	138	138
64	138	138	138	138	138	138	138	138	138	138	138	138
65	138	138	138	138	138	138	138	138	138	138	138	138
66	138	138	138	138	138	138	138	138	138	138	138	138
67	138	138	138	138	138	138	138	138	138	138	138	138
68	147	147	147	147	147	147	...	...	...	...	...	...
69	147	147	147	147	147	147	147	147	147	141	133	...
70	147	147	147	147	147	147	147	147	147	147	147	147
71	147	147	147	147	147	147	147	147	147	147	147	147
72	152	152	152	152	152	152	152	152	152	152	152	152
73	152	152	152	152	152	152	152	152	152	152	152	152
74	172	171	170	170	169	169	169	169	169	168	167	166
75	172	171	170	170	169	169	169	169	169	168	167	166
76	172	172	172	172	172	172	172	172	172	172	172	168
77	172	172	172	172	172	172	172	172	172	172	172	168
78	172	172	172	172	172	172	172	172	172	172	172	172
79	172	172	172	172	172	172	172	172	172	172	172	172
80	181	181	181	181	181	...	...	...	...	...	...	...
81	...	...	...	...	...	...	...	...	...	...	...	...
82	...	...	...	...	...	...	...	...	...	...	...	...
83	...	...	...	...	...	...	...	...	...	...	...	...
84	...	...	...	...	...	...	...	...	...	...	...	...
85	...	...	...	...	...	...	...	...	...	...	...	...
86	...	...	...	...	...	...	...	...	...	...	...	...

Table A-2M Design Stress Values for Bolting Materials (SI Units) (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM

Line No.	Design Stress, MPa, at Metal Temperature, °C [Note (1)]											
	550	575	600	625	650	675	700	725	750	775	800	825
61	138	...	...	...	...	...	...	...	...	...	...	...
62	138	...	...	...	...	...	...	...	...	...	...	...
63	138	...	...	...	...	...	...	...	...	...	...	...
64	138	...	...	...	...	...	...	...	...	...	...	...
65	138	...	...	...	...	...	...	...	...	...	...	...
66	138	...	...	...	...	...	...	...	...	...	...	...
67	138	...	...	...	...	...	...	...	...	...	...	...
68	...	...	...	...	...	...	...	...	...	...	...	...
69	...	...	...	...	...	...	...	...	...	...	...	...
70	147	...	...	...	...	...	...	...	...	...	...	...
71	147	...	...	...	...	...	...	...	...	...	...	...
72	152	...	...	...	...	...	...	...	...	...	...	...
73	152	...	...	...	...	...	...	...	...	...	...	...
74	164	...	...	...	...	...	...	...	...	...	...	...
75	164	...	...	...	...	...	...	...	...	...	...	...
76	162	...	...	...	...	...	...	...	...	...	...	...
77	162	...	...	...	...	...	...	...	...	...	...	...
78	172	...	...	...	...	...	...	...	...	...	...	...
79	172	...	...	...	...	...	...	...	...	...	...	...
80	...	...	...	...	...	...	...	...	...	...	...	...
81	...	...	...	...	...	...	...	...	...	...	...	...
82	...	...	...	...	...	...	...	...	...	...	...	...
83	...	...	...	...	...	...	...	...	...	...	...	...
84	...	...	...	...	...	...	...	...	...	...	...	...
85	...	...	...	...	...	...	...	...	...	...	...	...
86	...	...	...	...	...	...	...	...	...	...	...	...

Table A-2M Design Stress Values for Bolting Materials (SI Units) (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM

Line No.	Nominal Composition	Product Form	Spec. No.	Type/ Grade	UNS No.	Class/ Condition/ Temper	Size Range, Dia., mm	Notes
87	18Cr–10Ni–Cb	Nuts	A194	8CA	S34700	...	...	(42)
88	Naval brass	Bolts	B21	...	C46400	O60	...	(8f)
89	Naval brass	Bolts	B21	...	C48200	O60	...	(8f)
90	Naval brass	Bolts	B21	...	C48500	O60	...	(8f)
91	Cu	Bolts	B187	...	C10200	O60	...	(8f)
92	Cu	Bolts	B187	...	C11000	O60	...	(8f)
93	Cu	Bolts	B187	...	C12000	O60	...	(8f)
94	Cu	Bolts	B187	...	C12200	O60	...	(8f)
95	Cu–Si	Bolts	B98	...	C65100	O60	...	(8f) (52)
96	Cu–Si	Bolts	B98	...	C65500	O60	...	(8f) (52)
97	Cu–Si	Bolts	B98	...	C66100	O60	...	(8f) (52)
98	Cu–Si	Bolts	B98	...	C65500	H01	...	(8f)
99	Cu–Si	Bolts	B98	...	C66100	H01	...	(8f)
100	Cu–Si	Bolts	B98	...	C65500	H02	≤50	...
101	Cu–Si	Bolts	B98	...	C66100	H02	≤50	...
102	Cu–Si	Bolts	B98	...	C65100	H06	>25, ≤38	...
103	Cu–Si	Bolts	B98	...	C65100	H06	>13, ≤25	...
104	Cu–Si	Bolts	B98	...	C65100	H06	≤13	...
105	Al–Si–bronze	Bolts	B150	...	C64200	HR50	>25, ≤50	...
106	Al–Si–bronze	Bolts	B150	...	C64200	HR50	>13, ≤25	...
107	Al–Si–bronze	Bolts	B150	...	C64200	HR50	≤13	...
108	Al–bronze	Bolts	B150	...	C61400	HR50	>25, ≤50	...
109	Al–bronze	Bolts	B150	...	C61400	HR50	>13, ≤25	...
110	Al–bronze	Bolts	B150	...	C61400	HR50	≤13	...
111	Al–bronze	Bolts	B150	...	C63000	HR50	>50, ≤75	...
112	Al–bronze	Bolts	B150	...	C63000	M20	>75, ≤100	...
113	Al–bronze	Bolts	B150	...	C63000	HR50	>25, ≤50	...
114	Al–bronze	Bolts	B150	...	C63000	HR50	≥13, ≤25	...
115	Low C–Ni	Bolts	B160	...	N02201	Hot fin./ ann.	...	(8f)
116	Ni	Bolts	B160	...	N02200	Hot fin.	...	(8f)
117	Ni	Bolts	B160	...	N02200	Annealed	...	(8f)
118	Ni	Bolts	B160	...	N02200	Cold drawn	...	...
119	Ni–Cu	Bolts	B164	...	N04400	C.D./str. rel.	...	(54)
120	Ni–Cu	Bolts	B164	...	N04405	Cold drawn	...	(54)
121	Ni–Cu	Bolts	B164	...	N04400	Cold drawn	...	(54)
122	Ni–Cu	Bolts	B164	...	N04400	Annealed	...	(8f)
123	Ni–Cu	Bolts	B164	...	N04405	Annealed	...	(8f)
124	Ni–Cu	Rod	B164	...	N04405	Hot fin.	≤75	...

Table A-2M Design Stress Values for Bolting Materials (SI Units) (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM

Line No.	Min. Temp., °C (6)	Min. Tensile Strength, MPa	Min. Yield Strength, MPa	Max. Use Temp., °C	Design Stress, MPa, at Metal Temperature, °C [Note (1)] Min. Temp. to 40	65	100	125	150	175	200	225
87	−254	...	...	40	...	...	...	...	...	...	...	...
88	−198	345	138	149	86.2	86.2	86.2	86.2	86.2	...	...	...
89	−198	345	138	149	86.2	86.2	86.2	86.2	86.2	...	...	...
90	−198	345	138	149	86.2	86.2	86.2	86.2	86.2	...	...	...
91	−198	207	69	149	46.0	38.8	37.2	36.5	34.2	...	...	...
92	−198	207	69	149	46.0	38.8	37.2	36.5	34.2	...	...	...
93	−198	207	69	149	46.0	38.8	37.2	36.5	34.2	...	...	...
94	−198	207	69	149	46.0	38.8	37.2	36.5	34.2	...	...	...
95	−198	276	83	149	55.2	55.2	55.2	54.0	48.3	...	...	...
96	−198	359	103	149	68.9	68.9	68.9	68.9	68.8	...	...	...
97	−198	359	103	149	68.9	68.9	68.9	68.9	68.8	...	...	...
98	−198	379	165	149	68.9	68.9	68.9	68.9	68.8	...	...	...
99	−198	379	165	149	68.9	68.9	68.9	68.9	68.8	...	...	...
100	−198	483	262	149	68.9	68.9	68.9	68.9	68.8	...	...	...
101	−198	483	262	149	68.9	68.9	68.9	68.9	68.8	...	...	...
102	−198	517	276	149	68.9	68.9	68.9	68.9	68.9	...	...	...
103	−198	517	310	149	77.6	77.6	77.6	77.6	77.6	...	...	...
104	−198	586	379	149	94.8	94.8	94.8	94.8	94.8	...	...	...
105	−198	552	290	316	115	100	95.2	93.6	92.1	89.1	76.9	57.7
106	−198	586	290	316	115	100	95.2	93.6	92.1	89.1	76.9	57.7
107	−198	621	290	316	115	100	95.2	93.6	92.1	89.1	76.9	57.7
108	−198	483	221	260	121	121	121	121	121	121	119	115
109	−198	517	241	260	121	121	121	121	121	121	119	115
110	−198	552	276	260	124	124	124	124	124	124	122	118
111	−198	586	293	371	147	147	147	146	145	144	143	140
112	−198	586	293	371	138	137	134	133	132	131	130	128
113	−198	621	310	371	155	155	155	155	155	155	155	153
114	−198	689	345	371	155	155	155	155	155	155	155	153
115	−198	345	69	649	46.0	44.8	44.0	43.6	43.3	43.1	43.0	43.0
116	−198	414	103	316	68.9	68.9	68.9	68.9	68.9	68.9	68.9	68.9
117	−198	379	103	316	68.9	68.9	68.9	68.9	68.9	68.9	68.9	68.9
118	−198	448	276	316	68.9	68.9	68.9	68.9	68.9	68.9	68.9	68.9
119	−198	579	345	316	115	106	99.7	96.2	93.6	91.9	90.9	90.4
120	−198	586	345	260	115	106	99.7	96.2	93.6	91.9	90.9	90.4
121	−198	586	379	260	115	106	99.7	96.2	94.8	94.8	94.8	94.8
122	−198	483	172	482	115	106	99.7	96.2	93.6	91.9	90.9	90.4
123	−198	483	172	482	115	106	99.7	96.2	93.6	91.9	90.9	90.4
124	−198	517	241	482	115	106	99.7	96.2	93.6	91.9	90.9	90.4

Table A-2M Design Stress Values for Bolting Materials (SI Units) (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM

Line No.	Design Stress, MPa, at Metal Temperature, °C [Note (1)]											
	250	275	300	325	350	375	400	425	450	475	500	525
87	...	...	...	...	...	...	...	...	...	...	...	...
88	...	...	...	...	...	...	...	...	...	...	...	...
89	...	...	...	...	...	...	...	...	...	...	...	...
90	...	...	...	...	...	...	...	...	...	...	...	...
91	...	...	...	...	...	...	...	...	...	...	...	...
92	...	...	...	...	...	...	...	...	...	...	...	...
93	...	...	...	...	...	...	...	...	...	...	...	...
94	...	...	...	...	...	...	...	...	...	...	...	...
95	...	...	...	...	...	...	...	...	...	...	...	...
96	...	...	...	...	...	...	...	...	...	...	...	...
97	...	...	...	...	...	...	...	...	...	...	...	...
98	...	...	...	...	...	...	...	...	...	...	...	...
99	...	...	...	...	...	...	...	...	...	...	...	...
100	...	...	...	...	...	...	...	...	...	...	...	...
101	...	...	...	...	...	...	...	...	...	...	...	...
102	...	...	...	...	...	...	...	...	...	...	...	...
103	...	...	...	...	...	...	...	...	...	...	...	...
104	...	...	...	...	...	...	...	...	...	...	...	...
105	40.9	24.1	14.5	10.3	...	...	...	...	...	...	...	...
106	40.9	24.1	14.5	10.3	...	...	...	...	...	...	...	...
107	40.9	24.1	14.5	10.3	...	...	...	...	...	...	...	...
108	111	108	...	...	...	...	...	...	...	...	...	...
109	111	109	...	...	...	...	...	...	...	...	...	...
110	115	112	...	...	...	...	...	...	...	...	...	...
111	136	126	97.2	73.9	54.4	39.3	...	...	...	...	...	...
112	124	117	97.2	73.9	54.4	39.3	...	...	...	...	...	...
113	148	126	97.2	73.9	54.4	39.3	...	...	...	...	...	...
114	148	126	97.2	73.9	54.4	39.3	...	...	...	...	...	...
115	43.0	43.0	43.0	43.0	42.9	42.7	42.2	41.6	40.7	33.1	27.4	22.8
116	68.9	68.9	68.9	68.9	...	...	...	...	...	...	...	...
117	68.9	68.9	68.9	68.9	...	...	...	...	...	...	...	...
118	68.9	68.9	68.9	68.9	...	...	...	...	...	...	...	...
119	90.4	90.4	90.4	90.4	...	...	...	...	...	...	...	...
120	90.4	90.4	...	...	...	...	...	...	...	...	...	...
121	94.8	94.8	...	...	...	...	...	...	...	...	...	...
122	90.4	90.4	90.4	90.4	90.4	89.8	89.0	88.0	87.0	86.4	75.6	...
123	90.4	90.4	90.4	90.4	90.4	89.8	89.0	88.0	87.0	86.4	75.6	...
124	90.4	90.4	90.4	90.4	90.4	89.8	89.0	88.0	87.0	86.4	75.6	...

Table A-2M Design Stress Values for Bolting Materials (SI Units) (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM

Line No.	Design Stress, MPa, at Metal Temperature, °C [Note (1)]											
	550	575	600	625	650	675	700	725	750	775	800	825
87	...	...	...	...	...	...	...	...	...	...	...	...
88	...	...	...	...	...	...	...	...	...	...	...	...
89	...	...	...	...	...	...	...	...	...	...	...	...
90	...	...	...	...	...	...	...	...	...	...	...	...
91	...	...	...	...	...	...	...	...	...	...	...	...
92	...	...	...	...	...	...	...	...	...	...	...	...
93	...	...	...	...	...	...	...	...	...	...	...	...
94	...	...	...	...	...	...	...	...	...	...	...	...
95	...	...	...	...	...	...	...	...	...	...	...	...
96	...	...	...	...	...	...	...	...	...	...	...	...
97	...	...	...	...	...	...	...	...	...	...	...	...
98	...	...	...	...	...	...	...	...	...	...	...	...
99	...	...	...	...	...	...	...	...	...	...	...	...
100	...	...	...	...	...	...	...	...	...	...	...	...
101	...	...	...	...	...	...	...	...	...	...	...	...
102	...	...	...	...	...	...	...	...	...	...	...	...
103	...	...	...	...	...	...	...	...	...	...	...	...
104	...	...	...	...	...	...	...	...	...	...	...	...
105	...	...	...	...	...	...	...	...	...	...	...	...
106	...	...	...	...	...	...	...	...	...	...	...	...
107	...	...	...	...	...	...	...	...	...	...	...	...
108	...	...	...	...	...	...	...	...	...	...	...	...
109	...	...	...	...	...	...	...	...	...	...	...	...
110	...	...	...	...	...	...	...	...	...	...	...	...
111	...	...	...	...	...	...	...	...	...	...	...	...
112	...	...	...	...	...	...	...	...	...	...	...	...
113	...	...	...	...	...	...	...	...	...	...	...	...
114	...	...	...	...	...	...	...	...	...	...	...	...
115	18.7	15.6	12.9	10.0	8.2	...	...	...	...	...	...	...
116	...	...	...	...	...	...	...	...	...	...	...	...
117	...	...	...	...	...	...	...	...	...	...	...	...
118	...	...	...	...	...	...	...	...	...	...	...	...
119	...	...	...	...	...	...	...	...	...	...	...	...
120	...	...	...	...	...	...	...	...	...	...	...	...
121	...	...	...	...	...	...	...	...	...	...	...	...
122	...	...	...	...	...	...	...	...	...	...	...	...
123	...	...	...	...	...	...	...	...	...	...	...	...
124	...	...	...	...	...	...	...	...	...	...	...	...

Table A-2M Design Stress Values for Bolting Materials (SI Units) (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM

Line No.	Nominal Composition	Product Form	Spec. No.	Type/ Grade	UNS No.	Class/ Condition/ Temper	Size Range, Dia., mm	Notes
125	Ni–Cu	Hex	B164	...	N04400	Hot fin.	≥54, ≤100	(8f)
126	Ni–Cu	All except hex	B164	...	N04400	Hot fin.	>54	...
127	Ni–Cr–Fe	Rod	B166	...	N06600	Cold drawn	≤75	(41) (54)
128	Ni–Cr–Fe	Rod	B166	...	N06600	Hot fin.	≤75	...
129	Ni–Cr–Fe	Bolts	B166	...	N06600	Annealed	...	...
130	Ni–Cr–Fe	Rod	B166	...	N06600	Hot fin.	>75	...
131	Ni–Mo	Bolts	B335	...	N10001	Annealed	...	...
132	Ni–Mo–Cr	Bolts	B574	...	N10276	Sol. ann.	...	...
133	Aluminum alloy	Bolts	B211	6061	A96061	T6, T651 wld.	≥3, ≤200	(8f) (43) (63)
134	Aluminum alloy	Bolts	B211	6061	A96061	T6, T651	≥3, ≤200	(43) (63)
135	Aluminum alloy	Bolts	B211	2024	A92024	T4	>165, ≤200	(43) (63)
136	Aluminum alloy	Bolts	B211	2024	A92024	T4	>114, ≤165	(43) (63)
137	Aluminum alloy	Bolts	B211	2024	A92024	T4	>13, ≤114	(43) (63)
138	Aluminum alloy	Bolts	B211	2024	A92024	T4	≥3, <13	(43) (63)
139	Aluminum alloy	Bolts	B211	2014	A92014	T6, T651	≥3, ≤200	(43) (63)

Table A-2M Design Stress Values for Bolting Materials (SI Units) (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM

Line No.	Min. Temp., °C (6)	Min. Tensile Strength, MPa	Min. Yield Strength, MPa	Max. Use Temp., °C	Design Stress, MPa, at Metal Temperature, °C [Note (1)]							
					Min. Temp. to 40	65	100	125	150	175	200	225
125	−198	517	207	482	115	106	99.7	96.2	93.6	91.9	90.9	90.4
126	−198	552	276	482	115	106	99.7	96.2	93.6	91.9	90.9	90.4
127	−198	724	552	260	138	138	138	138	138	138	138	138
128	−198	621	276	649	115	112	109	107	105	103	101	99.0
129	−198	552	241	649	115	112	109	107	105	103	101	99.0
130	−198	586	241	649	115	112	109	107	105	103	101	99.0
131	−198	689	317	427	172	172	172	172	172	171	170	169
132	−198	689	283	538	172	172	170	164	158	153	148	143
133	−269	165	...	204	33.1	33.1	33.1	33.1	33.1	33.1	26.4	16.1
134	−269	290	241	204	57.9	57.9	57.9	57.9	57.9	47.3	34.9	21.1
135	−269	400	262	204	65.5	65.5	65.5	65.5	65.5	43.1	29.3	29.3
136	−269	427	276	204	68.9	68.9	68.9	68.9	68.9	46.1	31.3	31.3
137	−269	427	290	204	72.4	72.4	72.4	72.4	70.2	46.2	31.2	31.2
138	−269	427	310	204	77.6	77.6	77.6	77.6	70.2	46.2	31.2	31.2
139	−269	448	379	204	89.6	89.6	89.6	89.6	84.2	46.9	26.2	20.2

Table A-2M Design Stress Values for Bolting Materials (SI Units) (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM

Line No.	Design Stress, MPa, at Metal Temperature, °C [Note (1)] 250	275	300	325	350	375	400	425	450	475	500	525
125	90.4	90.4	90.4	90.4	90.4	89.8	89.0	88.0	87.0	86.4	75.6	...
126	90.4	90.4	90.4	90.4	90.4	89.8	89.0	88.0	87.0	86.4	75.6	...
127	138	138	...	...	...	...	...	...	...	...	...	...
128	97.3	95.6	94.0	92.6	91.2	89.9	88.7	87.7	86.7	85.8	75.6	58.4
129	97.3	95.6	94.0	92.6	91.2	89.9	88.7	87.7	86.7	85.8	75.6	58.4
130	97.3	95.6	94.0	92.6	91.2	89.9	88.7	87.7	86.7	85.8	75.6	58.4
131	168	166	164	162	160	158	157	156	155	...	...	...
132	139	135	131	128	125	122	120	118	117	115	115	114
133	...	...	...	...	...	...	...	...	...	...	...	...
134	...	...	...	...	...	...	...	...	...	...	...	...
135	...	...	...	...	...	...	...	...	...	...	...	...
136	...	...	...	...	...	...	...	...	...	...	...	...
137	...	...	...	...	...	...	...	...	...	...	...	...
138	...	...	...	...	...	...	...	...	...	...	...	...
139	...	...	...	...	...	...	...	...	...	...	...	...

Table A-2M Design Stress Values for Bolting Materials (SI Units) (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM

Line No.	Design Stress, MPa, at Metal Temperature, °C [Note (1)]											
	550	575	600	625	650	675	700	725	750	775	800	825
125	...	...	...	...	...	...	...	...	...	...	...	...
126	...	...	...	...	...	...	...	...	...	...	...	...
127	...	...	...	...	...	...	...	...	...	...	...	...
128	39.7	27.0	19.2	15.0	13.7	...	...	...	...	...	...	...
129	39.7	27.0	19.2	15.0	13.7	...	...	...	...	...	...	...
130	39.7	27.0	19.2	15.0	13.7	...	...	...	...	...	...	...
131	...	...	...	...	...	...	...	...	...	...	...	...
132	114	...	...	...	...	...	...	...	...	...	...	...
133	...	...	...	...	...	...	...	...	...	...	...	...
134	...	...	...	...	...	...	...	...	...	...	...	...
135	...	...	...	...	...	...	...	...	...	...	...	...
136	...	...	...	...	...	...	...	...	...	...	...	...
137	...	...	...	...	...	...	...	...	...	...	...	...
138	...	...	...	...	...	...	...	...	...	...	...	...
139	...	...	...	...	...	...	...	...	...	...	...	...

APPENDIX B
STRESS TABLES AND ALLOWABLE PRESSURE TABLES FOR NONMETALS

The data and Notes in Appendix B are requirements of this Code.

Specification Index for Appendix B (20)

Spec. No.	Title [Note (1)]
ASTM	
C361	Reinforced Concrete Low-Head Pressure Pipe
C582	Contact-Molded Reinforced Thermosetting Plastic (RTP) Laminates for Corrosion Resistant Equipment
C599	Process Glass Pipe and Fittings
D1785	PVC Plastic Pipe, Schedules 40, 80, and 120
D2239	PE Plastic Pipe (SIDR-PR) Based on Controlled Inside Diameter
D2241	PVC Plastic Pressure-Rated Pipe (SDR Series)
D2513	Thermoplastic Gas Pressure Pipe, Tubing and Fittings
D2517	Reinforced Epoxy Resin Gas Pressure Pipe and Fittings
D2662	PB Plastic Pipe (SDR-PR)
D2666	PB Plastic Tubing
D2672	Joints for IPS PVC Pipe Using Solvent Cement
D2737	PE Plastic Tubing
D2846	CPVC Plastic Hot- and Cold-Water Distribution Systems
D2996	Filament-Wound Fiberglass RTR Pipe [Note (2)]
D2997	Centrifugally Cast RTR Pipe [Note (2)]
D3000	PB Plastic Pipe (SDR-PR) Based on Outside Diameter
D3035	PE Plastic Pipe (DR-PR) Based on Controlled Outside Diameter
D3517	Fiberglass RTR Pressure Pipe [Note (2)]
D3754	Fiberglass RTR Sewer and Industrial Pressure Pipe [Note (2)]
F441	CPVC Plastic Pipe, Schedules 40 and 80
F442	CPVC Plastic Pipe (SDR-PR)
F2389	Pressure-Rated Polypropylene (PP) Piping Systems
F2788/F2788M	Metric and Inch-sized Crosslinked Polyethylene (PEX) Pipe
AWWA	
C300	Reinforced Concrete Pressure Pipe, Steel Cylinder Type, for Water and Other Liquids
C301	Prestressed Concrete Pressure Pipe, Steel Cylinder Type, for Water and Other Liquids
C302	Reinforced Concrete Pressure Pipe, Noncylinder Type
C950	Fiberglass Pressure Pipe

GENERAL NOTE: It is not practical to refer to a specific edition of each standard throughout the Code text. Instead, the approved edition references, along with the names and addresses of the sponsoring organizations, are shown in Appendix E.

NOTES:
(1) For names of plastics identified only by abbreviation, see para. A326.4.
(2) The term *fiberglass RTR* takes the place of the ASTM designation *"fiberglass" (glass-fiber-reinforced thermosetting resin)*.

(20) **Table B-1 Hydrostatic Design Stresses (HDS) and Recommended Temperature Limits for Thermoplastic Pipe**

ASTM Spec. No.	Pipe Designation	Material Designation	Cell Class	Recommended Temperature Limits, °F [Notes (1), (2)]		Hydrostatic Design Stress, ksi, at			
				Minimum	Maximum	73°F [Note (3)]	100°F	180°F	200°F
...	PR	ABS	43232	-40	176	...	...	...	...
D2846	SDR11	CPVC4120	23447	...	180	2.0	...	0.5	...
F441	Sch. 40	CPVC4120	23447	73	200	2.0	...	0.5	...
F441	Sch. 80	CPVC4120	23447	73	200	2.0	...	0.5	...
F442	SDR-PR	CPVC4120	23447	73	200	2.0	1.64	0.5	...
D2239	SIDR-PR	PE1404	...	73	...	0.40	...	...	...
D2737	SDR7.3, SDR9, SDR11	PE2305	...	73	...	0.50	...	...	...
D2737	SDR7.3, SDR9, SDR11	PE2306	...	73	...	0.63	...	...	...
D2737	SDR7.3, SDR9, SDR11	PE2406	...	73	...	0.63	...	...	...
D2737	SDR7.3, SDR9, SDR11	PE3306	...	73	...	0.63	...	...	...
D2737	SDR7.3, SDR9, SDR11	PE3406	...	73	...	0.63	...	...	...
D2737	SDR7.3, SDR9, SDR11	PE3408	...	73	...	0.80	...	...	...
D3035	DR-PR	PE1404	...	73	...	0.40	...	...	...
D3035	DR-PR	PE2708	...	73	...	0.80	...	...	...
D3035	DR-PR	PE3608	...	73	...	0.80	...	...	...
D3035	DR-PR	PE4608	...	73	...	0.80	...	...	...
D3035	DR-PR	PE4710	...	73	...	1.00	...	...	...
F714	SDR-PR	PE2708	...	73	...	0.80	...	...	...
F714	SDR-PR	PE3608	...	73	...	0.80	...	...	...
F714	SDR-PR	PE3708	...	73	...	0.80	...	...	...
F714	SDR-PR	PE3710	...	73	...	1.00	...	...	...
F714	SDR-PR	PE4608	...	73	...	0.80	...	...	...
F714	SDR-PR	PE4708	...	73	...	0.80	...	...	...
F714	SDR-PR	PE4710	...	73	...	1.00	...	...	...
F2788/ F2788M	SDR/DR-PR	PEX0006	...	−58	230	0.63	...	0.40	0.31
F2788/ F2788M	SDR/DR-PR	PEX0008	...	−58	230	0.80	...	0.40	0.31
F2389	SDR6, SDR7.3, SDR11	PP	...	0	210	0.63	0.50	0.20	...
D1785	Sch. 40, 80, 120	PVC1120	12454	73	...	2.00	...	...	...
D1785	Sch. 40, 80, 120	PVC1220	12454	73	...	2.00	...	...	...
D1785	Sch. 40, 80, 120	PVC2120	14333	73	...	2.00	...	...	...
D1785	Sch. 40, 80, 120	PVC2116	14333	73	...	1.60	...	...	...
D1785	Sch. 40, 80, 120	PVC2112	14333	73	...	1.25	...	...	...
D1785	Sch. 40, 80, 120	PVC2110	14333	73	...	1.00	...	...	...
D2241	PR (SDR series)	PVC1120	12454	73	...	2.00	...	...	...
D2241	PR (SDR series)	PVC1220	12454	73	...	2.00	...	...	...
D2241	PR (SDR series)	PVC2120	14333	73	...	2.00	...	...	...
D2241	PR (SDR series)	PVC2116	14333	73	...	1.60	...	...	...
D2241	PR (SDR series)	PVC2112	14333	73	...	1.25	...	...	...

Table B-1 Hydrostatic Design Stresses (HDS) and Recommended Temperature Limits for Thermoplastic Pipe (Cont'd)

ASTM Spec. No.	Pipe Designation	Material Designation	Cell Class	Recommended Temperature Limits, °F [Notes (1), (2)]		Hydrostatic Design Stress, ksi, at			
				Minimum	Maximum	73°F [Note (3)]	100°F	180°F	200°F
D2241	PR (SDR series)	PVC2110	14333	73	...	1.00	...	...	...

NOTES:

(1) These recommended limits are for low pressure applications with water and other fluids that do not significantly affect the properties of the thermoplastic. The upper temperature limits are reduced at higher pressures, depending on the combination of fluid and expected service life. Lower temperature limits are affected more by the environment, safeguarding, and installation conditions than by strength.

(2) These recommended limits apply only to materials listed. Manufacturers should be consulted for temperature limits on specific types and kinds of materials not listed.

(3) Use these hydrostatic design stress (HDS) values at all lower temperatures.

(20)

Table B-1M Hydrostatic Design Stresses (HDS) and Recommended Temperature Limits for Thermoplastic Pipe (SI Units)

ASTM Spec. No.	Pipe Designation	Material Designation	Cell Class	Recommended Temperature Limits, °C [Notes (1), (2)] Minimum	Maximum	Hydrostatic Design Stress, MPa, at 23°C [Note (3)]	38°C	82°C	93°C
...	PR	ABS	43232	−40	80	...	...	...	...
D2846	SDR11	CPVC4120	23447	...	82	13.8	...	3.45	...
F441	Sch. 40	CPVC4120	23447	23	93.3	13.8	...	3.45	...
F441	Sch. 80	CPVC4120	23447	23	93.3	13.8	...	3.45	...
F442	SDR-PR	CPVC4120	23447	23	93.3	13.8	11.3	3.45	...
D2239	SIDR-PR	PE1404	...	23	...	2.76	...	...	...
D2737	SDR7.3, SDR9, SDR11	PE2305	...	23	...	3.45	...	...	...
D2737	SDR7.3, SDR9, SDR11	PE2306	...	23	...	4.34	...	...	...
D2737	SDR7.3, SDR9, SDR11	PE2406	...	23	...	4.34	...	...	...
D2737	SDR7.3, SDR9, SDR11	PE3306	...	23	...	4.34	...	...	...
D2737	SDR7.3, SDR9, SDR11	PE3406	...	23	...	4.34	...	...	...
D2737	SDR7.3, SDR9, SDR11	PE3408	...	23	...	5.51	...	...	...
D3035	DR-PR	PE1404	...	23	...	2.76	...	...	...
D3035	DR-PR	PE2708	...	23	...	5.51	...	...	...
D3035	DR-PR	PE3608	...	23	...	5.51	...	...	...
D3035	DR-PR	PE4608	...	23	...	5.51	...	...	...
D3035	DR-PR	PE4710	...	23	...	6.89	...	...	...
F714	SDR-PR	PE2708	...	23	...	5.51	...	...	...
F714	SDR-PR	PE3608	...	23	...	5.51	...	...	...
F714	SDR-PR	PE3708	...	23	...	5.51	...	...	...
F714	SDR-PR	PE3710	...	23	...	6.89	...	...	...
F714	SDR-PR	PE4608	...	23	...	5.51	...	...	...
F714	SDR-PR	PE4708	...	23	...	5.51	...	...	...
F714	SDR-PR	PE4710	...	23	...	6.89	...	...	...
F2788/ F2788M	SDR/DR-PR	PEX0006	...	−50	110	4.34	...	2.76	2.17
F2788/ F2788M	SDR/DR-PR	PEX0008	...	−50	110	5.51	...	2.76	2.17
F2389	SDR6, SDR7.3, SDR11	PP	...	−18	99	4.34	3.45	1.38	...
D1785	Sch. 40, 80, 120	PVC1120	12454	23	...	13.8	...	...	...
D1785	Sch. 40, 80, 120	PVC1220	12454	23	...	13.8	...	...	...
D1785	Sch. 40, 80, 120	PVC2120	14333	23	...	13.8	...	...	...
D1785	Sch. 40, 80, 120	PVC2116	14333	23	...	11.0	...	...	...
D1785	Sch. 40, 80, 120	PVC2112	14333	23	...	8.6	...	...	...
D1785	Sch. 40, 80, 120	PVC2110	14333	23	...	6.9	...	...	...
D2241	PR (SDR series)	PVC1120	12454	23	...	13.8	...	...	...
D2241	PR (SDR series)	PVC1220	12454	23	...	13.8	...	...	...
D2241	PR (SDR series)	PVC2120	14333	23	...	13.8	...	...	...

Table B-1M Hydrostatic Design Stresses (HDS) and Recommended Temperature Limits for Thermoplastic Pipe (SI Units) (Cont'd)

ASTM Spec. No.	Pipe Designation	Material Designation	Cell Class	Recommended Temperature Limits, °C [Notes (1), (2)] Minimum	Maximum	Hydrostatic Design Stress, MPa, at 23°C [Note (3)]	38°C	82°C	93°C
D2241	PR (SDR series)	PVC2116	14333	23	...	11.0	...	...	...
D2241	PR (SDR series)	PVC2112	14333	23	...	8.6	...	...	...
D2241	PR (SDR series)	PVC2110	14333	23	...	6.9	...	...	...

NOTES:

(1) These recommended limits are for low pressure applications with water and other fluids that do not significantly affect the properties of the thermoplastic. The upper temperature limits are reduced at higher pressures, depending on the combination of fluid and expected service life. Lower temperature limits are affected more by the environment, safeguarding, and installation conditions than by strength.

(2) These recommended limits apply only to materials listed. Manufacturers should be consulted for temperature limits on specific types and kinds of materials not listed.

(3) Use these hydrostatic design stress (HDS) values at all lower temperatures.

Table B-2 Listed Specifications for Laminated Reinforced Thermosetting Resin Pipe

Spec. No.
ASTM C582

GENERAL NOTE: The intent of listing in this Table is to include all the types, grades, classes, and hydrostatic design bases in the listed specifications.

Table B-3 Listed Specifications for Filament Wound and Centrifugally Cast Reinforced Thermosetting Resin and Reinforced Plastic Mortar Pipe

Spec. Nos. (ASTM Except as Noted)		
D2517	D2997	D3754
D2996	D3517	AWWA C950

GENERAL NOTE: The intent of listing in this Table is to include all the types, grades, classes, and hydrostatic design bases in the listed specifications.

Table B-4 Allowable Pressures and Recommended Temperature Limits for Concrete Pipe

Spec. No.	Material	Class	Allowable Gage Pressure		Recommended Temperature Limits [Note (1)]			
					Minimum		Maximum	
			kPa	psi	°C	°F	°C	°F
ASTM C361	Reinforced concrete	25	69	10	...	...	...	...
		50	138	20	...	...	...	...
		75	205	30	...	...	...	...
		100	275	40	...	...	...	...
		125	345	50	...	...	...	...
AWWA C300	Reinforced concrete	...	1 795	260	...	...	...	...
AWWA C301	Reinforced concrete	Lined cylinder	1 725	250	...	...	...	...
		Embedded cylinder	2 415	350	...	...	...	...
AWWA C302	Reinforced concrete	...	310	45	...	...	...	...

NOTE: (1) These recommended limits apply only to materials listed. Manufacturers should be consulted for temperature limits on specific types and kinds of materials not listed.

Table B-5 Allowable Pressures and Recommended Temperature Limits for Borosilicate Glass Pipe

ASTM Spec. No.	Material	Size Range		Allowable Gage Pressure		Recommended Temperature Limits [Note (1)]			
						Minimum		Maximum	
		DN	NPS	kPa	psi	°C	°F	°C	°F
C599	Borosilicate glass	8–15	$\frac{1}{4}$–$\frac{1}{2}$	690	100	...	...	232	450
		20	$\frac{3}{4}$	515	75	...	...	232	450
		25–80	1–3	345	50	...	...	232	450
		100	4	240	35	...	...	232	450
		150	6	138	20	...	...	232	450

NOTE: (1) These recommended limits apply only to materials listed. Manufacturers should be consulted for temperature limits on specific types and kinds of materials not listed.

Table B-6 Allowable Pressures and Recommended Temperature Limits for PEX-AL-PEX and PE-AL-PE Pipe

ASTM Spec. No.	Material	Size Range		Allowable Gage Pressure		Maximum Temperature Limits [Note (1)]	
		mm	in.	kPa	psi	°C	°F
F1281	PEX-AL-PEX	9.12–60.75	$\frac{3}{8}$–2$\frac{1}{2}$	1 379	200	23	73.4
				1 103	160	60	140
				862	125	82.2	180
F1282	PE-AL-PE	9.12–60.75	$\frac{3}{8}$–2$\frac{1}{2}$	1 379	200	23	73.4
				1 103	160	60	140
				862	100	82.2	180
F1974	Metal insert fittings for PEX-AL-PEX systems	12.16–25.32	$\frac{1}{2}$–1	862	125	82	180
	Metal insert fittings for PE-AL-PE systems	12.16–25.32	$\frac{1}{2}$–1	1 103	160	60	140
				862	125	82	180

NOTE: (1) These recommended limits apply only to materials listed. Manufacturers should be consulted for temperature limits on specific types and kinds of materials not listed.

APPENDIX C
PHYSICAL PROPERTIES OF PIPING MATERIALS

Begins on the next page.

Table C-1 Thermal Expansion Data

A = Mean Coefficient of Thermal Expansion, 10^{-6} in./in./°F
B = Linear Thermal Expansion, in./100 ft
} in Going From 70°F to Indicated Temperature [Note (1)]

Material	Coefficient	Temperature Range 70°F to																
		−325	−150	−50	70	200	300	400	500	600	700	800	900	1,000	1,100	1,200	1,300	1,400
Group 1 carbon and low alloy steels [Note (2)]	*A*	5.5	5.9	6.2	6.4	6.7	6.9	7.1	7.3	7.4	7.6	7.8	7.9	8.1	8.2	8.3	8.4	8.4
	B	−2.6	−1.6	−0.9	0	1.0	1.9	2.8	3.7	4.7	5.7	6.8	7.9	9.0	10.1	11.3	12.4	14.7
Group 2 low alloy steels [Note (3)]	*A*	6.0	6.5	6.7	7.0	7.3	7.4	7.6	7.7	7.8	7.9	8.0	8.1	8.2	8.3	8.4	8.4	8.5
	B	−2.9	−1.7	−1.0	0	1.1	2.0	3.0	4.0	5.0	6.0	7.0	8.1	9.2	10.3	11.4	12.5	13.5
5Cr–1Mo steels	*A*	5.6	6.0	6.2	6.4	6.7	6.9	7.0	7.1	7.2	7.2	7.3	7.4	7.5	7.6	7.6	7.7	7.8
	B	−2.7	−1.6	−0.9	0	1.0	1.9	2.8	3.7	4.6	5.5	6.4	7.4	8.4	9.3	10.3	11.4	12.4
9Cr–1Mo steels	*A*	5.0	5.4	5.6	5.8	6.0	6.2	6.3	6.4	6.5	6.6	6.7	6.8	6.9	7.0	7.1	7.2	7.2
	B	−2.4	−1.4	−0.8	0	0.9	1.7	2.5	3.3	4.1	5.0	5.9	6.8	7.7	8.7	9.7	10.6	11.6
Straight chromium stainless steels																		
12Cr to 13Cr steels	*A*	5.1	5.5	5.7	5.9	6.2	6.3	6.4	6.5	6.5	6.6	6.7	6.7	6.8	6.8	6.9	6.9	7.0
	B	−2.4	−1.5	−0.8	0	1.0	1.7	2.5	3.3	4.2	5.0	5.8	6.7	7.6	8.5	9.4	10.2	11.1
15Cr to 17Cr steels	*A*	4.5	4.9	5.1	5.3	5.5	5.7	5.8	5.9	6.0	6.1	6.2	6.2	6.3	6.4	6.4	6.5	6.5
	B	−2.1	−1.3	−0.7	0	0.9	1.6	2.3	3.0	3.8	4.6	5.4	6.2	7.0	7.9	8.7	9.5	10.4
27Cr steels	*A*	4.3	4.7	4.9	5.0	5.2	5.2	5.3	5.4	5.4	5.5	5.6	5.7	5.7	5.8	5.9	5.9	6.0
	B	−2.0	−1.2	−0.7	0	0.8	1.4	2.1	2.8	3.5	4.2	4.9	5.6	6.4	7.2	8.0	8.7	9.6
Austenitic stainless steels (304, 305, 316, 317, 321, 347, 348, 19-9DL, XM-15, etc.)	*A*	7.5	8.0	8.2	8.5	8.9	9.2	9.5	9.7	9.9	10.0	10.1	10.2	10.3	10.4	10.6	10.7	10.8
	B	−3.6	−2.1	−1.2	0	1.4	2.5	3.8	5.0	6.3	7.5	8.8	10.2	11.5	12.9	14.3	15.8	17.2
Other austenitic stainless steels (309, 310, 315, XM-19, etc.)	*A*	7.1	7.6	7.8	8.2	8.5	8.7	8.9	9.1	9.2	9.3	9.4	9.5	9.6	9.7	9.8	9.9	10.1
	B	−3.4	−2.0	−1.1	0	1.3	2.4	3.5	4.7	5.8	7.0	8.2	9.5	10.7	12.0	13.3	14.7	16.1
Gray iron	*A*	...	...	...	...	5.8	5.9	6.1	6.3	6.5	6.7	6.8	7.0	7.2	...	...	...	...
	B	...	...	...	0	0.9	1.6	2.4	3.2	4.1	5.0	6.0	7.0	8.0	...	...	...	...
Ductile cast iron	*A*	...	4.9	5.3	5.7	6.0	6.3	6.6	6.8	7.0	7.1	7.3	7.4	7.5	...	...	...	...
	B	...	−1.3	−0.8	0	0.9	1.7	2.6	3.5	4.5	5.4	6.4	7.3	8.4	...	...	...	...

Table C-1 Thermal Expansion Data (Cont'd)

A = Mean Coefficient of Thermal Expansion, 10^{-6} in./in./°F
B = Linear Thermal Expansion, in./100 ft
} **in Going From 70°F to Indicated Temperature [Note (1)]**

Material	Coefficient	Temperature Range 70°F to																
		−325	−150	−50	70	200	300	400	500	600	700	800	900	1,000	1,100	1,200	1,300	1,400
Monel (67Ni–30Cu) N04400	*A*	5.8	6.8	7.2	7.7	8.1	8.3	8.5	8.7	8.8	8.9	8.9	9.0	9.1	9.1	9.2	9.2	9.3
	B	−2.7	−1.8	−1.0	0	1.3	2.3	3.4	4.5	5.6	6.7	7.8	9.0	10.1	11.3	12.4	13.6	14.8
Nickel alloys N02200 and N02201	*A*	5.3	6.0	6.3	6.6	7.2	7.5	7.7	7.9	8.0	8.2	8.3	8.4	8.5	8.6	8.7	8.8	8.9
	B	−2.7	−1.7	−1.0	0	1.1	2.1	3.1	4.1	5.1	6.2	7.3	8.4	9.5	10.7	11.8	13.0	14.2
Nickel alloy N06022	*A*	...	...	...	6.9	6.9	6.9	6.9	7.0	7.0	7.2	7.3	7.5	7.7	7.9	8.1	8.3	8.5
	B	...	...	...	0	1.1	1.9	2.7	3.6	4.5	5.4	6.4	7.5	8.6	9.8	11.0	12.2	13.6
Nickel alloy N06600	*A*	5.5	6.1	6.4	6.8	7.1	7.3	7.5	7.6	7.8	7.9	8.0	8.2	8.3	8.4	8.6	8.7	8.9
	B	−2.6	−1.6	−0.9	0	1.1	2.0	3.0	3.9	5.0	6.0	7.0	8.1	9.3	10.4	11.6	12.9	14.2
Nickel alloy N06625	*A*	...	...	...	6.7	7.1	7.2	7.3	7.4	7.4	7.5	7.6	7.7	7.9	8.0	8.2	8.4	8.5
	B	...	...	...	0	1.1	2.0	2.9	3.8	4.7	5.6	6.6	7.7	8.8	9.9	11.1	12.3	13.6
Nickel alloys N08800 and N08810	*A*	5.9	6.9	7.4	7.9	8.4	8.6	8.8	8.9	9.0	9.1	9.2	9.3	9.4	9.5	9.6	9.7	9.8
	B	−2.8	−1.7	−1.1	0	1.3	2.4	3.5	4.6	5.7	6.9	8.1	9.3	10.5	11.8	13.0	14.4	15.7
Nickel alloy N08825	*A*	...	...	7.2	7.5	7.7	7.9	8.0	8.1	8.2	8.3	8.4	8.5	8.6	...	...	...	...
	B	...	...	−1.0	0	1.2	2.2	3.2	4.2	5.2	6.3	7.4	8.5	9.6	...	...	...	...
Nickel alloy N10276	*A*	...	...	...	6.0	6.3	6.5	6.7	6.9	7.1	7.2	7.4	7.5	7.6	7.7	7.8	7.9	8.0
	B	...	...	...	0	1.0	1.8	2.7	3.6	4.5	5.5	6.4	7.5	8.5	9.5	10.6	11.7	12.8
Copper alloys C1XXXX series	*A*	7.7	8.7	9.0	9.3	9.6	9.7	9.8	9.9	10.0	...	...	...	...	...	...	...	...
	B	−3.7	−2.3	−1.3	0	1.5	2.7	3.9	5.1	6.4	...	...	...	...	...	...	...	...
Bronze alloys	*A*	8.4	8.8	9.2	9.6	10.0	10.1	10.2	10.3	10.4	10.5	10.6	10.7	10.8	10.9	11.0	...	...
	B	−4.0	−2.3	−1.3	0	1.6	2.8	4.0	5.3	6.6	8.0	9.3	10.7	12.1	13.5	14.9	...	...
Brass alloys	*A*	8.2	8.5	9.0	9.3	9.8	10.0	10.2	10.5	10.7	10.9	11.2	11.4	11.6	11.9	12.1	...	...
	B	−3.9	−2.2	−1.3	0	1.5	2.8	4.1	5.4	6.8	8.2	9.8	11.4	13.0	14.7	16.4	...	...
Copper–nickel (70Cu–30Ni)	*A*	6.7	7.4	7.8	8.1	8.5	8.7	8.9	9.1	9.2	9.2	...	...	...	...	...	...	...
	B	−3.2	−2.0	−1.1	0	1.3	2.4	3.5	4.7	5.8	7.0	...	...	...	...	...	...	...

Table C-1 Thermal Expansion Data (Cont'd)

A = Mean Coefficient of Thermal Expansion, 10^{-6} in./in./°F
B = Linear Thermal Expansion, in./100 ft
} in Going From 70°F to Indicated Temperature [Note (1)]

Material	Coefficient	Temperature Range 70°F to																
		−325	−150	−50	70	200	300	400	500	600	700	800	900	1,000	1,100	1,200	1,300	1,400
Aluminum alloys	*A*	9.9	10.9	11.6	12.1	13.0	13.3	13.6	13.9	14.2	...	...	...	...	...	...	...	...
	B	−4.7	−2.9	−1.7	0	2.0	3.7	5.4	7.2	9.0	...	...	...	...	...	...	...	...
Titanium alloys (Grades 1, 2, 3, 7, and 12)	*A*	...	...	4.5	4.6	4.7	4.8	4.8	4.9	4.9	5.0	5.1	...	...	...	...	...	...
	B	...	...	−0.6	0	0.7	1.3	1.9	2.5	3.1	3.8	4.5	...	...	...	...	...	...

NOTES:

(1) These data are for information and it is not to be implied that materials are suitable for all the temperature ranges shown.

(2) Group 1 alloys (by nominal composition):

Carbon steels (C, C–Si, C–Mn, and C–Mn–Si)
C–½Mo
½Cr–⅕Mo–V
½Cr–¼Mo–Si
½Cr–½Mo
½Cr–½Ni–¼Mo
¾Cr–½Ni–Cu
¾Cr–¾Ni–Cu–Al
1Cr–⅕Mo
1Cr–⅕Mo–Si
1Cr–½Mo
1Cr–½Mo–V
1¼Cr–½Mo
1¼Cr–½Mo–Si
1¾Cr–½Mo–Cu
2Cr–½Mo
2¼Cr–1Mo
3Cr–1Mo
½Ni–½Mo–V
½Ni–½Cr–¼Mo–V
¾Ni–½Mo–Cr–V
¾Ni–½Mo–⅓Cr–V
¾Ni–½Cu–Mo
¾Ni–½Cr–½Mo–V
¾Ni–1Mo–¾Cr
1Ni–½Cr–½Mo
1¼Ni–1Cr–½Mo
1¾Ni–¾Cr–¼Mo
2Ni–¾Cr–¼Mo
2Ni–¾Cr–⅓Mo
2½Ni
3½Ni
3½Ni–1¾Cr–½Mo–V

(3) Group 2 alloys (by nominal composition):

Mn–V
Mn–¼Mo
Mn–½Mo
Mn–½Mo–¼Ni
Mn–½Mo–½Ni
Mn–½Mo–¾Ni

TABLE STARTS ON NEXT PAGE

Table C-1M Thermal Expansion Data (SI Units)

A = Mean Coefficient of Thermal Expansion, 10^{-6} mm/mm/°C
B = Linear Thermal Expansion, mm/m
} **in Going From 20°C to Indicated Temperature Note [(1)]**

Material	Coefficient	Temperature Range 20°C to													
		−200	−100	−50	20	50	75	100	125	150	175	200	225	250	275
Group 1 carbon and low alloy steels [Note (2)]	*A*	9.9	10.7	11.1	11.5	11.8	11.9	12.1	12.3	12.4	12.6	12.7	12.9	13.0	13.2
	B	−2.2	−1.3	−0.8	0	0.4	0.7	1.0	1.3	1.6	2.0	2.3	2.6	3.0	3.4
Group 2 low alloy steels [Note (3)]	*A*	10.8	11.7	12.0	12.6	12.8	13.0	13.1	13.2	13.4	13.5	13.6	13.7	13.8	13.9
	B	−2.4	−1.4	−0.8	0	0.4	0.7	1.0	1.4	1.7	2.1	2.4	2.8	3.2	3.6
5Cr-1Mo steels	*A*	10.1	10.8	11.2	11.5	11.8	12.0	12.1	12.3	12.4	12.5	12.6	12.6	12.7	12.8
	B	−2.2	−1.3	−0.8	0	0.4	0.7	1.0	1.3	1.6	1.9	2.3	2.6	2.9	3.3
9Cr–1Mo steels	*A*	9.0	9.8	10.1	10.5	10.6	10.7	10.9	11.0	11.1	11.2	11.3	11.4	11.5	11.6
	B	−2.0	−1.2	−0.7	0	0.3	0.6	0.9	1.2	1.4	1.7	2.0	2.3	2.6	3.0
Straight chromium stainless steels															
12Cr to 13Cr steels	*A*	9.1	9.9	10.2	10.6	10.9	11.0	11.1	11.3	11.4	11.4	11.5	11.6	11.6	11.7
	B	−2.0	−1.2	−0.7	0	0.3	0.6	0.9	1.2	1.5	1.8	2.1	2.4	2.7	3.0
15Cr to 17Cr steels	*A*	8.1	8.8	9.1	9.6	9.7	9.9	10.0	10.1	10.2	10.3	10.4	10.5	10.6	10.7
	B	−1.8	−1.1	−0.6	0	0.3	0.5	0.8	1.1	1.3	1.6	1.9	2.2	2.4	2.7
27Cr steels	*A*	7.7	8.5	8.7	9.0	9.2	9.2	9.3	9.4	9.4	9.5	9.5	9.6	9.6	9.7
	B	−1.7	−1.0	−0.6	0	0.3	0.5	0.7	1.0	1.2	1.5	1.7	2.0	2.2	2.5
Austenitic stainless steels (304, (305, 316, 317, 321, 347, 348, 19-9DL, XM-15, etc.)	*A*	13.5	14.3	14.7	15.3	15.6	15.9	16.2	16.4	16.6	16.8	17.0	17.2	17.4	17.5
	B	−3.0	−1.7	−1.0	0	0.5	0.9	1.3	1.7	2.2	2.6	3.1	3.5	4.0	4.5
Other austenitic stainless steels (309, 310, 315, XM-19, etc.)	*A*	12.8	13.6	14.1	14.7	15.0	15.2	15.4	15.6	15.7	15.9	16.0	16.1	16.3	16.4
	B	−2.8	−1.6	−1.0	0	0.4	0.8	1.2	1.6	2.0	2.5	2.9	3.3	3.7	4.2
Gray iron	*A*	...	...	...	9.8	10.1	10.2	10.4	10.5	10.7	10.8	11.0	11.1	11.2	11.4
	B	...	...	...	0	0.3	0.6	0.8	1.1	1.4	1.7	2.0	2.3	2.6	2.9
Ductile cast iron	*A*	...	8.8	9.5	10.3	10.5	10.7	10.9	11.1	11.3	11.6	11.8	12.0	12.2	12.4
	B	...	−1.1	−0.7	0	0.3	0.6	0.9	1.2	1.5	1.8	2.1	2.5	2.8	3.1
Monel (67Ni–30Cu) N04400	*A*	10.4	12.2	13.0	13.8	14.1	14.4	14.6	14.8	15.0	15.1	15.3	15.4	15.5	15.6
	B	−2.3	−1.5	−0.9	0	0.4	0.8	1.2	1.6	1.9	2.3	2.8	3.2	3.6	4.0
Nickel alloys N02200 and N02201	*A*	9.6	10.8	11.4	11.9	12.4	12.7	13.0	13.3	13.5	13.7	13.9	14.0	14.2	14.3
	B	−2.2	−1.4	−0.8	0	0.4	0.7	1.0	1.4	1.8	2.1	2.5	2.9	3.3	3.6
Nickel alloy N06022	*A*	...	...	...	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.5	12.5	12.6
	B	...	...	...	0	0.4	0.7	1.0	1.3	1.6	1.9	2.2	2.6	2.9	3.2
Nickel alloy N06600	*A*	9.9	10.8	11.5	12.3	12.5	12.7	12.8	13.0	13.2	13.3	13.5	13.6	13.7	13.8
	B	−2.2	−1.3	−0.8	0	0.4	0.7	1.0	1.4	1.7	2.1	2.4	2.8	3.2	3.5
Nickel alloy N06625	*A*	...	...	...	12.0	12.4	12.6	12.8	12.9	13.0	13.1	13.2	13.2	13.2	13.3
	B	...	...	...	0	0.4	0.7	1.0	1.4	1.7	2.0	2.4	2.7	3.0	3.4

Table C-1M Thermal Expansion Data (SI Units)

A = Mean Coefficient of Thermal Expansion, 10^{-6} mm/mm/°C
B = Linear Thermal Expansion, mm/m
} in Going From 20°C to Indicated Temperature Note [(1)]

Temperature Range 20°C to																				
300	**325**	**350**	**375**	**400**	**425**	**450**	**475**	**500**	**525**	**550**	**575**	**600**	**625**	**650**	**675**	**700**	**725**	**750**	**775**	**800**
13.3	13.4	13.6	13.7	13.8	14.0	14.1	14.2	14.4	14.5	14.6	14.7	14.8	14.9	15.0	15.1	15.1	15.2	15.3	15.3	15.4
3.7	4.1	4.5	4.9	5.3	5.7	6.1	6.5	6.9	7.3	7.7	8.2	8.6	9.0	9.4	9.9	10.3	10.7	11.1	11.6	12.0
14.0	14.1	14.2	14.3	14.4	14.5	14.6	14.6	14.7	14.8	14.8	14.9	15.0	15.0	15.1	15.1	15.2	15.2	15.3	15.3	15.3
3.9	4.3	4.7	5.1	5.5	5.9	6.3	6.7	7.1	7.5	7.9	8.3	8.7	9.1	9.5	9.9	10.3	10.7	11.1	11.1	11.5
12.8	12.9	13.0	13.0	13.1	13.2	13.2	13.3	13.4	13.4	13.5	13.6	13.6	13.7	13.7	13.8	13.9	13.9	14.0	14.0	14.1
3.6	3.9	4.3	4.6	5.0	5.3	5.7	6.1	6.4	6.8	7.2	7.5	7.9	8.3	8.7	9.0	9.4	9.8	10.2	10.6	11.0
11.7	11.8	11.9	11.9	12.0	12.1	12.2	12.3	12.3	12.4	12.5	12.6	12.7	12.7	12.8	12.9	13.0	13.1	13.3	13.4	13.6
3.3	3.6	3.9	4.2	4.6	4.9	5.2	5.6	5.9	6.3	6.6	7.0	7.3	7.7	8.1	8.5	8.9	9.3	9.7	10.1	10.6
11.7	11.8	11.8	11.9	11.9	12.0	12.0	12.1	12.1	12.2	12.2	12.3	12.3	12.4	12.4	12.5	12.5	12.5	12.5	12.6	12.6
3.3	3.6	3.9	4.2	4.5	4.9	5.2	5.5	5.8	6.2	6.5	6.8	7.2	7.5	7.8	8.2	8.5	8.8	9.2	9.5	9.8
10.8	10.8	10.9	11.0	11.0	11.1	11.2	11.2	11.3	11.3	11.4	11.4	11.5	11.5	11.5	11.6	11.6	11.7	11.7	11.8	11.9
3.0	3.3	3.6	3.9	4.2	4.5	4.8	5.1	5.4	5.7	6.0	6.3	6.6	7.0	7.3	7.6	7.9	8.2	8.6	8.9	9.3
9.7	9.8	9.9	9.9	10.0	10.0	10.1	10.2	10.2	10.3	10.4	10.4	10.5	10.5	10.6	10.6	10.7	10.7	10.8	10.8	10.9
2.7	3.0	3.3	3.5	3.8	4.1	4.3	4.6	4.9	5.2	5.5	5.8	6.1	6.4	6.7	7.0	7.2	7.6	7.9	8.2	8.5
17.7	17.8	17.9	18.0	18.1	18.2	18.3	18.4	18.4	18.5	18.6	18.7	18.8	18.9	19.0	19.1	19.2	19.3	19.4	19.4	19.4
4.9	5.4	5.9	6.4	6.9	7.4	7.9	8.3	8.9	9.4	9.9	10.4	10.9	11.4	12.0	12.5	13.1	13.6	14.1	14.7	15.2
16.5	16.6	16.6	16.7	16.8	16.9	17.0	17.1	17.2	17.2	17.3	17.4	17.5	17.6	17.7	17.8	17.9	18.0	18.1	18.2	18.3
4.6	5.0	5.5	5.9	6.4	6.8	7.3	7.8	8.2	8.7	9.2	9.7	10.2	10.6	11.1	11.7	12.2	12.7	13.2	13.7	14.3
11.5	11.7	11.8	12.0	12.1	12.3	12.4	12.6	12.7	12.9	13.0	...	...	...	...	...	...	...	...	...	...
3.2	3.6	3.9	4.2	4.6	5.0	5.3	5.7	6.1	6.5	6.9	...	...	...	...	...	...	...	...	...	...
12.5	12.6	12.8	12.9	13.0	13.1	13.2	13.2	13.3	13.4	13.5	...	...	...	...	...	...	...	...	...	...
3.5	3.9	4.2	4.6	4.9	5.3	5.7	6.0	6.4	6.8	7.2	...	...	...	...	...	...	...	...	...	...
15.7	15.8	15.9	16.0	16.0	16.1	16.1	16.2	16.2	16.3	16.3	16.4	16.4	16.5	16.5	16.5	16.6	16.6	16.7	16.7	16.8
4.4	4.8	5.2	5.7	6.1	6.5	6.9	7.4	7.8	8.2	8.6	9.1	9.5	10.0	10.4	10.8	11.3	11.7	12.2	12.6	13.1
14.4	14.5	14.6	14.7	14.8	14.9	15.0	15.1	15.2	15.3	15.4	15.5	15.6	15.6	15.7	15.8	15.9	15.9	16.0	16.1	16.2
4.0	4.4	4.8	5.2	5.6	6.0	6.5	6.9	7.3	7.7	8.2	8.6	9.0	9.5	9.9	10.3	10.8	11.2	11.7	12.2	12.6
12.6	12.7	12.8	12.9	13.0	13.2	13.3	13.5	13.6	13.8	13.9	14.1	14.3	14.4	14.6	14.8	14.9	15.1	15.2	15.4	15.6
3.5	3.9	4.2	4.6	5.0	5.3	5.7	6.1	6.5	7.0	7.4	7.8	8.3	8.7	9.2	9.7	10.1	10.6	11.1	11.6	12.1
14.0	14.1	14.2	14.3	14.4	14.5	14.6	14.7	14.8	14.9	15.0	15.1	15.2	15.3	15.4	15.6	15.7	15.8	15.9	16.1	16.2
3.9	4.3	4.7	5.1	5.5	5.9	6.3	6.7	7.1	7.5	7.9	8.4	8.8	9.3	9.7	10.2	10.7	11.1	11.6	12.1	12.6
13.3	13.3	13.4	13.5	13.5	13.6	13.7	13.8	14.0	14.1	14.2	14.3	14.5	14.6	14.8	14.9	15.0	15.1	15.3	15.4	15.6
3.7	4.1	4.4	4.8	5.1	5.5	5.9	6.3	6.7	7.1	7.5	8.0	8.4	8.8	9.3	9.8	10.2	10.7	11.2	11.6	12.1

Table C-1M Thermal Expansion Data (SI Units) (Cont'd)

A = Mean Coefficient of Thermal Expansion, 10^{-6} mm/mm/°C
B = Linear Thermal Expansion, mm/m
} **in Going From 20°C to Indicated Temperature Note [(1)]**

Material	Coefficient	Temperature Range 20°C to −200	−100	−50	20	50	75	100	125	150	175	200	225	250	275
Nickel alloys N08800 and N08810	*A*	10.6	12.5	13.3	14.2	14.6	14.9	15.1	15.3	15.5	15.6	15.8	15.9	16.0	16.1
	B	−2.3	−1.5	−0.9	0	0.4	0.8	1.2	1.6	2.0	2.4	2.8	3.3	3.7	4.1
Nickel alloy N08825	*A*	...	...	12.9	13.5	13.6	13.7	13.9	14.0	14.2	14.3	14.4	14.4	14.5	14.6
	B	...	...	−0.9	0	0.4	0.8	1.1	1.5	1.8	2.2	2.6	3.0	3.3	3.7
Nickel alloy N10276	*A*	...	...	...	10.8	11.0	11.2	11.4	11.6	11.7	11.9	12.0	12.2	12.4	12.5
	B	...	...	...	0	0.3	0.6	0.9	1.2	1.5	1.8	2.2	2.5	2.8	3.2
Copper alloys C1XXXX series	*A*	13.9	15.7	16.2	16.7	17.0	17.2	17.3	17.4	17.5	17.6	17.7	17.8	17.8	17.9
	B	−3.1	−1.9	−1.1	0	0.5	0.9	1.4	1.8	2.3	2.7	3.2	3.6	4.1	4.6
Bronze alloys	*A*	15.1	15.8	16.4	17.2	17.6	17.9	18.0	18.2	18.2	18.3	18.4	18.5	18.5	18.6
	B	−3.3	−1.9	−1.1	0	0.5	1.0	1.4	1.9	2.4	2.8	3.3	3.8	4.3	4.7
Brass alloys	*A*	14.7	15.4	16.0	16.7	17.1	17.4	17.6	17.8	18.0	18.2	18.4	18.6	18.8	19.0
	B	−3.2	−1.9	−1.1	0	0.5	1.0	1.4	1.9	2.3	2.8	3.3	3.8	4.3	4.8
Copper–nickel (70Cu–30Ni)	*A*	11.9	13.4	14.0	14.5	14.9	15.2	15.3	15.5	15.7	15.8	16.0	16.1	16.3	16.4
	B	−2.6	−1.6	−1.0	0	0.4	0.8	1.2	1.6	2.0	2.5	2.9	3.3	3.7	4.2
Aluminum alloys	*A*	18.0	19.7	20.8	21.7	22.6	23.1	23.4	23.7	23.9	24.2	24.4	24.7	25.0	25.2
	B	−4.0	−2.4	−1.5	0	0.7	1.3	1.9	2.5	3.1	3.7	4.4	5.1	5.7	6.4
Titanium alloys (Grades 1, 2, 3, 7, and 12)	*A*	...	...	8.2	8.3	8.4	8.5	8.5	8.6	8.6	8.6	8.7	8.7	8.7	8.8
	B	...	...	−0.6	0	0.3	0.5	0.7	0.9	1.1	1.3	1.6	1.8	2.0	2.2

Table C-1M Thermal Expansion Data (SI Units) (Cont'd)

A = Mean Coefficient of Thermal Expansion, 10^{-6} mm/mm/°C
B = Linear Thermal Expansion, mm/m
} **in Going From 20°C to Indicated Temperature Note [(1)]**

Temperature Range 20°C to																				
300	**325**	**350**	**375**	**400**	**425**	**450**	**475**	**500**	**525**	**550**	**575**	**600**	**625**	**650**	**675**	**700**	**725**	**750**	**775**	**800**
16.2	16.3	16.4	16.5	16.5	16.6	16.7	16.8	16.8	16.9	17.0	17.1	17.2	17.2	17.3	17.4	17.5	17.6	17.7	17.8	17.9
4.5	5.0	5.4	5.8	6.3	6.7	7.2	7.6	8.1	8.5	9.0	9.5	9.9	10.4	10.9	11.4	11.9	12.4	12.9	13.4	14.0
14.7	14.8	14.9	15.0	15.1	15.1	15.2	15.3	15.4	15.5	15.6	...	...	...	...	...	...	...	...	...	...
4.1	4.5	4.9	5.3	5.7	6.1	6.5	7.0	7.4	7.8	8.3	...	...	...	...	...	...	...	...	...	...
12.6	12.8	12.9	13.0	13.1	13.2	13.3	13.4	13.5	13.6	13.7	13.8	13.9	14.0	14.1	14.2	14.3	14.3	14.4	14.5	14.6
3.5	3.9	4.3	4.6	5.0	5.4	5.7	6.1	6.5	6.9	7.3	7.7	8.1	8.5	8.9	9.3	9.7	10.1	10.5	10.9	11.4
18.0	18.0	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
5.0	5.5	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
18.7	18.8	18.9	19.0	19.0	19.1	19.2	19.3	19.4	19.4	19.5	19.6	19.7	19.7	19.8	...	...	...	...	...	...
5.2	5.7	6.2	6.7	7.2	7.7	8.3	8.8	9.3	9.8	10.3	10.9	11.4	11.9	12.5	...	...	...	...	...	...
19.2	19.3	19.5	19.6	19.8	20.1	20.3	20.5	20.7	20.8	21.0	21.2	21.4	21.6	21.8	...	...	...	...	...	...
5.4	5.9	6.4	7.0	7.5	8.2	8.7	9.3	9.9	10.5	11.1	11.8	12.4	13.1	13.7	...	...	...	...	...	...
16.5	16.5	16.6	16.6	16.7	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
4.6	5.0	5.5	5.9	6.3	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
25.5	25.6	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
7.1	7.8	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
8.8	8.8	8.9	8.9	9.0	9.2	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
2.5	2.7	2.9	3.2	3.4	3.7	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...

Table C-1M Thermal Expansion Data (SI Units) (Cont'd)

NOTES:
(1) These data are for information and it is not to be implied that materials are suitable for all the temperature ranges shown.
(2) Group 1 alloys (by nominal composition):

Carbon steels (C, C–Si, C–Mn, and C–Mn–Si)	3Cr–1Mo
C–$^1/_2$Mo	$^1/_2$Ni–$^1/_2$Mo–V
$^1/_2$Cr–$^1/_5$Mo–V	$^1/_2$Ni–$^1/_2$Cr–$^1/_4$Mo–V
$^1/_2$Cr–$^1/_4$Mo–Si	$^3/_4$Ni–$^1/_2$Mo–Cr–V
$^1/_2$Cr–$^1/_2$Mo	$^3/_4$Ni–$^1/_2$Mo–$^1/_3$Cr–V
$^1/_2$Cr–$^1/_2$Ni–$^1/_4$Mo	$^3/_4$Ni–$^1/_2$Cu–Mo
$^3/_4$Cr–$^1/_2$Ni–Cu	$^3/_4$Ni–$^1/_2$Cr–$^1/_2$Mo–V
$^3/_4$Cr–$^3/_4$Ni–Cu–Al	$^3/_4$Ni–1Mo–$^3/_4$Cr
1Cr–$^1/_5$Mo	1Ni–$^1/_2$Cr–$^1/_2$Mo
1Cr–$^1/_5$Mo–Si	1$^1/_4$Ni–1Cr–$^1/_2$Mo
1Cr–$^1/_2$Mo	1$^3/_4$Ni–$^3/_4$Cr–$^1/_4$Mo
1Cr–$^1/_2$Mo–V	2Ni–$^3/_4$Cr–$^1/_4$Mo
1$^1/_4$Cr–$^1/_2$Mo	2Ni–$^3/_4$Cr–$^1/_3$Mo
1$^1/_4$Cr–$^1/_2$Mo–Si	2$^1/_2$Ni
1$^3/_4$Cr–$^1/_2$Mo–Cu	3$^1/_2$Ni
2Cr–$^1/_2$Mo	3$^1/_2$Ni–1$^3/_4$Cr–$^1/_2$Mo–V
2$^1/_4$Cr–1Mo	

(3) Group 2 alloys (by nominal composition):

Mn–V	Mn–$^1/_2$Mo–$^1/_4$Ni
Mn–$^1/_4$Mo	Mn–$^1/_2$Mo–$^1/_2$Ni
Mn–$^1/_2$Mo	Mn–$^1/_2$Mo–$^3/_4$Ni

Table C-5 Thermal Expansion Coefficients, Nonmetals

Material Description	Mean Coefficients (Divide Table Values by 10^6)			
	in./in., °F	Range, °F	mm/mm, °C	Range, °C
Thermoplastics				
Acetal AP2012	2	...	3.6	...
Acrylonitrile-butadiene-styrene				
ABS 1208	60	...	108	...
ABS 1210	55	45–55	99	7–13
ABS 1316	40	...	72	...
ABS 2112	40	...	72	...
Cellulose acetate butyrate				
CAB MH08	80	...	144	...
CAB S004	95	...	171	...
Chlorinated poly(vinyl chloride)				
CPVC 4120	35	...	63	...
Polybutylene PB 2110	72	...	130	...
Polyether, chlorinated	45	...	81	...
Polyethylene				
PE2606	100	46–100	180	8–38
PE2706	100	46–100	180	8–38
PE3608	90	46–100	162	8–38
PE3708	90	46–100	162	8–38
PE3710	90	46–100	162	8–38
PE4708	80	46–100	144	8–38
PE4710	80	46–100	144	8–38
Cross-linked polyethylene				
PEX0006	78	−58 to 212	140	−50 to 100
PEX0008	78	−58 to 212	140	−50 to 100
Polyphenylene POP 2125	30	...	54	...
Polypropylene				
PP1110	48	33–67	86	1–19
PP1208	43	...	77	...
PP2105	40	...	72	...
PP0210B44002	80	...	144	...
PP0210G07G11030	19	...	35	...
Poly(vinyl chloride)				
PVC1120	30	23–37	54	−5 to 3
PVC1220	35	34–40	63	1–4
PVC2110	50	...	90	...
PVC2112	45	...	81	...
PVC2116	40	37–45	72	3–7

Table C-5 Thermal Expansion Coefficients, Nonmetals (Cont'd)

Material Description	Mean Coefficients (Divide Table Values by 10^6)			
	in./in., °F	Range, °F	mm/mm, °C	Range, °C
PVC2120	30	...	54	...
Poly(vinylidene fluoride)	79	...	142	...
Poly(vinylidene chloride)	100	...	180	...
Poly(tetrafluoroethylene)	55	73–140	99	23–60
Poly(fluorinated ethylene propylene)	46–58	73–140	83–104	23–60
Poly(perfluoroalkoxy alkane)	67	70–212	121	21–100
Poly(perfluoroalkoxy alkane)	94	212–300	169	100–149
Poly(perfluoroalkoxy alkane)	111	300–408	200	149–209
Reinforced Thermosetting Resins and Reinforced Plastic Mortars				
Glass–epoxy, centrifugally cast	9–13	...	16–23.5	...
Glass–polyester, centrifugally cast	9–15	...	16–27	...
Glass–polyester, filament-wound	9–11	...	16–20	...
Glass–polyester, hand lay-up	12–15	...	21.5–27	...
Glass–epoxy, filament-wound	9–13	...	16–23.5	...
Other Nonmetallic Materials				
Borosilicate glass	1.8	...	3.25	...

GENERAL NOTES:

(a) For Code references to this Appendix, see para. A319.3.1. These data are for use in the absence of more-applicable data. It is the designer's responsibility to verify that materials are suitable for the intended service at the temperatures shown.

(b) Individual compounds may vary from the values shown. Consult manufacturer for specific values for products.

Table C-6 Moduli of Elasticity for Metals

	E = Modulus of Elasticity, psi (Multiply Tabulated Values by 10^6) [Note (1)]																		
	Temperature, °F																		
Material	**−425**	**−325**	**−200**	**−100**	**70**	**200**	**300**	**400**	**500**	**600**	**700**	**800**	**900**	**1,000**	**1,100**	**1,200**	**1,300**	**1,400**	**1,500**
Carbon steels with carbon content 0.30% or less	31.9	31.4	30.8	30.3	29.4	28.8	28.3	27.4	27.3	26.5	25.5	24.2	22.5	20.4	18.0	...	...	...	...
Carbon steels with carbon content above 0.30%	31.7	31.2	30.6	30.1	29.2	28.6	28.1	27.7	27.1	26.4	25.3	24.0	22.3	20.2	17.9	15.4	...	...	...
Carbon–molybdenum steels	31.7	31.1	30.5	30.0	29.0	28.5	28.0	27.6	27.0	26.3	25.3	23.9	22.2	20.1	17.8	15.3	...	...	...
Nickel steels, Ni 2% to 9%	30.1	29.6	29.0	28.6	27.8	27.1	26.7	26.2	25.7	25.1	24.6	23.9	23.2	22.4	21.5	20.4	19.2	17.7	...
Chromium steels:																			
$\frac{1}{2}$Cr through 2Cr	32.1	31.6	30.9	30.5	29.6	29.0	28.5	28.0	27.4	26.9	26.2	25.6	24.8	23.9	23.0	21.8	20.5	18.9	...
$2\frac{1}{4}$Cr through 3Cr	33.1	32.6	31.9	31.4	30.6	29.9	29.4	28.8	28.3	27.7	27.0	26.3	25.6	24.7	23.7	22.5	21.1	19.4	...
5Cr through 9Cr	33.4	33.0	32.4	31.9	31.0	30.3	29.7	29.2	28.6	28.1	27.5	26.9	26.2	25.4	24.4	23.3	22.0	20.5	...
Austenitic stainless steels:																			
Type 304, 18Cr–8Ni	30.8	30.3	29.7	29.2	28.3	27.5	27.0	26.4	25.9	25.3	24.8	24.1	23.5	22.8	22.0	21.2	20.3	19.2	18.1
Type 310, 25Cr-20Ni	30.8	30.3	29.7	29.2	28.3	27.5	27.0	26.4	25.9	25.3	24.8	24.1	23.5	22.8	22.0	21.2	20.3	19.2	18.1
Type 316, 16Cr–12Ni–2Mo	30.8	30.3	29.7	29.2	28.3	27.5	27.0	26.4	25.9	25.3	24.8	24.1	23.5	22.8	22.0	21.2	20.3	19.2	18.1
Type 321, 18Cr–10Ni–Ti	30.8	30.3	29.7	29.2	28.3	27.5	27.0	26.4	25.9	25.3	24.8	24.1	23.5	22.8	22.0	21.2	20.3	19.2	18.1
Type 347, 18Cr–10Ni–Cb	30.8	30.3	29.7	29.2	28.3	27.5	27.0	26.4	25.9	25.3	24.8	24.1	23.5	22.8	22.0	21.2	20.3	19.2	18.1
Type 309, 23Cr–12Ni	30.8	30.3	29.7	29.2	28.3	27.5	27.0	26.4	25.9	25.3	24.8	24.1	23.5	22.8	22.0	21.2	20.3	19.2	18.1
Straight chromium stainless steels (12Cr, 17Cr, 27Cr)	31.8	31.2	30.7	30.2	29.2	28.4	27.9	27.3	26.8	26.2	25.5	24.5	23.2	21.5	19.2	16.5	...	...	...
Gray iron	...	...	...	...	13.4	13.2	12.9	12.6	12.2	11.7	11.0	10.2	...	...	...	...	...	...	...
Nickel Alloys																			
N02200	32.7	32.2	31.4	30.9	30.0	29.4	28.9	28.5	28.1	27.6	27.2	26.7	26.2	25.7	25.1	24.5	23.8	23.1	22.4
N02201	32.7	32.2	31.4	30.9	30.0	29.4	28.9	28.5	28.1	27.6	27.2	26.7	26.2	25.7	25.1	24.5	23.8	23.1	22.4
N04400	28.3	27.8	27.2	26.8	26.0	25.5	25.1	24.7	24.3	23.9	23.6	23.1	22.7	22.2	21.7	21.2	20.6	20.0	19.4
N06002	31.1	30.5	29.9	29.3	28.5	27.9	27.5	27.1	26.7	26.2	25.8	25.4	24.9	24.3	23.8	23.2	22.5	21.9	21.2

Table C-6 Moduli of Elasticity for Metals (Cont'd)

Material	*E* = Modulus of Elasticity, psi (Multiply Tabulated Values by 10^6) [Note (1)]																		
	Temperature, °F																		
	−425	−325	−200	−100	70	200	300	400	500	600	700	800	900	1,000	1,100	1,200	1,300	1,400	1,500
Nickel Alloys (Cont'd)																			
N06007	30.3	29.8	29.1	28.6	27.8	27.2	26.8	26.4	26.0	25.6	25.2	24.7	24.3	23.8	23.2	22.6	22.0	21.4	20.7
N06022	...	32.1	31.3	30.8	29.9	29.3	28.8	28.4	28.0	27.5	27.1	26.6	26.1	25.6	25.0	24.4	23.7	23.0	22.3
N06030	...	31.5	30.7	30.2	29.3	28.7	28.2	27.8	27.4	27.0	26.5	26.1	25.6	25.1	24.5	23.9	23.2	22.5	21.9
N06035	29.2	29.1	29.0	28.8	28.5	28.1	27.8	27.5	27.1	26.7	26.3	25.8	25.5	24.8	24.1	23.6	...	...	...
N06059	...	32.7	31.9	31.3	30.5	29.9	29.4	29.0	28.5	28.1	27.6	27.1	26.6	26.0	25.4	24.8	24.1	23.4	22.8
N06230	...	32.8	32.0	31.5	30.6	29.9	29.5	29.0	28.6	28.2	27.7	27.2	26.7	26.1	25.5	24.9	24.2	23.6	22.8
N06455	32.5	32.0	31.2	30.7	29.8	29.2	28.7	28.3	27.9	27.4	27.0	26.5	26.0	25.5	24.9	24.3	23.6	22.9	22.2
N06600	33.8	33.3	32.5	31.9	31.0	30.3	29.9	29.4	29.0	28.6	28.1	27.6	27.1	26.5	25.9	25.3	23.7	23.0	22.3
N06617	...	...	...	...	29.2	28.4	28.0	27.7	27.4	27.0	26.5	26.0	25.5	24.9	24.3	23.8	23.2	22.5	21.8
N06625	32.7	32.2	31.4	30.9	30.0	29.4	28.9	28.5	28.1	27.6	27.2	26.7	26.2	25.7	25.1	24.5	23.7	23.0	22.3
N08020	...	30.0	29.3	28.8	28.0	27.4	27.0	26.6	26.2	25.8	25.4	24.9	24.4	23.9	23.4	22.8	22.2	21.6	20.9
N08031	...	30.7	30.1	29.5	28.7	28.1	27.7	27.2	26.8	26.4	26.0	25.5	25.0	24.5	24.0	23.4	22.8	22.1	21.4
N08320	...	...	...	28.6	27.8	27.1	26.7	26.4	26.0	25.7	25.3	24.7	24.2	23.6	23.2	22.7	...	...	...
N08800	31.1	30.5	29.9	29.3	28.5	27.9	27.5	27.1	26.7	26.2	25.8	25.4	24.9	24.4	23.8	23.2	22.6	21.9	21.2
N08810	31.1	30.5	29.9	29.3	28.5	27.9	27.5	27.1	26.7	26.2	25.8	25.4	24.9	24.4	23.8	23.2	22.6	21.9	21.2
N08825	...	30.0	29.3	28.8	28.0	27.4	27.0	26.6	26.2	25.8	25.4	24.9	24.4	23.9	23.4	22.8	22.2	21.6	20.9
N10001	33.9	33.4	32.6	32.0	31.1	30.4	30.0	29.5	29.1	28.7	28.2	27.7	27.2	26.6	26.0	25.3	22.6	21.9	21.2
N10276	32.5	32.0	31.2	30.7	29.8	29.2	28.7	28.3	27.9	27.4	27.0	26.5	26.0	25.5	24.9	24.3	23.6	22.9	22.2
N10665	34.2	33.7	32.9	32.3	31.4	30.7	30.2	29.8	29.3	28.9	28.4	27.9	27.4	26.8	26.2	25.6	24.9	24.2	23.4
N10675	...	33.7	32.9	32.3	31.4	30.7	30.2	29.8	29.3	28.9	28.4	27.9	27.4	26.8	26.2	25.6	24.9	24.2	23.4
Aluminum and Aluminum Alloys																			
A24430	11.4	11.1	10.8	10.5	10.0	9.6	9.2	8.7	8.1	...	...	...	...	...	...	...	...	...	...
A91060	11.4	11.1	10.8	10.5	10.0	9.6	9.2	8.7	8.1	...	...	...	...	...	...	...	...	...	...
A91100	11.4	11.1	10.8	10.5	10.0	9.6	9.2	8.7	8.1	...	...	...	...	...	...	...	...	...	...
A93003	11.4	11.1	10.8	10.5	10.0	9.6	9.2	8.7	8.1	...	...	...	...	...	...	...	...	...	...
A93004	11.4	11.1	10.8	10.5	10.0	9.6	9.2	8.7	8.1	...	...	...	...	...	...	...	...	...	...
A96061	11.4	11.1	10.8	10.5	10.0	9.6	9.2	8.7	8.1	...	...	...	...	...	...	...	...	...	...
A96063	11.4	11.1	10.8	10.5	10.0	9.6	9.2	8.7	8.1	...	...	...	...	...	...	...	...	...	...
A95052	11.6	11.3	11.0	10.7	10.2	9.7	9.4	8.9	8.3	...	...	...	...	...	...	...	...	...	...
A95154	11.6	11.3	11.0	10.7	10.2	9.7	9.4	8.9	8.3	...	...	...	...	...	...	...	...	...	...

Table C-6 Moduli of Elasticity for Metals (Cont'd)

Material	E = Modulus of Elasticity, psi (Multiply Tabulated Values by 10^6) [Note (1)]																		
	Temperature, °F																		
	−425	**−325**	**−200**	**−100**	**70**	**200**	**300**	**400**	**500**	**600**	**700**	**800**	**900**	**1,000**	**1,100**	**1,200**	**1,300**	**1,400**	**1,500**
Aluminum and Aluminum Alloys (Cont'd)																			
A95454	11.6	11.3	11.0	10.7	10.2	9.7	9.4	8.9	8.3	...	...	...	...	...	...	...	...	...	...
A95652	11.6	11.3	11.0	10.7	10.2	9.7	9.4	8.9	8.3	...	...	...	...	...	...	...	...	...	...
A03560	11.7	11.4	11.1	10.8	10.3	9.8	9.5	9.0	8.3	...	...	...	...	...	...	...	...	...	...
A95083	11.7	11.4	11.1	10.8	10.3	9.8	9.5	9.0	8.3	...	...	...	...	...	...	...	...	...	...
A95086	11.7	11.4	11.1	10.8	10.3	9.8	9.5	9.0	8.3	...	...	...	...	...	...	...	...	...	...
A95456	11.7	11.4	11.1	10.8	10.3	9.8	9.5	9.0	8.3	...	...	...	...	...	...	...	...	...	...
Copper and Copper Alloys																			
C83600	...	14.8	14.6	14.4	14.0	13.7	13.4	13.2	12.9	12.5	12.0	...	...	...	...	...	...	...	...
C92200	...	14.8	14.6	14.4	14.0	13.7	13.4	13.2	12.9	12.5	12.0	...	...	...	...	...	...	...	...
C46400	...	15.9	15.6	15.4	15.0	14.6	14.4	14.1	13.8	13.4	12.8	...	...	...	...	...	...	...	...
C65500	...	15.9	15.6	15.4	15.0	14.6	14.4	14.1	13.8	13.4	12.8	...	...	...	...	...	...	...	...
C95200	...	15.9	15.6	15.4	15.0	14.6	14.4	14.1	13.8	13.4	12.8	...	...	...	...	...	...	...	...
C95400	...	15.9	15.6	15.4	15.0	14.6	14.4	14.1	13.8	13.4	12.8	...	...	...	...	...	...	...	...
C10200	...	18.0	17.7	17.5	17.0	16.6	16.3	16.0	15.6	15.1	14.5	...	...	...	...	...	...	...	...
C11000	...	18.0	17.7	17.5	17.0	16.6	16.3	16.0	15.6	15.1	14.5	...	...	...	...	...	...	...	...
C12000	...	18.0	17.7	17.5	17.0	16.6	16.3	16.0	15.6	15.1	14.5	...	...	...	...	...	...	...	...
C12200	...	18.0	17.7	17.5	17.0	16.6	16.3	16.0	15.6	15.1	14.5	...	...	...	...	...	...	...	...
C12500	...	18.0	17.7	17.5	17.0	16.6	16.3	16.0	15.6	15.1	14.5	...	...	...	...	...	...	...	...
C14200	...	18.0	17.7	17.5	17.0	16.6	16.3	16.0	15.6	15.1	14.5	...	...	...	...	...	...	...	...
C23000	...	18.0	17.7	17.5	17.0	16.6	16.3	16.0	15.6	15.1	14.5	...	...	...	...	...	...	...	...
C61400	...	18.0	17.7	17.5	17.0	16.6	16.3	16.0	15.6	15.1	14.5	...	...	...	...	...	...	...	...
C70600	...	19.0	18.7	18.5	18.0	17.6	17.3	16.9	16.5	16.0	15.4	...	...	...	...	...	...	...	...
C97600	...	20.1	19.8	19.6	19.0	18.5	18.2	17.9	17.5	16.9	16.2	...	...	...	...	...	...	...	...
C71000	...	21.2	20.8	20.6	20.0	19.5	19.2	18.8	18.4	17.8	17.1	...	...	...	...	...	...	...	...
C71500	...	23.3	22.9	22.6	22.0	21.5	21.1	20.7	20.2	19.6	18.8	...	...	...	...	...	...	...	...
Unalloyed Titanium																			
Grades 1, 2, 3, 7, and 12	...	...	...	...	15.5	15.0	14.6	14.0	13.3	12.6	11.9	11.2	...	...	...	...	...	...	...

Table C-6 Moduli of Elasticity for Metals (Cont'd)

Material	E = Modulus of Elasticity, psi (Multiply Tabulated Values by 10^6) [Note (1)]																		
	Temperature, °F																		
	−425	−325	−200	−100	70	200	300	400	500	600	700	800	900	1,000	1,100	1,200	1,300	1,400	1,500
Zirconium Alloys																			
R60702	...	...	...	...	14.4	13.5	12.6	11.7	10.9	10.1	9.3	8.2	...	...	...	...	...	...	...
R60705	...	...	...	...	13.7	13.1	12.7	12.2	11.7	11.3	10.8	10.4	...	...	...	...	...	...	...

NOTE: (1) These data are for information and it is not to be implied that materials are suitable for all the temperature ranges shown.

Table C-6M Moduli of Elasticity for Metals (SI Units)

Material	*E* = Modulus of Elasticity, MPa (Multiply Tabulated Values by 10^3) [Note (1)]																				
	Temperature, °C																				
	−255	−200	−125	−75	25	100	150	200	250	300	350	400	450	500	550	600	650	700	750	800	850
Carbon steels with carbon content 0.30% or less	220	216	212	209	202	198	195	192	189	185	179	171	162	151	137	122	107	...	...	...	...
Carbon steels with carbon content above 0.30%	218	215	211	207	201	197	194	191	188	183	178	170	161	149	136	121	106	...	...	...	...
Carbon–molybdenum steels	218	214	210	207	200	196	193	190	187	183	177	170	160	149	135	121	106	...	...	...	...
Nickel steels, Ni 2% to 9%	207	204	200	197	191	187	184	181	178	174	171	167	163	158	153	147	141	133	...	...	...
Chromium steels:																					
½Cr through 2Cr	221	218	213	210	204	200	197	193	190	186	183	179	174	169	164	157	150	142	...	...	...
2¼Cr through 3Cr	228	225	220	217	210	206	202	199	196	192	188	184	180	175	169	162	155	146	...	...	...
5Cr through 9Cr	230	228	223	220	213	208	205	201	198	195	191	187	183	179	174	168	161	153	...	...	...
Austenitic stainless steels:																					
Type 304, 18Cr–8Ni	212	209	204	201	195	189	186	183	179	176	172	169	165	160	156	151	146	140	134	127	...
Type 310, 25Cr–20Ni	212	209	204	201	195	189	186	183	179	176	172	169	165	160	156	151	146	140	134	127	...
Type 316, 16Cr–12Ni–2Mo	212	209	204	201	195	189	186	183	179	176	172	169	165	160	156	151	146	140	134	127	...
Type 321, 18Cr–10Ni–Ti	212	209	204	201	195	189	186	183	179	176	172	169	165	160	156	151	146	140	134	127	...
Type 347, 18Cr–10Ni–Cb	212	209	204	201	195	189	186	183	179	176	172	169	165	160	156	151	146	140	134	127	...
Type 309. 23Cr–12Ni	212	209	204	201	195	189	186	183	179	176	172	169	165	160	156	151	146	140	134	127	...
Straight chromium stainless steels (12Cr, 17Cr, 27Cr)	219	215	212	208	201	195	192	189	186	182	178	173	166	157	145	131	...	...	...	...	...
Gray iron	...	...	...	...	92	91	89	87	85	82	78	73	67	...	...	...	...	...	...	...	...
Nickel Alloys																					
N02200	225	222	216	213	207	202	199	197	194	191	189	186	183	180	176	172	169	164	160	156	...
N02201	225	222	216	213	207	202	199	197	194	191	189	186	183	180	176	172	169	164	160	156	...
N04400	195	192	188	185	179	175	173	171	168	166	163	161	158	155	152	149	146	142	139	135	...
N06002	214	211	206	202	196	192	189	187	184	182	179	176	173	170	167	163	160	156	152	148	...
N06007	209	205	200	197	191	187	185	182	180	177	175	172	169	166	163	160	156	152	148	144	...

Table C-6M Moduli of Elasticity for Metals (SI Units) (Cont'd)

Material	*E* = Modulus of Elasticity, MPa (Multiply Tabulated Values by 10^3) [Note (1)]																				
	Temperature, °C																				
	−255	−200	−125	−75	25	100	150	200	250	300	350	400	450	500	550	600	650	700	750	800	850
Nickel Alloys (Cont'd)																					
N06022	...	221	216	212	206	201	199	196	193	191	188	185	182	179	175	172	168	164	160	155	151
N06030	...	217	212	208	202	197	195	192	189	187	184	181	178	175	172	168	165	161	156	152	148
N06035	201	201	200	199	196	194	192	190	187	185	182	179	176	173	170	166	162	...	...	...	...
N06059	...	225	220	216	210	205	203	200	197	194	192	189	185	182	178	175	171	167	162	158	154
N06230	...	226	221	217	211	206	203	200	198	195	192	189	186	183	179	176	172	168	163	159	154
N06455	224	220	215	212	205	201	198	195	193	190	187	184	181	178	175	171	167	163	159	155	...
N06600	233	229	224	220	213	209	206	203	201	198	195	192	189	186	182	178	174	170	165	161	...
N06617	...	...	...	...	201	196	193	191	189	187	184	181	178	174	171	167	164	160	156	152	146
N06625	225	222	216	213	207	202	199	197	194	191	189	186	183	180	176	172	169	164	160	156	...
N08020	...	207	202	199	193	189	186	184	181	179	176	173	170	167	164	161	157	153	150	...	...
N08031	...	212	207	204	198	193	191	188	185	183	180	178	175	172	168	165	161	157	153	149	145
N08320	...	...	...	198	192	187	185	182	180	177	175	172	169	167	163	159	156	152	149	144	...
N08800	214	211	206	202	196	192	189	187	184	182	179	176	173	170	167	164	160	156	152	148	...
N08810	214	211	206	202	196	192	189	187	184	182	179	176	173	170	167	164	160	156	152	148	...
N08825	...	207	202	199	193	189	186	184	181	179	176	173	170	167	164	161	157	153	150	...	...
N10001	233	230	224	221	214	209	206	204	201	198	196	193	189	186	182	178	174	170	166	161	...
N10276	224	220	215	212	205	201	198	195	193	190	187	184	181	178	175	171	167	163	159	155	...
N10665	235	232	227	223	216	211	208	206	203	200	197	194	191	188	184	180	176	172	168	163	...
N10675	...	232	227	223	216	211	208	206	203	200	197	194	191	188	184	180	176	172	168	...	...
Aluminum and Aluminum Alloys																					
A24430	78	77	74	72	69	66	63	60	57	52	46	...	...	...	...	...	...	...	...	...	...
A91060	78	77	74	72	69	66	63	60	57	52	46	...	...	...	...	...	...	...	...	...	...
A91100	78	77	74	72	69	66	63	60	57	52	46	...	...	...	...	...	...	...	...	...	...
A93003	78	77	74	72	69	66	63	60	57	52	46	...	...	...	...	...	...	...	...	...	...
A93004	78	77	74	72	69	66	63	60	57	52	46	...	...	...	...	...	...	...	...	...	...
A96061	78	77	74	72	69	66	63	60	57	52	46	...	...	...	...	...	...	...	...	...	...
A96063	78	77	74	72	69	66	63	60	57	52	46	...	...	...	...	...	...	...	...	...	...
A95052	80	78	76	74	70	67	65	62	58	53	47	...	...	...	...	...	...	...	...	...	...
A95154	80	78	76	74	70	67	65	62	58	53	47	...	...	...	...	...	...	...	...	...	...

Table C-6M Moduli of Elasticity for Metals (SI Units) (Cont'd)

Material	*E* = Modulus of Elasticity, MPa (Multiply Tabulated Values by 10^3) [Note (1)]																				
	Temperature, °C																				
	−255	−200	−125	−75	25	100	150	200	250	300	350	400	450	500	550	600	650	700	750	800	850
Aluminum and Aluminum Alloys (Cont'd)																					
A95454	80	78	76	74	70	67	65	62	58	53	47	...	...	...	...	...	...	...	...	...	...
A95652	80	78	76	74	70	67	65	62	58	53	47	...	...	...	...	...	...	...	...	...	...
A03560	80	79	76	75	71	68	65	62	58	54	47	...	...	...	...	...	...	...	...	...	...
A95083	80	79	76	75	71	68	65	62	58	54	47	...	...	...	...	...	...	...	...	...	...
A95086	80	79	76	75	71	68	65	62	58	54	47	...	...	...	...	...	...	...	...	...	...
A95456	80	79	76	75	71	68	65	62	58	54	47	...	...	...	...	...	...	...	...	...	...
Copper and Copper Alloys																					
C83600	...	102	101	99	96	94	93	91	89	87	84	81	...	...	...	...	...	...	...	...	...
C92200	...	102	101	99	96	94	93	91	89	87	84	81	...	...	...	...	...	...	...	...	...
C46400	...	110	108	106	103	101	99	97	96	93	90	86	...	...	...	...	...	...	...	...	...
C65500	...	110	108	106	103	101	99	97	96	93	90	86	...	...	...	...	...	...	...	...	...
C95200	...	110	108	106	103	101	99	97	96	93	90	86	...	...	...	...	...	...	...	...	...
C95400	...	110	108	106	103	101	99	97	96	93	90	86	...	...	...	...	...	...	...	...	...
C10200	...	124	122	121	117	114	112	110	108	106	102	98	...	...	...	...	...	...	...	...	...
C11000	...	124	122	121	117	114	112	110	108	106	102	98	...	...	...	...	...	...	...	...	...
C12000	...	124	122	121	117	114	112	110	108	106	102	98	...	...	...	...	...	...	...	...	...
C12200	...	124	122	121	117	114	112	110	108	106	102	98	...	...	...	...	...	...	...	...	...
C12500	...	124	122	121	117	114	112	110	108	106	102	98	...	...	...	...	...	...	...	...	...
C14200	...	124	122	121	117	114	112	110	108	106	102	98	...	...	...	...	...	...	...	...	...
C23000	...	124	122	121	117	114	112	110	108	106	102	98	...	...	...	...	...	...	...	...	...
C61400	...	124	122	121	117	114	112	110	108	106	102	98	...	...	...	...	...	...	...	...	...
C70600	...	131	129	127	124	121	119	117	...	...	...	...	...	...	...	...	...	...	...	...	...
C97600	...	139	137	135	131	128	126	123	...	...	...	...	...	...	...	...	...	...	...	...	...
C71000	...	146	144	142	138	134	132	130	...	...	...	...	...	...	...	...	...	...	...	...	...
C71500	...	161	158	156	152	148	145	143	...	...	...	...	...	...	...	...	...	...	...	...	...
Unalloyed Titanium																					
Grades 1, 2, 3, 7, and 12	...	...	...	...	107	103	101	97	93	88	84	80	75	71	...	...	...	...	...	...	...

Table C-6M Moduli of Elasticity for Metals (SI Units) (Cont'd)

Material	E = Modulus of Elasticity, MPa (Multiply Tabulated Values by 10^3) [Note (1)]																				
	Temperature, °C																				
	−255	**−200**	**−125**	**−75**	**25**	**100**	**150**	**200**	**250**	**300**	**350**	**400**	**450**	**500**	**550**	**600**	**650**	**700**	**750**	**800**	**850**
Zirconium Alloys																					
R60702	...	...	...	...	99	92	87	81	76	71	66	60	...	...	...	...	...	...	...	...	...
R60705	...	...	...	...	94	90	87	84	82	79	76	73	...	...	...	...	...	...	...	...	...

NOTE: (1) These data are for information and it is not to be implied that materials are suitable for all the temperature ranges shown.

Table C-8 Modulus of Elasticity, Nonmetals

Material Description	*E*, ksi (73.4°F)	*E*, MPa (23°C)
Thermoplastics [Note (1)]		
Acetal	410	2 830
ABS, Type 1210	250	1 725
ABS, Type 1316	340	2 345
CAB	120	825
PVC, Type 1120	420	2 895
PVC, Type 1220	410	2 825
PVC, Type 2110	340	2 345
PVC, Type 2116	380	2 620
Chlorinated PVC	420	2 895
Chlorinated polyether	160	1 105
PE2606	100	690
PE2706	100	690
PE3608	125	860
PE3708	125	860
PE3710	125	860
PE4708	130	895
PE4710	130	895
PEX0006	71	440
PEX0008	88	490
Polypropylene	120	825
Poly(vinylidene chloride)	100	690
Poly(vinylidene fluoride)	194	1 340
Poly(tetrafluoroethylene)	57	395
Poly(fluorinated ethylene propylene)	67	460
Poly(perfluoroalkoxy alkane)	100	690
Thermosetting Resins, Axially Reinforced		
Epoxy–glass, centrifugally cast	1,200–1,900	8 275–13 100
Epoxy–glass, filament-wound	1,100–2,000	7 585–13 790
Polyester–glass, centrifugally cast	1,200–1,900	8 275–13 100
Polyester–glass, hand lay-up	800–1,000	5 515–6 895
Other		
Borosilicate glass	9,800	67 570

GENERAL NOTE: For Code references to this Appendix, see para. A319.3.2. These data are for use in the absence of more-applicable data. It is the designer's responsibility to verify that materials are suitable for the intended service at the temperatures shown.

NOTE: (1) The modulus of elasticity data shown for thermoplastics are based on short-term tests. The manufacturer should be consulted to obtain values for use under long-term loading.

APPENDIX D
(20) # FLEXIBILITY AND STRESS INTENSIFICATION FACTORS

DELETED (see ASME B31J)

APPENDIX E REFERENCE STANDARDS

(20)

Standards incorporated in this Code by reference, and the names and addresses of the sponsoring organizations, are shown in this Appendix. It is not practical to refer to a specific edition of each standard throughout the Code text; instead, the specific edition reference dates are shown here. Specific edition reference dates are not provided for ASME codes and standards. For ASME codes and standards, the latest published edition in effect at the time this Code is specified is the specific edition referenced by this Code unless otherwise specified in the engineering design. Subsequent issues and revisions of these referenced standards and any new standards incorporated in the Code by reference will be listed (after review and acceptance by the Code Committee) in revisions of this Appendix E.

A component ordinarily is not marked to indicate the edition date of the standard to which it is manufactured. It is therefore possible that an item taken from inventory was produced in accordance with a superseded edition, or an edition not yet approved by the Code (because it is of later date than that listed and is in use). If compliance with a specific edition is a requirement of the intended service, it usually will be necessary to state the specific requirement in the purchase specification and to maintain identification of the component until it is put in service.

ASTM Specifications

A20-96a
A36/A36M-19
A47/A47M-99 (R2018)$^{\varepsilon1}$
A48/A48M-03 (R2016)

A53/A53M-07

A105/A105M-09
A106/A106M-08
A126-04
A134/A134M-18
A135/A135M-06
A139/A139M-04

A179-90a (R2005)
A181/A181M-06
A182/A182M-17
A193/A193M-10a
A194/A194M-17a
A197/A197M-00 (R2015)

A203/A203M-17
A204/A204M-03 (R2007)
A210/A210M-19
A213-09b
A216/A216M-08
A217/A217M-08
A234/A234M-07
A240/A240M-16a
A249/A249M-16a

ASTM Specifications (Cont'd)

A263-94a
A264-94a
A265-94a
A268/A268M-05
A269-08
A270/A270M-15
A276/A276M-16a
A278/A278M-01 (R2015)
A283/A283M-18

A285/A285M-17
A299/A299M-04

A302/A302M-03 (R2007)
A307-07b
A312/A312M-17
A320/A320M-10
A333/A333M-05
A334/A334M-04a
A335/A335M-06
A350/A350M-07

A351/A351M-16
A352/A352M-06
A353/A353M-04
A354-17$^{\varepsilon1}$
A358/A358M-15
A369/A369M-06
A370-11
A376/A376M-17

ASTM Specifications (Cont'd)

A381/A381M-18
A387/A387M-06a
A395/A395M-99 (R2018)

A403/A403M-16
A409/A409M-15
A420/A420M-07
A426/A426M-08
A437/A437M-10a

A451/A451M-06
A453/A453M-12
A479/A479M-17
A487/A487M-93 (R2007)
A494/A494M-17a

A508/A508M-18
A515/A515M-03 (R2007)
A516/A516M-06
A524-96 (R2005)
A536-84 (R2014)
A537/A537M-08

A553/A553M-06
A563-07a
A571/A571M-01 (R2015)
A587-96 (R2005)

A645/A645M-05
A671/A671M-16
A672-08

ASTM Specifications (Cont'd)

A675/A675M-03 (R2009)
A691-98 (R2007)
A694/A694M-16
A696-90a (R2012)

A707/A707M-14
A723/A723M-18a
A789/A789M-17a
A790/A790M-17

A813/A813M-09
A814/A814M-08
A815/A815M-10a
A860/A860M-14

A928/A928M-11
A992/A992M-11 (R2015)
A995/A995M-13

A1010/A1010M-01 (R2009)
A1011/A1011M-18a
A1053/A1053M-11

B21/B21M-06
B26/B26M-09
B32-08
B42-02$^{\varepsilon 1}$
B43-98 (R2004)

B61-08
B62-09
B68-02/B68M-99 (R2005)
B75-02/B75M-99 (R2005)
B88-03/B88M-05
B96/B96M-11
B98/B98M-08

B127-05
B148-97 (R2009)
B150/B150M-08

B152/B152M-06a$^{\varepsilon 1}$
B160-05 (R2009)
B161-05$^{\varepsilon 1}$
B162-99 (R2005)$^{\varepsilon 1}$
B163-11$^{\varepsilon 2}$
B164-03 (R2008)
B165-05
B166-19
B167-11 (R2016)
B168-11

ASTM Specifications (Cont'd)

B169/B169M-05
B171/B171M-09
B187/B187M-06

B209-07
B210/B210M-19
B211/B211M-19
B221-08
B241/B241M-16
B247-02a

B265-15
B280-08
B283/B283M-14a

B333-03 (R2008)
B335-03 (R2008)
B336-04b
B338-17
B348-13

B361-08
B363-14
B366/B366M-16
B367-13
B371/B371M-08
B381-13

B407-08a (R2014)
B408-06 (R2016)
B409-06 (R2016)
B423-05
B424-05
B425-99 (R2005)
B435-06
B443-00 (R2005)
B444-06
B446-03 (R2008)

B462-18
B463-04
B464-05
B466/B466M-07
B467-88 (R2003)
B474/B474M-15
B491/B491M-06
B493/B493M-14 (R2019)

B514-05 (R2014)
B515-95 (R2014)
B517-05 (R2014)

ASTM Specifications (Cont'd)

B523/B523M-18
B550/B550M-07 (R2019)

B551/B551M-12 (R2017)
B564-15
B572-06 (R2016)
B574-10
B575-10
B581-02 (R2008)
B582-07
B584-08a

B619-10$^{\varepsilon 1}$
B620-03 (R2008)
B621-02 (R2006)
B622-10
B625-05
B626-17a
B649-17

B658/B658M-11 (R2016)
B668-05
B675-02 (R2018)
B688-18
B690-18

B704-03 (R2014)
B705-05 (R2014)
B709-04
B725-05
B729-05
B804-02 (R2007)
B813-10
B828-02
B861-14
B862-14

C14-07
C301-04
C361-08

C582-09
C599-91 (R1995)

D1527-99 (R2005)
D1600-08
D1694-95 (R2000)
D1785-15

D2235-04
D2239-12

ASTM Specifications (Cont'd)

D2241-15
D2282-99$^{\varepsilon1}$
D2321-08
D2464-06
D2466-06
D2467-06
D2468-96a

D2513-09
D2517-06
D2564-04$^{\varepsilon1}$
D2609-02 (R2008)
D2657-07
D2662-96a
D2666-96a
D2672-96a (R2003)
D2683-04
D2737-03

D2837-08
D2846/D2846M-19
D2855-96 (R2002)
D2992-06
D2996-01 (R2007)$^{\varepsilon1}$
D2997-01 (R2007)$^{\varepsilon1}$
D3000-95a

D3035-15
D3139-98 (R2005)
D3261-03

D3517-06
D3754-06
D3839-08
D3840-01 (R2005)

D4024-05
D4161-01 (R2005)

D5421-05
D5685-05
D6041-97 (R2002)

E29-13
E94/E94M-17
E112-13
E114-15
E155-15
E165/E165M-18
E186-15
E213-14$^{\varepsilon1}$

ASTM Specifications (Cont'd)

E272-19
E280-15 (R2019)$^{\varepsilon1}$
E310-15
E446-15
E709-15

F336-02 (R2009)
F437-09
F438-09
F439-09
F441/F441M-15
F442/F442M-13
F493-04
F714-13

F1055-98 (R2006)
F1281-03$^{\varepsilon1}$
F1282-03$^{\varepsilon1}$
F1290-98a (R2004)
F1412-09
F1476-07 (R2013)
F1498-08
F1545-15a
F1548-01 (R2018)
F1673-04
F1970-05
F1974-04
F2389-17a
F2788/F2788M-18
F3125/F3125M-15a

AISC Publication

325-05 (Steel Construction Manual, 2006)

ASCE Standard

ASCE/SEI 7-16

ASME Codes (Use Latest Edition)

ASME Boiler and Pressure Vessel Code
Section I
Section II, Part C
Section II, Part D
Section III, Division 1, Subsection NH
Section V
Section VIII, Division 1
Section VIII, Division 2
Section VIII, Division 3
Section IX

ASME Standards (Use Latest Edition)

A13.1
B1.1
B1.20.1
B1.20.3
B1.20.7

B16.1
B16.3
B16.4
B16.5
B16.9
B16.10
B16.11
B16.14
B16.15
B16.18
B16.20

B16.21
B16.22
B16.24
B16.25
B16.26
B16.34
B16.36
B16.39
B16.42
B16.47
B16.48
B16.50

B18.2.1
B18.2.2
B31P
B18.31.2

B36.10M
B36.19M

B46.1
BPE
PCC-1
PCC-2
PTC 19.3 TW

API Specifications

5B, 2008
5L, 2009
6D, 2014 with Errata 1–9 and Addenda 1–2
15LE, 2008
15LR, 2001

API Standards

526, 2017 with Errata 1
570, 2016 with Errata 1 and Addenda 1-2
594, 2017
599, 2013
600, 2015

602, 2015 with Errata 1
603, 2013
608, 2012
609, 2016 with Errata

API Recommended Practice

RP 941, 8th Ed., 2016 with Errata 1-2

ASQ Standards

9001: 2015
Q9000-2: 1997
Q9000-3: 1997

AWS Standards

A3.0M/A3.0:2020
A5.4/A5.4M:2012
A5.8M/A5.8:2019
A5.9/A5.9M:2017 (ISO 14343:2009 MOD)
A5.11/A5.11M:2018
A5.14/A5.14M:2018
A5.22/A5.22M:2012
A5.31M/A5.31:2012
B4.0:2016
B4.0M:2000 (R2010)
D10.10/D10.10M:1999 (R2009)
QC1:2016-AMD1

AWWA Standards

C110/A21.10-12
C111/A21.11-17
C115/A21.15-11
C150/A21.50-14
C151/A21.51-17
C200-17
C207-18
C208-17

AWWA Standards (Cont'd)

C300-16
C301-14
C302-16
C500-09

C606-15
C900-16
C950-2013 with Errata

CEN Technical Report

CEN/TR 14549:2004

CGA Publication

G-4.1-2009

CSA Publication

Z245.1-2014

EJMA Publication

EJMA Standards, Tenth Edition, 2015

ISO Standard

ISO 15649:2001

MSS Standard Practices

SP-6-2017
SP-9-2018
SP-25-2018
SP-42-2013
SP-43-2013
SP-44-2016 (2017 Reissue)
SP-45-2003 (R2008)
SP-51-2012
SP-53-2012
SP-55-2011
SP-58-2018
SP-65-2012
SP-70-2011
SP-71-2018
SP-72-2010a

MSS Standard Practices (Cont'd)

SP-75-2014
SP-78-2011
SP-79-2018
SP-80-2013
SP-81-2017
SP-83-2018
SP-85-2011
SP-88-2015
SP-93-2014
SP-95-2018
SP-97-2019

SP-105-2016a
SP-106-2019
SP-119-2010
SP-122-2017

NACE Standards and Publications

MR0103-2012
MR0175/ISO 15156-2:2009/Cir.2:2014
MR0175/ISO 15156-3:2009/Cir.4:2014
SP0170-2012
SP0472-2010

NFPA Specifications

54/Z223.1-2018
1963-2014

PFI Standards

ES-7-2013
ES-24-2013
ES-48-2015

PPI Technical Report

TR-21-2001

SAE Standards

J513-1999 (R2019)
J514-2012
J518-1-2013
J518-2-2017

GENERAL NOTE: The issue date shown immediately following the hyphen after the number of the standard (e.g., C207-18 and SP-6-2017) is the effective date of the issue (edition) of the standard. Any additional number shown following the issue date and prefixed by the letter "R" is the latest date of reaffirmation [e.g., B408-06 (R2016)].

Specifications and standards of the following organizations appear in Appendix E:

AISC American Institute of Steel Construction
130 East Randolph Street
Suite 2000
Chicago, Illinois 60601
(312) 670-2400
www.aisc.org

API American Petroleum Institute
Publications and Distribution Section
1220 L Street, NW
Washington, DC 20005-4070
(202) 682-8375
www.api.org

ASCE American Society of Civil Engineers
1801 Alexander Bell Drive
Reston, Virginia 20191
(800) 548-2723
www.asce.org

ASME The American Society of Mechanical Engineers
Two Park Avenue
New York, New York 10016-5990
(800) 843-2763
www.asme.org

ASQ American Society for Quality
P.O. Box 3005
Milwaukee, Wisconsin 53201
(800) 248-1946
www.asq.org

ASTM American Society for Testing and Materials (ASTM International)
100 Barr Harbor Drive
P.O. Box C700
West Conshohocken, Pennsylvania 19428-2959
(610) 832-9585
www.astm.org

AWS American Welding Society
8669 NW 36 Street, No. 130
Miami, Florida 33166
(800) 443-9353
www.aws.org

AWWA American Water Works Association
6666 West Quincy Avenue
Denver, Colorado 80235
(800) 926-7337
www.awwa.org

CEN European Committee for Standardization
Avenue Marnix 17, B-1000
Brussels, Belgium
+32 2 550 08 11
www.cen.eu

CGA Compressed Gas Association, Inc.
14501 George Carter Way, Suite 103
Chantilly, Virginia 20151
(703) 788-2700
www.cganet.com

CSA Canadian Standards Association
178 Rexdale Boulevard
Toronto, Ontario
M9W 1R3, Canada
(416) 747-4044 or (800) 463-6727
www.csagroup.org

EJMA Expansion Joint Manufacturers Association, Inc.
25 North Broadway
Tarrytown, New York 10591
(914) 332-0040
www.ejma.org

ISO International Organization for Standardization
Central Secretariat
Chemin de Blandonnet 8
Case Postale 401
1214 Vernier, Geneva
Switzerland
+41 22 749 01 11
www.iso.org

MSS Manufacturers Standardization Society of the Valve and Fittings Industry, Inc.
127 Park Street, NE
Vienna, Virginia 22180
(703) 281-6613
www.msshq.org

NACE NACE International
15835 Park Ten Place
Houston, Texas 77084-4906
(281) 228-6200
www.nace.org

NFPA National Fire Protection Association
1 Batterymarch Park
Quincy, Massachusetts 02169-7471
(617) 770-3000 or (800) 344-3555
www.nfpa.org

PFI Pipe Fabrication Institute
511 Avenue of the Americas
New York, New York 10011
(514) 634-3434
www.pfi-institute.org

PPI Plastics Pipe Institute
105 Decker Court, Suite 825
Irving, Texas 75062
(469) 499-1044
www.plasticpipe.org

SAE SAE International
400 Commonwealth Drive
Warrendale, Pennsylvania 15096
(724) 776-4841 or (877) 606-7323
www.sae.org

SEMI Semiconductor Equipment and Materials International
3081 Zanker Road
San Jose, California 95134
(408) 943-6900
www.semi.org

GENERAL NOTE TO LIST OF ORGANIZATIONS: Some of the organizations listed above publish standards that have been approved as American National Standards. Copies of these standards may also be obtained from:

ANSI	American National Standards Institute 25 West 43rd Street New York, New York 10036 (212) 642-4900 www.ansi.org

APPENDIX F
GUIDANCE AND PRECAUTIONARY CONSIDERATIONS

F300 GENERAL

This Appendix provides guidance and precautionary considerations relating to particular fluid services and piping applications. These are not Code requirements but should be taken into account as applicable in the engineering design. Further information on these subjects can be found in the literature.

F300.1 Piping That Has Been Placed in Service

Examples of industry standards that address piping that has been placed in service are ASME PCC-2, Repair of Pressure Equipment and Piping, and API 570, Piping Inspection Code: In-service Inspection, Rating, Repair, and Alteration of Piping Systems.

(20) **F300.1.5 Rounding.** The following are examples of rounding in accordance with para. 300.1.5:

(a) If the requirement were 6 mm maximum, a measured value of 6.2 mm would be acceptable because the measured value would first be rounded to 6 mm before comparing it to the requirement.

(b) If the requirement were 6.0 mm maximum, a measured value of 6.2 mm would not meet the requirement.

(c) The basic allowable stress at temperature from Appendix A is 19.0 ksi. A calculated stress due to sustained loads of 19,049 psi would be acceptable because the calculated value would first be rounded to 19.0 ksi before comparing it to the requirement.

F301 DESIGN CONDITIONS

Selection of pressures, temperatures, forces, and other conditions that may apply to the design of piping can be influenced by unusual requirements that should be considered when applicable. These include but are not limited to the following.

F301.4 Ambient Effects

Where fluids can be trapped (e.g., in double seated valves) and subjected to heating and consequent expansion, means of pressure relief should be considered to avoid excessive pressure buildup.

F301.5 Dynamic Effects

F301.5.1 Impact

(a) Impact caused by unsteady fluid flow is possible when condensation occurs inside piping normally handling a gas such as steam. Means should be considered to provide drainage of condensate from low areas to avoid damage from hydraulic shock or liquid slugging that may result from the presence of the condensate.

(b) Geysering is an effect that can occur in piping handling fluids at or near their boiling temperatures under conditions when rapid evolution of vapor within the piping causes rapid expulsion of liquid. In such cases, a pressure surge can be generated that may be destructive to the piping. Geysering usually is associated with vertical pipelines but may occur in inclined lines under certain conditions.

F301.7 Thermal Expansion and Contraction Effects

bowing during cooldown : an effect that can occur, usually in horizontal piping, on introduction of a fluid at or near its boiling temperature and at a flow rate that allows stratified two-phase flow, causing large circumferential temperature gradients and possibly unacceptable stresses at anchors, supports, guides, and within pipe walls. (Two-phase flow can also generate excessive pressure oscillations and surges that may damage the piping.)

F301.10 Cyclic Effects

F301.10.1 Pressure Cycling. The rules in para. K304.8 may be considered where fatigue due to pressure cycling is a concern.

F301.10.2 Fatigue at Mixing Points. Consideration (20)
should be given to the potential for fatigue on surfaces exposed to cyclic thermal gradients and pressure variations resulting from chemically thermic reactions or physical mixing of widely differing temperature streams.

F301.10.3 Severe Cyclic Conditions. Designating piping as being under severe cyclic conditions should be considered when piping is subjected to both a high stress range and many cycles. The phrase *many cycles* can be taken as when the stress range factor, f, is less than the maximum, f_m. The phrase *high stress range* is normally taken as when the calculated stress range approaches the allowable stress range. Examples include piping associated with batch chemical reactors that cycle more frequently than once a day and piping that has a reasonable likelihood of vibrating.

Frequently, failures occur at small branch connections attached to main piping runs that do not have a high stress range. When experience shows that these small branch connections might be vulnerable to fatigue failure, consideration should be given to designating such piping as being under severe cyclic conditions. See the following references for guidance on the design of small branch connections to avoid fatigue failure:

(a) Guidelines for the Avoidance of Vibration Induced Fatigue Failure in Process Pipework, published by Energy Institute

(b) Design Guideline for Small Diameter Branch Connections, published jointly by Gas Machinery Research Council, Pipeline Research Council International, and Southwest Research Institute

More-conservative approaches to designating piping as being under severe cyclic conditions should be taken when the fluid handled is toxic, flammable, or damaging to human tissue; when failure of the piping would be costly; and also when examination of the piping during operation or normal outages is impracticable.

(20) F302 DESIGN CRITERIA

F302.2 Pressure–Temperature Design Criteria

F302.2.4 Allowances for Pressure and Temperature Variations. Consideration should be given to the occasional variations in pressure and temperature resulting from the mixing of fluids during which an exothermic reaction occurs.

F304 PRESSURE DESIGN

F304.7 Pressure Design of Other Metallic Components

F304.7.4 Expansion Joints. The following are specific considerations to be evaluated by the designer when specifying expansion joint requirements, in addition to the guidelines given in EJMA Standards:

(a) susceptibility to stress corrosion cracking of the materials of construction, considering specific alloy content, method of manufacture, and final heat treated condition.

(b) consideration of not only the properties of the flowing medium but also the environment external to the expansion joint and the possibility of condensation or ice formation due to the operation of the bellows at a reduced temperature.

(c) consideration of specifying a minimum bellows or ply thickness. The designer is cautioned that requiring excessive bellows thickness may reduce the fatigue life of the expansion joint and increase end reactions.

(d) accessibility of the expansion joint for maintenance and inspection.

(e) need for leak tightness criteria for mechanical seals on slip type joints.

(f) specification of installation procedures and shipping or preset bars so that the expansion joint will not be extended, compressed, or offset to compensate for improper alignment of piping, other than the intentional offset specified by the piping designer.

(g) need to request data from the expansion joint manufacturer, including

(1) effective thrust area

(2) lateral, axial, and rotational stiffness (spring constant)

(3) calculated design cycle life under specified design conditions

(4) friction force in hinges, tie rods, etc.

(5) installed length and weight

(6) requirements for additional support or restraint in the piping

(7) expansion joint elements that are designed to be uninsulated during operation

(8) certification of pressure containing and/or restraining materials of construction

(9) maximum test pressure

(10) design calculations

F307 VALVES

(a) Extended bonnet valves are recommended where necessary to establish a temperature differential between the valve stem packing and the fluid in the piping, to avoid packing leakage and external icing or other heat flux problems. The valve should be positioned to provide this temperature differential. Consideration should be given to possible packing shrinkage in low temperature fluid service.

(b) The effect of external loads on valve operability and leak tightness should be considered.

F308 FLANGES AND GASKETS

F308.2 Specific Flanges

Slip-On Flanges. The need for venting the space between the welds in double-welded slip-on flanges should be considered for fluid services (including vacuum) that require leak testing of the inner fillet weld, or when fluid handled can diffuse into the enclosed space, resulting in possible failure.

F308.4 Gaskets

Materials should be selected such that they are suitable for all of the expected service conditions. The following are some specific considerations:

(a) Gasket materials not subject to cold flow should be considered for use with raised-face flanges for fluid services at elevated pressures with temperatures significantly above or below ambient.

(b) Use of full-face gaskets with flat-faced flanges should be considered when using gasket materials subject to cold flow for low pressure and vacuum services at moderate temperatures. When such gasket materials are used in other fluid services, the use of tongue-and-groove or other gasket-confining flange facings should be considered.

(c) The effect of flange facing finish should be considered in gasket material selection.

F309 BOLTING

F309.1 General

The use of controlled bolting procedures should be considered in high, low, and cycling temperature services, and under conditions involving vibration or fatigue, to reduce

(a) the potential for joint leakage due to differential thermal expansion

(b) the possibility of stress relaxation and loss of bolt tension

F312 FLANGED JOINTS

F312.1 General

Three distinct elements of a flanged joint must act together to provide a leak-free joint — the flanges, the gasket, and the bolting. Factors that affect performance include the following:

(a) *Selection and Design*

(1) consideration of service conditions (including external loads, bending moments, and application of thermal insulation)

(2) flange rating, type, material, facing, and facing finish (see para. F308.2)

(3) gasket type, material, thickness, and design (see para. F308.4)

(4) bolt material, strength (cold and at temperature), and specifications for tightening of bolts (see para. F309.1)

(5) design for access to the joint

(b) *Installation.* See para. 335.2.5.

(1) condition of flange mating surfaces

(2) joint alignment and gasket placement before bolt-up

(3) implementation of specified bolting procedures

F321 PIPING SUPPORT

F321.4 Wear of Piping at Support Points

The use of pads or other means of pipe attachment at support points should be considered for piping systems subject to wear and pipe wall metal loss from relative movement between the pipe and its supports (e.g., from wave action on offshore production applications).

F322 DESIGN CONSIDERATIONS FOR SPECIFIC SYSTEMS

F322.6 Pressure Relief Piping

Stop Valves in Pressure Relief Piping. If stop valves are located in pressure relief piping in accordance with para. 322.6.1(a), and if any of these stop valves are to be closed while the equipment is in operation, an authorized person should be present. The authorized person should remain in attendance at a location where the operating pressure can be observed and should have access to means for relieving the system pressure in the event of overpressure. Before leaving the station, the authorized person should lock or seal the stop valves in the open position.

F323 MATERIALS (20)

(a) Selection of materials to resist deterioration in service is not within the scope of this Code. However, suitable materials should be specified or selected for use in piping and associated facilities not covered by this Code but that affect the safety of the piping. Consideration should be given to allowances made for temperature and pressure effects of process reactions, for properties of reaction or decomposition products, and for hazards from instability of contained fluids. Consideration should be given to the use of cladding, lining, or other protective materials to reduce the effects of corrosion, erosion, and abrasion.

(b) Information on material performance can be found in ASME BPVC, Section II, Part D, Nonmandatory Appendix A.

F323.1 General Considerations

The following are some general considerations that should be evaluated when selecting and applying materials in piping (see also para. FA323.4):

(a) the possibility of exposure of the piping to fire and the melting point, degradation temperature, loss of strength at elevated temperature, and combustibility of the piping material under such exposure

(b) the susceptibility to brittle failure or failure from thermal shock of the piping material when exposed to fire or to fire-fighting measures, and possible hazards from fragmentation of the material in the event of failure

(c) the ability of thermal insulation to protect piping against failure under fire exposure (e.g., its stability, fire resistance, and ability to remain in place during a fire)

(d) the susceptibility of the piping material to crevice corrosion under backing rings, in threaded joints, in socket welded joints, and in other stagnant, confined areas

(e) the possibility of adverse electrolytic effects if the metal is subject to contact with a dissimilar metal

(f) the compatibility of lubricants or sealants used on threads with the fluid service

(g) the compatibility of packing, seals, and O-rings with the fluid service

(h) the compatibility of materials, such as cements, solvents, solders, and brazing materials, with the fluid service

(i) the chilling effect of sudden loss of pressure on highly volatile fluids as a factor in determining the lowest expected service temperature

(j) the possibility of pipe support failure resulting from exposure to low temperatures (which may embrittle the supports) or high temperatures (which may weaken them)

(k) the compatibility of materials, including sealants, gaskets, lubricants, and insulation, used in strong oxidizer fluid service (e.g., oxygen or fluorine)

(l) the possibility of adverse effects from microbiologically influenced corrosion (MIC) or its remediation

F323.2 Temperature Limitations

F323.2.2 Lower Temperature Limits. Regarding materials considered for use at a lower exemption temperature without impact testing using para. 323.2.2(h) or 323.2.2(i), the simplified rules of para. 323.2.2 should not be used for piping systems that are anticipated to experience shock loading or thermal bowing, or if they contain welds between dissimilar materials, especially welds between austenitic and ferritic materials. More rigorous means of testing or analysis should be used for such piping systems. For example, the additional stress due to circumferential shear near a dissimilar weld due to differential thermal contraction and its effect on the combined stress should be determined.

The modulus of elasticity for the condition under consideration should be used when evaluating the reactions.

Cold springing or misalignment can result in significant stresses in the ambient condition. The designer is responsible for ensuring that such stresses are accounted for before any credit is taken for reduction in minimum design temperature without impact testing.

F323.4 Specific Material Considerations — Metals

The following are some specific considerations that should be evaluated when applying certain metals in piping:

(a) Cast Irons — Gray, Malleable, and High Silicon (14.5%). Their lack of ductility and their sensitivity to thermal and mechanical shock.

(b) Carbon Steel, and Low and Intermediate Alloy Steels

(1) the possibility of embrittlement when handling alkaline or strong caustic fluids

(2) the possible conversion of carbides to graphite during long time exposure to temperatures above 427°C (800°F) of carbon steels, plain nickel steel, carbon-manganese steel, manganese-vanadium steel, and carbon-silicon steel

(3) the possible conversion of carbides to graphite during long time exposure to temperatures above 468°C (875°F) of carbon-molybdenum steel, manganese-molybdenum-vanadium steel, and chromium-vanadium steel

(4) the advantages of silicon-killed carbon steel (0.1% silicon minimum) for temperatures above 482°C (900°F)

(5) the possibility of damage due to hydrogen exposure at elevated temperature (see API RP 941); hydrogen damage (blistering) may occur at lower temperatures under exposure to aqueous acid solutions[1]

(6) the possibility of stress corrosion cracking when exposed to cyanides, acids, acid salts, or wet hydrogen sulfide; a maximum hardness limit is usually specified (see NACE MR0175/ISO 15156-2 or MR0103 and SP0472)[1]

(7) the possibility of sulfidation in the presence of hydrogen sulfide at elevated temperatures

(c) High Alloy (Stainless) Steels

(1) the possibility of stress corrosion cracking of austenitic stainless steels exposed to media such as chlorides and other halides either internally or externally; the latter can result from improper selection or application of thermal insulation, or from use of marking inks, paints, labels, tapes, adhesives, and other accessory materials containing chlorides or other halides (see NACE MR0175/ISO 15156-3)[1]

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[1] Titles of referenced documents are

API RP 941, Steels for Hydrogen Service at Elevated Temperatures and Pressures in Petroleum Refineries and Petrochemical Plants

NACE MR0103, Materials Resistant to Sulfide Stress Cracking in Corrosive Petroleum Refining Environments

NACE MR0175/ISO 15156-2, Petroleum and natural gas industries — Materials for use in H_2S-containing environments in oil and gas production — Part 2: Cracking-resistant carbon and low alloy steels, and the use of cast irons

NACE MR0175/ISO 15156-3, Petroleum and natural gas industries — Materials for use in H_2S-containing environments in oil and gas production — Part 3: Cracking-resistant CRAs (corrosion-resistant alloys) and other alloys

NACE SP0472, Methods and Controls to Prevent In-Service Environmental Cracking of Carbon Steel Weldments in Corrosive Petroleum Refining Environments

NACE SP0170, Protection of Austenitic Stainless Steels and Other Austenitic Alloys from Polythionic Acid Stress Corrosion Cracking During a Shutdown of Refinery Equipment

(2) the susceptibility to intergranular corrosion of austenitic stainless steels sensitized by exposure to temperatures between 427°C and 871°C (800°F and 1,600°F); as an example, stress corrosion cracking of sensitized metal at room temperature by polythionic acid (reaction of oxidizable sulfur compound, water, and air); stabilized or low carbon grades may provide improved resistance (see NACE SP0170)[1]

(3) the susceptibility to intercrystalline attack of austenitic stainless steels on contact with liquid metals (including aluminum, antimony, bismuth, cadmium, gallium, lead, magnesium, tin, and zinc) or their compounds

(4) the brittleness of ferritic and martensitic stainless steels at room temperature after service at temperature above 371°C (700°F)

(d) Nickel and Nickel Base Alloys

(1) the susceptibility to grain boundary attack of nickel and nickel base alloys not containing chromium when exposed to small quantities of sulfur at temperatures above 316°C (600°F)

(2) the susceptibility to grain boundary attack of nickel base alloys containing chromium at temperatures above 593°C (1,100°F) under reducing conditions and above 760°C (1,400°F) under oxidizing conditions

(3) the possibility of stress corrosion cracking of nickel-copper Alloy 400 in hydrofluoric acid vapor in the presence of air, if the alloy is highly stressed (including residual stresses from forming or welding)

(e) Aluminum and Aluminum Alloys

(1) the compatibility with aluminum of thread compounds used in aluminum threaded joints to prevent seizing and galling

(2) the possibility of corrosion from concrete, mortar, lime, plaster, or other alkaline materials used in buildings or structures

(3) the susceptibility of Alloy Nos. 5083, 5086, 5154, and 5456 to exfoliation or intergranular attack; and the upper temperature limit of 66°C (150°F) shown in Appendix A to avoid such deterioration

(f) Copper and Copper Alloys

(1) the possibility of dezincification of brass alloys

(2) the susceptibility to stress-corrosion cracking of copper-based alloys exposed to fluids such as ammonia or ammonium compounds

(3) the possibility of unstable acetylide formation when exposed to acetylene

(g) Titanium and Titanium Alloys. The possibility of deterioration of titanium and its alloys above 316°C (600°F).

(h) Zirconium and Zirconium Alloys. The possibility of deterioration of zirconium and zirconium alloys above 316°C (600°F).

(i) Tantalum. Above 299°C (570°F), the possibility of reactivity of tantalum with all gases except the inert gases. Below 299°C, the possibility of embrittlement of tantalum by nascent (monatomic) hydrogen (but not molecular hydrogen). Nascent hydrogen is produced by galvanic action, or as a product of corrosion by certain chemicals.

(j) Metals With Enhanced Properties. The possible loss of strength, in a material whose properties have been enhanced by heat treatment, during long-continued exposure to temperatures above its tempering temperature.

(k) The desirability of specifying some degree of production impact testing, in addition to the weld procedure qualification tests, when using materials with limited low temperature service experience below the minimum temperature stated in Table A-1 or Table A-1M.

F331 HEAT TREATMENT

F331.1 Heat Treatment Considerations (20)

Heat treatment temperatures listed in Table 331.1.1 for some materials may be higher than the minimum tempering temperatures specified in the ASTM specifications for the base material. For higher-strength normalized and tempered materials, there is consequently a possibility of reducing tensile properties of the base material, particularly if long holding times at the higher temperatures are used.

F335 ASSEMBLY AND ERECTION

F335.9 Cleaning of Piping

The following are some general considerations that may be evaluated in determining the need for cleaning of piping:

(a) requirements of the service, including possible contaminants and corrosion products during fabrication, assembly, storage, erection, and testing.

(b) for low temperature service, removal of moisture, oil, grease, and other contaminants to prevent sticking of valves or blockage of piping and small cavities.

(c) for strong oxidizer fluid service (e.g., oxygen or fluorine), special cleaning and inspection. Reference may be made to the Compressed Gas Association's Pamphlet G-4.1 Cleaning Equipment for Oxygen Service.

(d) purging, flushing, or blowing down unwanted dirt, debris, and residual fluid from the inside of a piping system should be performed with caution and control. It is left to the discretion, knowledge, and responsibility of the owner or designer as to the degree of caution and control necessary for a safe work environment. The fluid selected for the purpose of purging, flushing, or blowing down shall preferably be inert. However, for cases in which the use of a flammable or toxic fluid is unavoidable, e.g., when displacing residual testing or flushing fluid with the service fluid, the implementation of additional precautionary considerations may be necessary. Those precautionary considerations should include

(1) the discharge of liquids to a safe collection point

(2) the discharge of flammable liquids away from ignition sources and personnel

(3) venting of gases to a safe outdoor location

(4) venting of flammable gases away from ignition sources and personnel

(5) further protection of personnel via controlled access of the work area, including perimeter warning signs for personnel not involved in the purging process

(6) for precautionary requirements and recommendations regarding the displacement of flushing and testing fluids using a flammable gas, refer to ANSI Z223.1/NFPA 54, National Fuel Gas Code

F335.10 Identification of Piping

Consideration should be given to identifying the contents of piping, with special consideration given to piping conveying flammable, hazardous, or fire-quenching fluids. Reference may be made to ASME A13.1, Scheme for the Identification of Piping Systems.

F345 TESTING

F345.2.3 Special Provisions for Testing. When piping subassemblies are tested separately, consideration should be given to performing an additional leak test of the assembled piping system prior to initial operation. The test fluid should be nonhazardous to the process and the people performing the examination. Examination for leaks should be at all joints that have not been previously examined for leaks, or that have been reassembled after being examined for leaks. Examples include flanges where isolation blanks were removed after the leak test and joints where instrumentation or other components were removed for the leak test.

F345.4 Hydrostatic Leak Test

F345.4.1 Test Fluid. Consideration should be given to susceptibility to microbiologically influenced corrosion (MIC). This condition is especially prevalent in no-flow, high-moisture environments. Internal MIC may also depend on the characteristics of the treated or untreated test fluid.

Internal MIC may be lessened or possibly eliminated by properly draining and drying systems and/or by proper selection of test fluid.

F345.5 Pneumatic Leak Test

F345.5.1 Precautions. Consideration should be given to the risk associated with the release of stored energy and to the establishment of the minimum safe distance between personnel and the equipment being tested. Equations and considerations are available in ASME PCC-2, Repair of Pressure Equipment and Piping, Article 5.1.

FA323 MATERIALS

FA323.4 Material Considerations — Nonmetals

The following are some considerations to be evaluated when applying nonmetals in piping. See also paras. F323 and F323.1.

(a) *Static Charges.* Because of the possibility of producing hazardous electrostatic charges in nonmetallic piping and metallic piping lined with nonmetals, consideration should be given to grounding such systems conveying nonconductive fluids.

(b) *Compressed Gases.* If nonmetallic piping is used above ground for compressed air or other compressed gases, special precautions should be observed. In determining the needed safeguarding for such services, the energetics and the specific failure mechanism need to be evaluated. Encasement of the plastic piping in shatter-resistant material may be considered.

(c) *Brittle Piping.* If borosilicate glass or other brittle piping material is used, take into account its lack of ductility and its sensitivity to thermal and mechanical shock.

FA328 BONDING OF PLASTICS (20)

FA328.2 Bonding Qualifications

FA328.2.1 Qualification Requirements. Nonmetallic piping joined using a solvent-cement joining method should follow the manufacturer's recommended cure time. Solvent cement manufacturers specify these cure times by taking into account pipe material, solvent cement type, pipe size, temperature, and humidity.

FK300 GENERAL STATEMENTS

The rules in Chapter IX provide an alternative to those in Chapters I through VI. They include special considerations for thick-walled piping components such as the theory of failure and the approaches to fatigue and thermal stresses, generally resulting in lower design factors with respect to burst strength than the base Code. Chapter IX rules may allow thinner piping components than the base Code, resulting in lower piping weight, balanced against increased requirements for material testing, fatigue analysis, fabrication, and examination. Although High Pressure Fluid Service is often considered to be service exceeding that allowed by the ASME B16.5, Class 2500 pressure–temperature rating for a particular material group, there are no pressure limitations for the application of these rules. The decision by an owner to specify High Pressure Fluid Service is based on the economic, technical, and other issues pertaining to the piping.

FU315 HYGIENIC CLAMP JOINTS

To lower the probability of leaks in piping that is subject to transient temperature and pressure fluctuations, consider the use of a two-bolt clamp to increase clamping force in lieu of a hinged clamp for those processes that require

(a) passivation
(b) clean-in-place (CIP)
(c) steam- (or sterilize-) in-place (SIP)

APPENDIX G
SAFEGUARDING

G300 SCOPE

(a) Safeguarding is the provision of protective measures to minimize the risk of accidental damage to the piping or to minimize the harmful consequences of possible piping failure.

(b) In most instances, the safeguarding inherent in the facility (the piping, the plant layout, and its operating practices) is sufficient without need for additional safeguarding. In some instances, however, engineered safeguards must be provided.

(c) Appendix G outlines some considerations pertaining to the selection and utilization of safeguarding. Where safeguarding is required by the Code, it is necessary to consider only the safeguarding that will be suitable and effective for the purposes and functions stated in the Code or evident from the designer's analysis of the application.

G300.1 General Considerations

In evaluating a piping installation design to determine what safeguarding may exist or is necessary, the following should be reviewed:

(a) the hazardous properties of the fluid, considered under the most severe combination of temperature, pressure, and composition in the range of expected operating conditions.

(b) the quantity of fluid that could be released by piping failure, considered in relation to the environment, recognizing the possible hazards ranging from large releases of otherwise innocuous fluids to small leakages of toxic fluids.

(c) expected conditions in the environment, evaluated for their possible effect on the hazards caused by a possible piping failure. This includes consideration of ambient or surface temperature extremes, degree of ventilation, proximity of fired equipment, etc.

(d) the probable extent of operating, maintenance, and other personnel exposure, as well as reasonably probable sources of damage to the piping from direct or indirect causes.

(e) the probable need for grounding of static charges to prevent ignition of flammable vapors.

(f) the safety inherent in the piping by virtue of materials of construction, methods of joining, and history of service reliability.

G300.2 Safeguarding by Plant Layout and Operation

Representative features of plant layout and operation that may be evaluated and selectively utilized as safeguarding include

(a) plant layout features, such as open-air process equipment structures; spacing and isolation of hazardous areas; slope and drainage; buffer areas between plant operations and populated communities; or control over plant access

(b) protective installations, such as fire protection systems; barricades or shields; ventilation to remove corrosive or flammable vapors; instruments for remote monitoring and control; containment and/or recovery facilities; or facilities (e.g., incinerators) for emergency disposal of hazardous materials

(c) operating practices, such as restricted access to processing areas; work permit system for hazardous work; or special training for operating, maintenance, and emergency crews

(d) means for safe discharge of fluids released during pressure relief device operation, blowdown, cleanout, etc.

(e) procedures for startup, shutdown, and management of operating conditions, such as gradual pressurization or depressurization, and gradual warmup or cooldown, to minimize the possibility of piping failure, e.g., brittle fracture

G300.3 Engineered Safeguards

Engineered safeguards that may be evaluated and selectively applied to provide added safeguarding include

(a) means to protect piping against possible failures, such as

(1) thermal insulation, shields, or process controls to protect from excessively high or low temperature and thermal shock

(2) armor, guards, barricades, or other protection from mechanical abuse

(3) damping or stabilization of process or fluid flow dynamics to eliminate or to minimize or protect against destructive loads (e.g., severe vibration pulsations, cyclic operating conditions)

(b) means to protect people and property against harmful consequences of possible piping failure, such as confining and safely disposing of escaped fluid by

shields for flanged joints, valve bonnets, gages, or sight glasses; or for the entire piping system if of frangible material; limiting the quantity or rate of fluid escaping by automatic shutoff or excess flow valves, additional block valves, flow-limiting orifices, or automatic shutdown of pressure source; limiting the quantity of fluid in process at any time, where feasible

APPENDIX H
SAMPLE CALCULATIONS FOR BRANCH REINFORCEMENT

H300 INTRODUCTION (SI UNITS)

The following examples are intended to illustrate the application of the rules and definitions in para. 304.3.3 for welded branch connections.

(20) H301 EXAMPLE 1

A DN 200 (NPS 8) run (header) in an oil piping system has a DN 100 (NPS 4) branch at right angles (see Figure H301). Both pipes are Schedule 40 API 5L Grade A seamless. The design conditions are 2 068 kPa at 200°C. The fillet welds at the crotch are minimum size in accordance with para. 328.5.4. A corrosion allowance of 2.5 mm is specified. Is additional reinforcement necessary?

Solution

From Appendix A, Table A-1M, S = 110 MPa for API 5L Grade A; from Table A-1B, E = 1.0 for API 5L seamless; W = 1.0.

$$T_h = (8.18)(0.875) = 7.16 \text{ mm}$$

$$T_b = (6.02)(0.875) = 5.27 \text{ mm}$$

$$\begin{aligned} L_4 &= (2.5)(7.16 - 2.5) = 11.65 \text{ mm} \\ &\quad \text{or } (2.5)(5.27 - 2.5) = 6.93 \text{ mm, whichever is less} \\ &= 6.93 \text{ mm} \end{aligned}$$

$$d_1 = [114.3 - (2)(5.27 - 2.5)]/(\sin 90) \text{ deg} = 108.8 \text{ mm}$$

$$\begin{aligned} d_2 &= (5.27 - 2.5) + (7.16 - 2.5) + 109/2 \\ &= 61.9 \text{ mm} \end{aligned}$$

Use d_1 or d_2, whichever is greater.

$$d_1 = 108.8 \text{ mm}$$

$$t_h = \frac{(2\,068)(219.1)}{(2)(110,000)(1.0)(1.00) + (2)(0.4)(2\,068)} = 2.04 \text{ mm}$$

$$t_b = \frac{(2\,068)(114.3)}{(2)(110,000)(1.0)(1.00) + (2)(0.4)(2\,068)} = 1.07 \text{ mm}$$

$$\begin{aligned} t_c &= (0.7)(6.02) = 4.21 \text{ mm, or 6 mm, whichever is less} \\ &= 4.21 \text{ mm} \end{aligned}$$

Minimum leg dimension of fillet weld

$$4.21/0.707 = 6.0 \text{ mm}$$

Thus, the required area

$$A_1 = (2.04)(108.8)(2 - \sin 90 \text{ deg}) = 222 \text{ mm}^2$$

The reinforcement area in run wall

$$A_2 = (108.8)(7.16 - 2.04 - 2.5) = 285 \text{ mm}^2$$

in branch wall

$$A_3 = (2)(6.93)[(5.27 - 1.07) - 2.5] = 24 \text{ mm}^2$$

in branch welds

$$A_4 = (2)\left(\tfrac{1}{2}\right)(6.0)^2 = 36 \text{ mm}^2$$

The total reinforcement area = 345 mm^2. This is more than the 222 mm^2 so that no additional reinforcement is required to sustain the internal pressure.

H302 EXAMPLE 2 (20)

There is a DN 200 (NPS 8) branch at right angles to a DN 300 (NPS 12) header (Figure H301). Both run and branch are of aluminum alloy Schedule 80 ASTM B241 6061-T6 seamless pipe. The connection is reinforced by a ring 350 mm O.D. (measured along the run) cut from a piece of DN 300 (NPS 12) Schedule 80 ASTM B241 6063-T6 seamless pipe and opened slightly to fit over the run pipe. Allowable stresses for welded construction apply in accordance with Appendix A, Note (33). The fillet welds have the minimum dimensions permitted in para. 328.5.4. A zero corrosion allowance is specified. What is the maximum permissible design pressure if the design temperature is −195°C?

Solution

From Appendix A, Table A-1M, S = 55.2 MPa for Grade 6061-T6 (welded) pipe and S = 39.3 MPa for Grade 6063-T6 (welded) pad, both at −195°C. From Table A-1B, E = 1.0 for ASTM B241; W = 1.0.

Leg dimensions of welds to the branch

$$\begin{aligned} t_c &= \text{lesser of } 0.7\overline{T}_b \text{ or } 6\text{ mm} \\ &= 6\text{ mm} \end{aligned}$$

$$\frac{12.7}{0.707} \text{ or } \frac{6}{0.707} = 8.5\text{ mm}$$

and to the reinforcing pad

$$\frac{0.5\overline{T}_r}{0.707} = \frac{(0.5)(17.48)}{0.707} = 12.36\text{ mm}$$

$$T_h = (17.48)(0.875) = 15.3\text{ mm}$$

$$T_b = (12.7)(0.875) = 11.1\text{ mm}$$

$$T_r = (17.48)(0.875) = 15.3\text{ mm}$$

$$L_4 = (2.5)(15.3 - 0.0) = 38.25\text{ mm}$$

[This is smaller than (2.5)(11.1 – 0) + 15.3 = 43.05 mm]

$$d_1 = 219.1 - (2)(11.1 - 0) = 197\text{ mm}$$

$$d_2 = d_1 \text{ because this is greater than } T_b + T_c + d_1/2$$

$$t_h = \frac{323.8P}{(2)(55\,200)(1.0)(1.0) + (2)(0.4)P}$$

$$t_b = \frac{219.1P}{(2)(55\,200)(1.0)(1.0) + (2)(0.4)P}$$

Using the symbol

$$q = \frac{P}{110{,}400 + 0.8P}$$

we can briefly write

$$t_h = 323.8q \text{ and } t_b = 219.1q$$

The required area

$$A_1 = 197t_h = 63\,789q$$

The reinforcement area in the run wall

$$\begin{aligned} A_2 &= (197)(15.3 - 323.8q - 0) \\ &= 3\,014 - 63\,789q \end{aligned}$$

in branch wall

$$\begin{aligned} A_3 &= (2)(38.25)(11.1 - 219.1q - 0) \\ &= 849 - 16\,761q \end{aligned}$$

in reinforcing ring

$$A_4 = (15.3)(350 - 219.1)(39\,300/55\,200) = 1\,426\text{ mm}^2$$

in fillet welds

$$A_4 = (2)\left(1/2\right)(8.5)^2 + (2)\left(1/2\right)(12.36)^2 = 225\text{ mm}^2$$

The total reinforcement area = 5 514 – 80 550q.

At the maximum permissible normal operating pressure, the required area and the reinforcement area are equal; thus

$$\begin{aligned} 63\,789q &= 5\,514 - 80\,550q \\ 144\,339q &= 5\,514 \\ q &= 0.0382 \end{aligned}$$

But also

$$q = \frac{P}{110\,400 + 0.8P}$$

Thus

$$\begin{aligned} P &= (0.0382)(110\,400 + 0.8P) = 4\,217 + 0.03P \\ 0.97P &= 4\,217 \\ P &= 4\,347\text{ kPa} \end{aligned}$$

H303 EXAMPLE 3 (20)

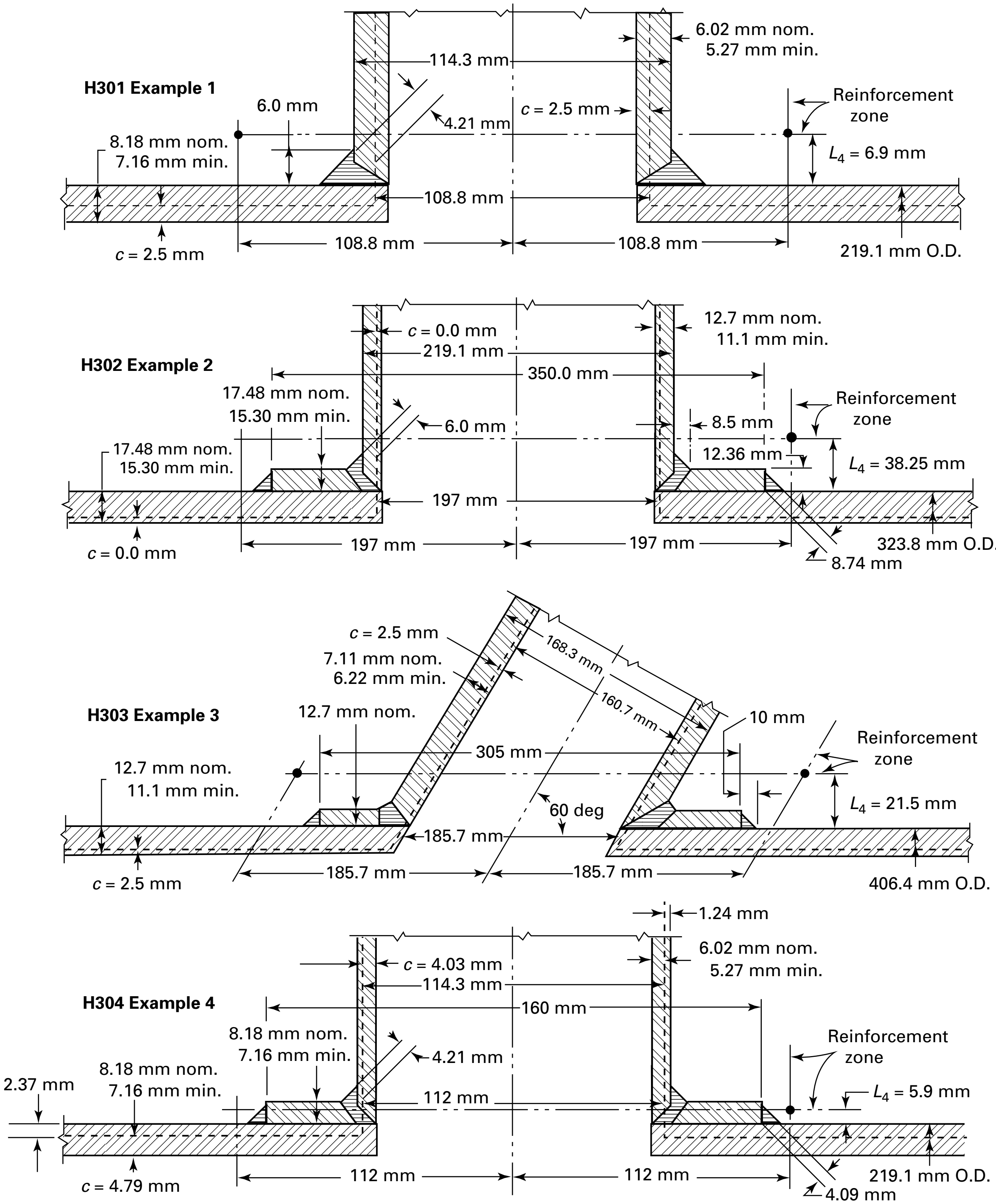
A DN 150 (NPS 6) Schedule 40 branch has its axis at a 60 deg angle to the axis of a DN 400 (NPS 16) Schedule 40 run (header) in an oil piping system (Figure H301). Both pipes are API 5L Grade A seamless. The connection is reinforced with a ring 305 mm O.D. (measured along the run) made from 12.7 mm ASTM A285 Grade C plate. All fillet welds are equivalent to 45 deg fillet welds with 10 mm legs. Corrosion allowance = 2.5 mm. The design pressure is 3 450 kPa at 370°C. Is the design adequate for the internal pressure?

Solution

From Appendix A, Table A-1M, S = 99.3 MPa for API 5L Grade A and ASTM A285 Grade C; from Table A-1B, E = 1.0 for API 5L seamless pipe; W = 1.0.

$$T_h = (12.7)(0.875) = 11.1\text{ mm}$$

Figure H301 Illustrations for SI Units Examples in Appendix H



$$T_b = (7.11)(0.875) = 6.22 \text{ mm}$$

$$T_r = 12.7 \text{ mm}$$

$$\begin{aligned} L_4 &= \text{lesser of } (2.5)(6.22 - 2.5) + 12.7 = 22 \text{ mm} \\ &\quad \text{or } (2.5)(11.1 - 2.5) = 21.5 \text{ mm} \\ &= 21.5 \text{ mm} \end{aligned}$$

$$t_h = \frac{(3\,450)(406.4)}{(2)(99\,300)(1.0)(1.0) + (2)(0.4)(3\,450)} = 6.96 \text{ mm}$$

$$t_b = \frac{(3\,450)(168.3)}{(2)(99\,300)(1.0)(1.0) + (2)(0.4)(3\,450)} = 2.88 \text{ mm}$$

$$d_1 = d_2 = \frac{168.3 - (2)(6.22 - 2.5)}{\sin 60 \text{ deg}} = \frac{160.9}{0.866} = 185.7 \text{ mm}$$

The required area

$$A_1 = (6.96)(185.7)(2 - 0.866) = 1\,466 \text{ mm}^2$$

The reinforcement in the run wall

$$A_2 = (185.7)(11.1 - 6.96 - 2.5) = 305 \text{ mm}^2$$

in branch wall

$$A_3 = (2)\left(\frac{21.5}{0.866}\right)(6.22 - 2.88 - 2.5) = 41.7 \text{ mm}^2$$

in ring

$$A_4 = (12.7)\left(305 - \frac{168.3}{0.866}\right) = 1\ 405\ \text{ mm}^2$$

in fillet welds

$$A_4 = (4)\left(\tfrac{1}{2}\right)(10)^2 = 200 \text{ mm}^2$$

The total reinforcement is

$$200 + 1\,405 + 41.7 + 305 = 1\,952 \text{ mm}^2$$

This total is greater than the 1 466 mm^2, so that no additional reinforcement is required.

(20) H304 EXAMPLE 4

A DN 200 (NPS 8) run (header) in an oil piping system has a DN 100 (NPS 4) branch at right angles (Figure H301). Both pipes are Schedule 40 API 5L Grade A seamless. The design conditions are 2 400 kPa at 205°C. It is assumed that the piping system is to remain in service until all metal thickness, in both branch and run, in excess of that required by eq. (3a) of para. 304.1.2 has corroded away so that area A_2 as defined in para. 304.3.3(c)(1) is zero. What reinforcement is required for this connection?

Solution

From Appendix A, Table A-1M, S = 110 MPa for API 5L Grade A; from Table A-1B, E = 1.0 for API 5L seamless; W = 1.0.

$$t_h = \frac{(2\,400)(219.1)}{(2)(110\,000)(1.0)(1.0) + (2)(0.4)(2\,400)} = 2.37 \text{ mm}$$

$$t_b = \frac{(2\,400)(114.3)}{(2)(110\,000)(1.0)(1.0) + (2)(0.4)(2\,400)} = 1.24 \text{ mm}$$

$$d_1 = 114.3 - (2)(1.24) = 112 \text{ mm}$$

Required reinforcement area

$$A_1 = (2.37)(112) = 265 \text{ mm}^2$$

Try fillet welds only

$$L_4 = (2.5)(2.37) = 5.9 \text{ mm}$$

$$\text{or } (2.5)(1.24) = 3.1 \text{ mm}$$

Use 3.1 mm.

Due to limitation in the height at the reinforcement zone, no practical fillet weld size will supply enough reinforcement area; therefore, the connection must be further reinforced. Try a 160 mm O.D. reinforcing ring (measured along the run). Assume the ring to be cut from a piece of DN 200 (NPS 8) Schedule 40 API 5L Grade A seamless pipe and welded to the connection with minimum size fillet welds.

Minimum ring thickness

$$T_r = (8.18)(0.875) = 7.16 \text{ mm}$$

$$\text{New } L_4 = (2.5)(1.24) + 7.16 = 10.3 \text{ mm}$$

$$\text{or } (2.5)(2.37) = 5.9 \text{ mm}$$

Use 5.9 mm.

Reinforcement area in the ring (considering only the thickness within L_4)

$$X_1 = (5.9)(160 - 114.3) = 270 \text{ mm}^2$$

$$\text{Leg dimension of weld} = \frac{(0.5)(8.18)}{0.707} = 5.8 \text{ mm}$$

Reinforcement area in fillet welds

$$X_2 = (2)\left(\tfrac{1}{2}\right)(5.8)^2 = 34 \text{ mm}^2$$

Total reinforcement area

$$A_4 = X_1 + X_2 = 304 \text{ mm}^2$$

This total reinforcement area is greater than the required area; therefore, a reinforcing ring 160 mm O.D., cut from a piece of DN 200 (NPS 8) Schedule 40 API 5L Grade A seamless pipe and welded to the connection with minimum size fillet welds would provide adequate reinforcement for this connection.

H305 EXAMPLE 5 (Not Illustrated)

A DN 40 (NPS 1½) Class 3000 forged steel socket welding coupling has been welded at right angles to a DN 200 (NPS 8) Schedule 40 run (header) in oil service, using a weld conforming to Figure 328.5.4D, illustration (a). The run is ASTM A53 Grade B seamless pipe. The design pressure is 2 760 kPa and the design temperature is 230°C. The corrosion allowance is 2.5 mm. Is additional reinforcement required?

Solution

No. According to para. 304.3.2(b), the design is adequate to sustain the internal pressure and no calculations are necessary. It is presumed, of course, that calculations have shown the run pipe to be satisfactory for the service conditions according to eqs. (2) and (3).

H310 INTRODUCTION (U.S. CUSTOMARY UNITS)

The following examples are intended to illustrate the application of the rules and definitions in para. 304.3.3 for welded branch connections.

H311 EXAMPLE 1

An NPS 8 run (header) in an oil piping system has an NPS 4 branch at right angles (see Figure H311). Both pipes are Schedule 40 API 5L Grade A seamless. The design conditions are 300 psig at 400°F. The fillet welds at the crotch are minimum size in accordance with para. 328.5.4. A corrosion allowance of 0.10 in. is specified. Is additional reinforcement necessary?

Solution

From Appendix A, S = 16.0 ksi for API 5L Grade A (Table A-1); E = 1.0 for API 5L seamless (Table A-1B); W = 1.0.

$$T_h = (0.322)(0.875) = 0.282 \text{ in.}$$

$$T_b = (0.237)(0.875) = 0.207 \text{ in.}$$

$$\begin{aligned} L_4 &= (2.5)(0.282 - 0.1) = 0.455 \text{ in.} \\ &\quad \text{or } (2.5)(0.207 - 0.1) + 0 = 0.268 \text{ in.,} \\ &\quad \text{whichever is less} \\ &= 0.268 \text{ in.} \end{aligned}$$

$$d_1 = [4.5 - (2)(0.207 - 0.1)]/\sin 90 \text{ deg} = 4.286 \text{ in.}$$

$$\begin{aligned} d_2 &= (0.207 - 0.1) + (0.282 - 0.1) + 4.286/2 \\ &= 2.432 \text{ in.} \end{aligned}$$

Use d_1 or d_2, whichever is greater.

$$d_1 = 4.286 \text{ in.}$$

$$t_h = \frac{(300)(8.625)}{(2)(16{,}000)(1.0)(1.0) + (2)(0.4)(300)} = 0.080 \text{ in.}$$

$$t_b = \frac{(300)(4.500)}{(2)(16{,}000)(1.0)(1.0) + (2)(0.4)(300)} = 0.042 \text{ in.}$$

$$\begin{aligned} t_c &= (0.7)(0.237) = 0.166 \text{ in., or } 0.25\text{, whichever is less} \\ &= 0.166 \text{ in.} \end{aligned}$$

Minimum leg dimension of fillet weld

$$0.166/0.707 = 0.235 \text{ in.}$$

Thus, the required area

$$A_1 = (0.080)(4.286)(2 - \sin 90 \text{ deg}) = 0.343 \text{ sq in.}$$

The reinforcement area in run wall

$$A_2 = (4.286)(0.282 - 0.08 - 0.10) = 0.437 \text{ sq in.}$$

in branch wall

$$A_3 = (2)(0.268)[(0.207 - 0.042) - 0.10] = 0.035 \text{ sq in.}$$

in branch welds

$$A_4 = (2)\left(\tfrac{1}{2}\right)(0.235)^2 = 0.055 \text{ sq in.}$$

The total reinforcement area = 0.527 sq in. This is more than 0.343 sq in. so that no additional reinforcement is required to sustain the internal pressure.

H312 EXAMPLE 2

There is an NPS 8 branch at right angles to an NPS 12 header (Figure H311). Both run and branch are of aluminum alloy Schedule 80 ASTM B241 6061-T6 seamless pipe. The connection is reinforced by a ring 14 in. O.D. (measured along the run) cut from a piece of NPS 12 Schedule 80 ASTM B241 6063-T6 seamless pipe and opened slightly to fit over the run pipe. Allowable stresses for welded construction apply in accordance with Appendix A, Note (33). The fillet welds have the minimum dimensions permitted in para. 328.5.4. A zero corrosion allowance is specified. What is the maximum permissible design pressure if the design temperature is −320°F?

Solution

From Appendix A, Table A-1, S = 8.0 ksi for Grade 6061-T6 (welded) pipe and S = 5.7 ksi for Grade 6063-T6 (welded) pad, both at −320°F. From Table A-1B, E = 1.0 for ASTM B241; W = 1.0.

Leg dimensions of welds

$$\frac{t_c}{0.707} = \frac{0.250}{0.707} = 0.354 \text{ in.}$$

$$\frac{(0.5)(0.687)}{0.707} = 0.486 \text{ in.}$$

$$T_h = (0.687)(0.875) = 0.601 \text{ in.}$$

$$T_b = (0.500)(0.875) = 0.438 \text{ in.}$$

$$T_r = (0.687)(0.875) = 0.601 \text{ in.}$$

$$L_4 = (2.5)(0.601 - 0.00) = 1.503 \text{ in.}$$

[This is smaller than (2.5)(0.438 − 0.00) + 0.601 = 1.696 in.]

$$d_2 = d_1 = 8.625 - (2)(0.438 - 0.00) = 7.749 \text{ in.}$$

$$t_h = \frac{12.75P}{(2)(8{,}000)(1.0)(1.0) + (2)(0.4)(P)}$$

$$t_b = \frac{8.625P}{(2)(8{,}000)(1.0)(1.0) + (2)(0.4)(P)}$$

Using the symbol

$$q = \frac{P}{16{,}000 + 0.8P}$$

we can briefly write

$$t_h = 12.75q \text{ and } t_b = 8.625q$$

The required area

$$A_1 = 7.749t_h = 98.80q$$

The reinforcement area in run wall

$$A_2 = (7.749)(0.601 - 12.75q - 0.00) = 4.657 - 98.80q$$

in branch wall

$$A_3 = (2)(1.503)(0.438 - 8.625q - 0.00) = 1.317 - 25.93q$$

in ring

$$A_4 = (0.601)(14 - 8.625)(5{,}700/8{,}000) = 2.302$$

in fillet welds

$$A_4 = (2)\left(\tfrac{1}{2}\right)(0.354)^2 + (2)\left(\tfrac{1}{2}\right)(0.486)^2 = 0.362$$

The total reinforcement area = 8.638 − 124.73q.

At the maximum permissible normal operating pressure, the required area and the reinforcement area are equal; thus

$$98.80q = 8.638 - 124.73q$$

$$223.53q = 8.638$$

$$q = 0.0386$$

But also

$$q = \frac{P}{16{,}000 + 0.8P}$$

Thus

$$P = (0.0386)(16{,}000 + 0.8P) = 618.3 + 0.0309P$$

$$0.961P = 618.3$$

$$P = 643.1 \text{ psig}$$

which is the maximum permissible design pressure.

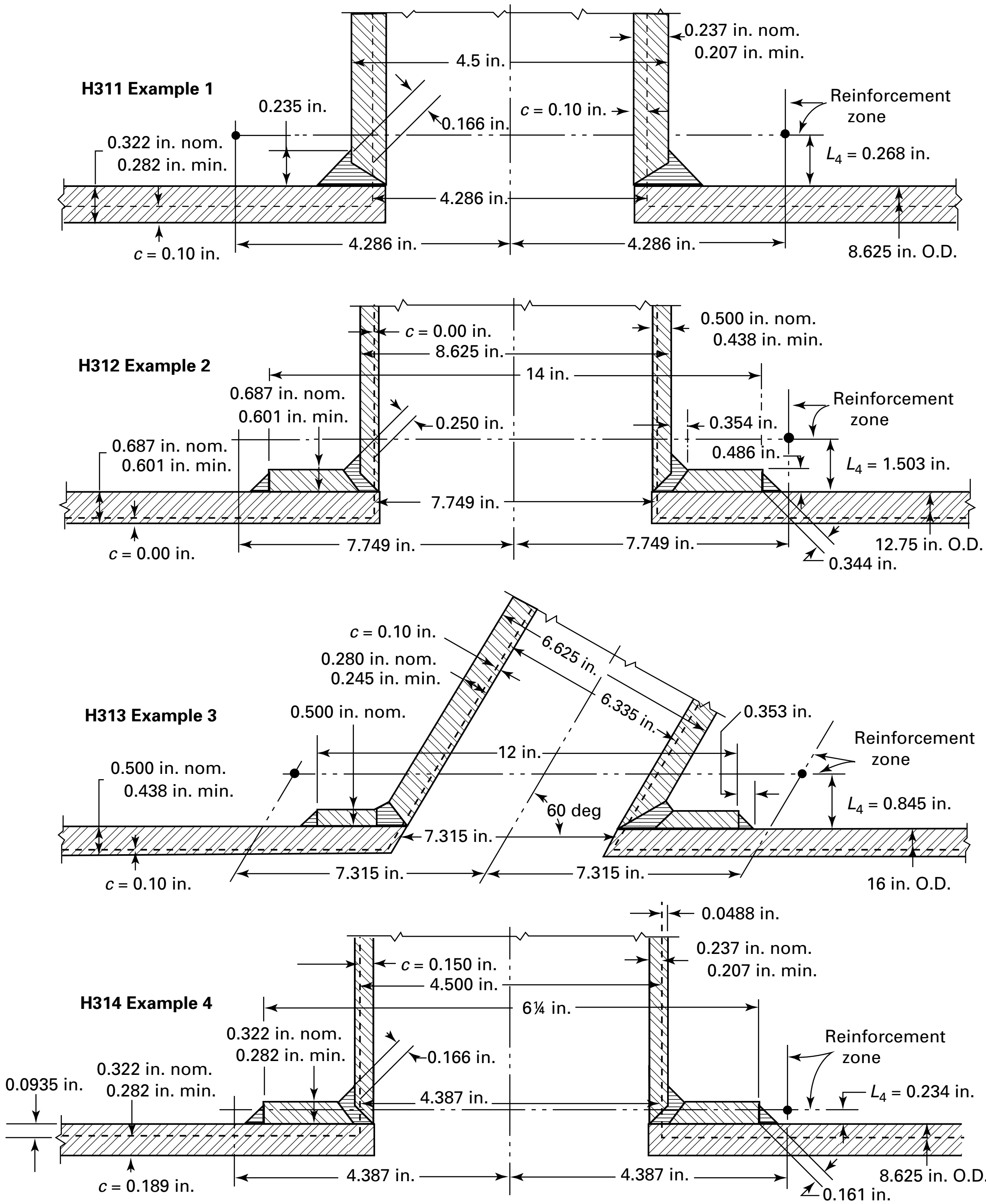
H313 EXAMPLE 3

An NPS 6 Schedule 40 branch has its axis at a 60 deg angle to the axis of an NPS 16 Schedule 40 run (header) in an oil piping system (Figure H311). Both pipes are API 5L Grade A seamless. The connection is reinforced with a ring 12 in. O.D. (measured along the run) made from ½ in. ASTM A285 Grade C plate. All fillet welds are equivalent to 45 deg fillet welds with ⅜ in. legs. Corrosion allowance = 0.10 in. The design pressure is 500 psig at 700°F. Is the design adequate for the internal pressure?

Solution

From Appendix A, S = 14.4 ksi for API 5L Grade A and ASTM A285 Grade C (Table A-1); E = 1.0 for API 5L seamless pipe (Table A-1B); W = 1.0.

Figure H311 Illustrations for U.S. Customary Units Examples in Appendix H



$$T_h = (0.500)(0.875) = 0.438 \text{ in.}$$

$$T_b = (0.280)(0.875) = 0.245 \text{ in.}$$

$$T_r = 0.500 \text{ in.}$$

$$L_4 = (2.5)(0.245 - 0.10) + 0.500 = 0.8625$$

This is greater than 2.5(0.438 – 0.10) = 0.845 in.

$$t_h = \frac{(500)(16)}{(2)(14{,}400)(1.0)(1.0) + (2)(0.4)(500)} = 0.274 \text{ in.}$$

$$t_b = \frac{(500)(6.625)}{(2)(14{,}400)(1.0)(1.0) + (2)(0.4)(500)} = 0.113 \text{ in.}$$

$$d_2 = d_1 = \frac{6.625 - (2)(0.245 - 0.10)}{\sin 60 \text{ deg}} = \frac{6.335}{0.866} = 7.315 \text{ in.}$$

The required area

$$A_1 = (0.274)(7.315)(2 - 0.866) = 2.27 \text{ sq in.}$$

The reinforcement in the run wall

$$A_2 = (7.315)(0.438 - 0.274 - 0.10) = 0.468 \text{ sq in.}$$

in branch wall

$$A_3 = (2)\left(\frac{0.845}{0.866}\right)(0.245 - 0.113 - 0.10) = 0.062 \text{ sq in.}$$

in ring

$$A_4 = (0.500)\left(12 - \frac{6.625}{0.866}\right) = 2.175 \text{ sq in.}$$

in fillet welds

$$A_4 = (4)\left(^1/_2\right)\left(^3/_8\right)^2 = 0.281 \text{ sq in.}$$

The total reinforcement = 2.986 sq in. This total is greater than 2.27 sq in., so that no additional reinforcement is required.

H314 EXAMPLE 4

An NPS 8 run (header) in an oil piping system has an NPS 4 branch at right angles (Figure H311). Both pipes are Schedule 40 API 5L Grade A seamless. The design conditions are 350 psig at 400°F. It is assumed that the piping system is to remain in service until all metal thickness, in both branch and run, in excess of that required by eq. (3a) of para. 304.1.2 has corroded away so that area A_2 as defined in para. 304.3.3(c)(1) is zero. What reinforcement is required for this connection?

Solution

From Appendix A, S = 16.0 ksi for API 5L Grade A (Table A-1); E = 1.0 for API 5L seamless (Table A-1B); W = 1.0.

$$t_h = \frac{(350)(8.625)}{(2)(16{,}000)(1.0)(1.0) + (2)(0.4)(350)} = 0.0935 \text{ in.}$$

$$t_b = \frac{(350)(4.500)}{(2)(16{,}000)(1.0)(1.0) + (2)(0.4)(350)} = 0.0488 \text{ in.}$$

$$d_1 = 4.500 - (2)(0.0488) = 4.402 \text{ in.}$$

Required reinforcement area

$$A_1 = (0.0935)(4.402) = 0.412 \text{ sq in.}$$

Try fillet welds only

$$L_4 = (2.5)(0.0935) = 0.234 \text{ in.}$$
$$\text{or } (2.5)(0.0488) = 0.122 \text{ in.}$$

Use 0.122 in.

Due to limitation in the height at the reinforcement zone, no practical fillet weld size will supply enough reinforcement area; therefore, the connection must be further reinforced. Try a $6^1/_4$ in. O.D. reinforcing ring (measured along the run). Assume the ring to be cut from a piece of NPS 8 Schedule 40 API 5L Grade A seamless pipe and welded to the connection with minimum size fillet welds.

Minimum ring thickness

$$T_r = (0.322)(0.875) = 0.282 \text{ in.}$$

$$\text{New } L_4 = (2.5)(0.0488) + 0.282 = 0.404 \text{ in.}$$

$$\text{or } (2.5)(0.0935) = 0.234 \text{ in.}$$

Use 0.234 in.

Reinforcement area in the ring (considering only the thickness within L_4)

$$X_1 = (0.234)(6.25 - 4.5) = 0.410 \text{ sq in.}$$

$$\text{Leg dimension of weld} = \frac{(0.5)(0.322)}{0.707} = 0.228 \text{ in.}$$

Reinforcement area in fillet welds

$$X_2 = (2)\left(\frac{1}{2}\right)(0.228)^2 = 0.052 \text{ sq in.}$$

Total reinforcement area

$$A_4 = X_1 + X_2 = 0.462 \text{ sq in.}$$

This total reinforcement area is greater than the required area; therefore, a reinforcing ring $6^1/_4$ in. O.D., cut from a piece of NPS 8 Schedule 40 API 5L Grade A seamless pipe and welded to the connection with minimum size fillet welds would provide adequate reinforcement for this connection.

H315 EXAMPLE 5 (Not Illustrated)

An NPS $1^1/_2$ Class 3000 forged steel socket welding coupling has been welded at right angles to an NPS 8 Schedule 40 run (header) in oil service, using a weld conforming to Figure 328.5.4D, illustration (a). The run is ASTM A53 Grade B seamless pipe. The design pressure is 400 psi and the design temperature is 450°F. The corrosion allowance is 0.10 in. Is additional reinforcement required?

Solution

No. According to para. 304.3.2(b), the design is adequate to sustain the internal pressure and no calculations are necessary. It is presumed, of course, that calculations have shown the run pipe to be satisfactory for the service conditions according to eqs. (2) and (3).

APPENDIX J
NOMENCLATURE (20)

Symbol	Definition	Units [Note (1)] SI	U.S. Customary	Reference Paragraph	Table/Fig./App.	Equation
A	Factor for determining minimum value of R_1	...	...	304.2.3	...	(5)
A_1	Area required for branch reinforcement	mm^2	in.^{2}	304.3.3 304.3.4	304.3.3 304.3.4 App. H	(6) (6a) (9) (9a)
A_2	Area available for branch reinforcement in run pipe	mm^2	in.^{2}	304.3.3 304.3.4	304.3.3 304.3.4 App. H	(6a) (7) (9a) (10)
A_3	Area available for branch reinforcement in branch pipe	mm^2	in.^{2}	304.3.3 304.3.4	304.3.3 304.3.4 App. H	(6a) (8) (9a) (11)
A_4	Area available for branch reinforcement in pad or connection	mm^2	in.^{2}	304.3.3 304.3.4	304.3.3 304.3.4 App. H	(6a) (9a) (12)
A_f	Conveyed fluid cross-sectional area considering nominal pipe thickness less allowances	mm^2	in.^{2}	320.2	...	(23d)
A_p	Pipe cross-sectional area considering nominal pipe thickness less allowances	mm^2	in.^{2}	320.2	...	(23d)
A_p	Cross-sectional area of pipe	mm^2	in.^{2}	319.4.4	...	(17)
a	Rupture life exponent	...	...	V303.1.4 V304	...	(V3)
C	Cold spring factor	...	...	319.5.1	...	(21)
C	Material constant used in computing Larson-Miller parameter	...	...	V303.1.3 V303.1.4	...	(V2) (V3)
C_1	Estimated self-spring or relaxation factor	...	...	319.5.1	...	(22)
C_x	Size of fillet weld, socket welds other than flanges	mm	in.	...	328.5.2C	...
CF	Welded joint fatigue curve coefficient	...	...	W302.2	W302.1-1 W302.1-2 W302.1-3	(W1) (W9)

Symbol	Definition	Units [Note (1)]		Reference		
		SI	U.S. Customary	Paragraph	Table/Fig./App.	Equation
c	Sum of mechanical allowances (thread or groove depth) plus corrosion and erosion allowances	mm	in.	302.4 304.1.1 304.1.2 304.2.3 304.3.3 304.3.4 304.4.1 304.5.2 304.5.3 A304.1.1 K302.3.5 K302.4 K304.1.1 K304.5.2 K304.5.3 K304.8.3 S301.2 V303.1.1 V304	304.3.3 304.3.4 328.5.5 H301	(2) (3b) (4a) (4b) (4c) (7) (8) (10) (11) (12) (13) (14) (15) (25) (33) (36) (37)
c_i	Sum of internal allowances	mm	in.	K304.1.1 K304.1.2	...	(34b) (35a) (35b)
c_o	Sum of external allowances	mm	in.	K304.1.1 K304.1.2	...	(34a) (35a) (35b)
D	Outside diameter of pipe as listed in tables of standards and specifications or as measured	mm	in.	304.1.1 304.1.2 304.1.3 304.2.1 304.2.3 319.4.1 A304.1.1 A304.1.2 A328.2.5 K304.1.1 K304.1.2 K304.1.3 K304.8.3 S301.2 V304	304.1.1 304.2.3 341.3.2 K305.1.2 App. A Notes	(3a) (3c) (3d) (3e) (5) (16) (26a) (26b) (26c) (27) (34a) (35a) (37)
D_b	Outside diameter of branch pipe	mm	in.	304.3.1 304.3.3 304.3.4	304.3.3 304.3.4	...
D_h	Outside diameter of header pipe	mm	in.	304.3.1 304.3.3 304.3.4	304.3.3 304.3.4	...
D_x	Distance from node to node (for stress analysis)	m	ft	...	S301.3.2 S303.3	...
D_y	Distance from node to node (for stress analysis)	m	ft	...	S301.3.2 S303.3	...
D_z	Distance from node to node (for stress analysis)	m	ft	...	S301.3.2 S303.3	...

Symbol	Definition	Units [Note (1)] SI	U.S. Customary	Reference Paragraph	Table/Fig./App.	Equation
d	Inside diameter of pipe (note differences in definition between paras. 304.1.1 and K304.1.1)	mm	in.	304.1.1 304.1.2 K304.1.1 K304.1.2	K305.1.2	(3b) (34b) (35b)
d	Pipe inside diameter considering nominal pipe thickness less allowances	mm	in.	320.2	...	(23d)
d_1	Effective length removed from pipe at branch	mm	in.	304.3.3	304.3.3 App. H	(6) (7)
d_2	Half-width of reinforcement zone	mm	in.	304.3.3 304.3.4	304.3.3 304.3.4 App. H	(7) (10)
d_b	Inside diameter of branch pipe	mm	in.	...	304.3.4	...
d_g	Inside or pitch diameter of gasket	mm	in.	304.5.3	304.5.3 U304.5.3	(15)
d_h	Inside diameter of header pipe	mm	in.	...	304.3.4	...
d_t	Fatigue damage due to thermal stress with constant amplitude	...	...	W302.1 W305.1	...	(W2) (W5)
d_w	Fatigue damage due to wave stress with variable amplitude	...	...	...	...	(W5) (W8)
d_x	Design inside diameter of extruded outlet	mm	in.	304.3.4	304.3.4	(9) (10)
E	Quality factor	...	...	302.3.1 304.1.1 304.1.2 304.2.3 304.3.3 304.4.1 304.5.1 304.5.2 304.5.3 K304.5.3 S301.1 S301.2 S303.1 V304	Appendix A Notes App. H	(3a) (3b) (3c) (4a) (4b) (4c) (15)
E	Modulus of elasticity (at specified condition)	MPa	ksi	A319.3.2 W302.1 X302.2.3	App. C	(X1)
E_a	Reference modulus of elasticity at 21°C (70°F)	MPa	ksi	319.3.2 319.4.1 319.4.4 319.5.1	...	(21) (22)

Symbol	Definition	Units [Note (1)] SI	U.S. Customary	Reference Paragraph	Table/Fig./App.	Equation
E_c	Casting quality factor	...	...	302.3.1 302.3.3 302.3.5 302.3.6 305.2.3 306.1.4 V303.1.1	302.3.3C Table A-1A	...
E_{CSA}	Modulus of elasticity of carbon steel at ambient temperature of 21°C (70°F)	MPa	ksi	W302.1	...	...
E_j	Joint quality factor	...	...	302.3.1 302.3.4 302.3.5 305.2.3 306.1.4 321.1.3 341.4.1 341.5.1 K302.3.4 K305.1.1 K306.1.1 V303.1.1 X302.2.2	302.3.4 App. A Notes Table A-1B	...
E_m	Modulus of elasticity at maximum or minimum temperature	MPa	ksi	319.3.2 319.5 319.5.1	...	(21) (22)
E_t	Modulus of elasticity at test temperature	MPa	ksi	X302.2.3	...	(X1)
F	Service (design) factor	...	...	A302.3.2 A304.1.1 A304.1.2	...	(26c)
F_a	Axial force range between any two conditions being evaluated	N	lbf	319.4.4	...	(17)
F_a	Sustained longitudinal force	N	lb	320.2	...	(23d)
F_{avg}	Multiplier applied to the average stress for rupture in 100 000 h	...	...	302.3.2	...	...
F_x	Force along the x-axis	N	lb	...	S301.5.2 S302.5.1 S302.6.3.1 S303.7.1 S303.7.2 S303.7.3	...
F_y	Force along the y-axis	N	lb	...	S301.5.2 S302.5.1 S302.6.3.1	...
f	Stress range factor	...	...	302.3.5 S301.1 S301.7 S303.1	302.3.5	(1a) (1b) (1c)

Symbol	Definition	Units [Note (1)] SI	U.S. Customary	Reference Paragraph	Table/Fig./App.	Equation
f_E	Environment correction factor	...	...	W302.1	W302.1-3 W302.1-4	(W1) (W9)
f_I	Fatigue improvement factor	...	...	W302.1 W302.2	W302.1-3	(W1) (W9)
$f_{M,k}$	Fatigue factor for stress ratio	...	...	W302.1	...	(W1) (W9)
f_m	Maximum value of stress range factor	...	...	302.3.5	...	(1c)
f_t	Temperature correction factor	...	...	W302.1	...	(W1) (W9)
g	Root gap for welding	mm	in.	K328.4.3	328.4.4 K328.5.4	...
h	Nominal thread depth	mm	in.	K304.1.1	304.1.1	...
h	Weibull stress range shape distribution parameter	...	...	W302.2 W302.3	W301-1	(W3) (W4) (W8)
h_F	Through-wall dimension (height) of a flaw drawn normal to the inside pressure-retaining surface of the component	mm	in.	R307	R307 R308.1 R308.2	...
h_x	Height of extruded outlet	mm	in.	304.3.4	304.3.4	...
I_a	Sustained longitudinal index	...	...	320.1 320.2 323.2.2	...	(23d)
I_i	Sustained in-plane moment index	...	...	320.1 320.2 323.2.2	...	(23b)
I_o	Sustained out-plane moment index	...	...	320.1 320.2 323.2.2	...	(23b)
I_t	Sustained torsional moment index	...	...	320.1 320.2 323.2.2	...	(23c)
i	Stress intensification factor	...	...	319.3.6	...	...
i	Service condition	...	...	V303.1.1 V303.1.4 V303.2 V304	...	...
i_a	Axial force stress intensification factor	...	...	319.4.4	...	(17)
i_i	In-plane stress intensification factor	...	...	319.4.4 320.2 S301.7	...	(18) (23b)
i_o	Out-plane stress intensification factor	...	...	319.4.4 320.2	...	(18) (23b)

Symbol	Definition	Units [Note (1)] SI	U.S. Customary	Reference Paragraph	Table/Fig./App.	Equation
i_t	Torsional stress intensification factor	...	...	319.4.4	...	(17)
K	Factor determined by ratio of branch diameter to run diameter	...	...	304.3.4	304.3.4	(9)
K_1	Constant in empirical flexibility equation	...	...	319.4.1	...	(16)
k	Flexibility factor	...	...	319.3.6	...	...
k	Fatigue strength thickness exponent	...	...	W302.2	W302.1-1 W302.1-2 W302.1-3	(W1) (W9)
L	Developed length of piping between anchors (the running centerline length between stiffened sections of pipe)	m	ft	304.1.3 319.4.1 K304.2.4	...	(16)
L_4	Height of reinforcement zone outside run pipe	mm	in.	304.3.3	304.3.3 App. H	(8)
L_5	Height of reinforcement zone for extruded outlet	mm	in.	304.3.4	304.3.4	(11)
L_d	Piping cycle design life	...	...	W302.2	...	(W7)
L_w	Design storm period of occurrence	...	...	W302.2	...	(W6)
LMP	Larson-Miller parameter, used to estimate design life	...	...	V303.1.3 V303.1.4 V304	...	(V2) (V3)
l_F	Length of a flaw drawn parallel to the inside pressure-retaining surface of the component	mm	in.	R307	R307 R308.1 R308.2	...
M	Length of full thickness pipe adjacent to miter bend	mm	in.	304.2.3	304.2.3	...
M_i	In-plane moment range between any two conditions being evaluated	N-mm	in.-lbf	319.4.4	319.4.4A 319.4.4B	(18)
M_i	In-plane bending moment for the sustained condition being evaluated	N-mm	in.-lbf	320.2	...	(23b)
M_o	Out-plane moment range between any two conditions being evaluated	N-mm	in.-lbf	319.4.4	319.4.4A 319.4.4B	(18)
M_o	Out-plane bending moment for the sustained condition being evaluated	N-mm	in.-lbf	320.2	...	(23b)
M_t	Sustained torsional moment	N-mm	in.-lbf	320.2	...	(23c)
M_t	Torsional moment range between any two conditions being evaluated	N-mm	in.-lbf	319.4.4	319.4.4A 319.4.4B	...

Symbol	Definition	Units [Note (1)] SI	U.S. Customary	Reference Paragraph	Table/Fig./App.	Equation
M_y	Moment along the y-axis	N-m	ft-lb	...	S303.7.1 S303.7.2 S303.7.3	...
M_z	Moment along the z-axis	N-m	ft-lb	...	S301.5.2	...
m	Misfit of branch pipe	mm	in.	328.4.3 K328.4.3	328.4.4 K328.5.4	...
m	Welded joint fatigue curve exponent	...	...	W302.2	W301-1 W302.1-1 W302.1-2 W302.1-3	(W1) (W8) (W9)
N	Equivalent number of full displacement cycles	...	...	300.2 302.3.5 K304.8.1	302.3.5	(1c) (1d)
N_d	Design number of pipe stress cycles	...	...	...	...	(W7) (W8)
N_E	Number of cycles of maximum computed displacement stress range	...	...	302.3.5	...	(1d)
N_i	Number of cycles associated with displacement stress range, S_i (i = 1, 2, ...)	...	...	302.3.5	...	(1d)
N_i	Number of cycles for loading condition i	...	...	W302.1	...	(W2)
N_{ti}	Allowable number of cycles for loading condition i	...	...	W302.1	W302.1-3	(W1) (W2)
N_w	Design storm wave height associated cycles	...	...	W302.2	...	(W4) (W6) (W8)
n	Slope of log time to rupture versus log stress plot at 100 000 h	...	...	302.3.2	...	...
P	Internal design gage pressure	kPa	psi	304.1.1 304.1.2 304.2.1 304.4.1 304.5.1 304.5.2 304.5.3 345.4.2 A304.1.1 A304.1.2 A304.5.1 H302 K304.1.2 K304.7.2 K304.8.3 K345.4.2 S301.2	...	(3a) (3b) (3c) (15) (24) (26a) (26b) (26c) (34a) (34b) (35a) (35b) (37) (38)
P_{a2}	See ASME BPVC, Section VIII, Division 1, UG-28	...	...	304.1.3	...	...

Symbol	Definition	Units [Note (1)] SI	Units [Note (1)] U.S. Customary	Reference Paragraph	Reference Table/Fig./App.	Reference Equation
P_i	Gage pressure during service condition *i*	kPa	psi	V303.1.1 V303.2	...	(V1)
P_j	Piping internal gage pressure for the condition being considered; the as-installed and operating conditions are subscripted as *j* = 1, 2, 3, ...	kPa	psi	320.2 S300.1 S301 S302 S303	S301.1 S301.3.1 S302.1 S302.6.2.1	(23d)
P_m	Maximum allowable internal pressure for miter bends	kPa	psi	304.2.3	...	(4a) (4b) (4c)
P_{max}	Maximum allowable gage pressure for continuous operation of component at maximum design temperature	kPa	psi	V303.1.1 V304	...	(V1)
P_S	Limiting design pressure based on column instability, for convoluted U-shaped bellows	kPa	psi	X302.2.3	...	(X1)
P_T	Minimum test gage pressure	kPa	psi	345.4.2 A382.2.5 K345.4.2 X302.2.3	...	(24) (27) (38) (X1)
q	Temporary symbol for D/t	...	...	H302	...	...
q	Weibull stress range scale distribution factor	MPa	ksi	...	...	(W3) (W4)
R	Range of reaction forces or moments in flexibility analysis	N or N-mm	lbf or in.-lbf	319.5.1	...	(21)
R_1	Effective radius of miter bend	mm	in.	304.2.3	304.2.3	(4b) (5)
R_1	Bend radius of welding elbow or pipe bend	mm	in.	304.2.1	304.2.1	(3d) (3e)
R_a	Estimated instantaneous reaction force or moment at installation temperature	N or N-mm	lbf or in.-lbf	319.5.1	...	...
R_a	Roughness average	µm	µin.	K302.3.3	302.3.3C 341.3.2 K341.3.2	...
R_m	Estimated instantaneous maximum reaction force or moment at maximum or minimum metal temperature	N or N-mm	lbf or in.-lbf	319.5.1	...	(21)
R_T	Ratio of the average temperature-dependent trend curve value of tensile strength to the room temperature tensile strength	...	...	302.3.2 K302.3.2	...	(31d)
R_Y	Ratio of the average temperature-dependent trend curve value of yield strength to the room temperature yield strength	...	...	302.3.2 K302.3.2	...	(31c)
r	Corner radius of lap joint stub end	mm	in.	308.2.1	...	...
r_2	Mean radius of pipe using nominal wall thickness, $\overline{T}$	mm	in.	304.2.3 319.4.4	304.2.3	(4a) (4b) (4c)

Symbol	Definition	Units [Note (1)] SI	U.S. Customary	Reference Paragraph	Table/Fig./App.	Equation
r_i	Ratio of lesser computed displacement stress range, S_i, to maximum computed stress range, S_E (i = 1, 2, ...)	...	...	302.3.5	...	(1d)
r_x	External contour radius of extruded outlet	mm	in.	304.3.4	304.3.4	(12)
S	Basic allowable stress for metals	MPa	ksi	300.2 302.3.1 302.3.5 304.1.1 304.1.2 304.1.3 304.2.1 304.2.3 304.3.3 304.4.1 304.5.1 304.5.2 304.5.3 304.7.2 345.4.2 H300 S301.2 V304	A-1 A-1M	(3a) (3b) (3c) (4a) (4b) (4c) (15) (24)
S	Bolt design stress	MPa	ksi	300.2 302.3.1	A-2	...
S	Design stress for nonmetals	...	...	A302.3.1 A304.1.1 A304.1.2 A304.5.2 A345.4.2	B-1	(26a) (26b) (26c)
S	Allowable stress for metals	MPa	ksi	K302.3.2 K304.1.2 K304.5.3 K304.7.2 K345.4.2	K-1	(31a) (31b) (34a) (34b) (35a) (35b) (38)
S	Stress intensity	MPa	ksi	K304.8.3	...	(37)
S_A	Allowable displacement stress range	MPa	ksi	300.2 302.3.5 319.2.3 319.3.4 319.4.1 319.4.4 K302.3.5 S301.7 S303.8	S301.7 S303.7.1 S303.7.2 S303.7.3	(1a) (1b) (16) (32)
S_a	Bolt design stress at atmospheric temperature	MPa	ksi	304.5.1 A304.5.1	...	...
S_a	Axial stress range due to displacement strains	MPa	ksi	319.4.4	...	(17)
S_a	Stress due to sustained longitudinal force	MPa	ksi	320.2	...	(23a) (23d)

Symbol	Definition	Units [Note (1)] SI	U.S. Customary	Reference Paragraph	Table/Fig./App.	Equation
S_{aw}	Allowable maximum probable stress range during N_w wave cycles	MPa	ksi	W302.2 W305.3.2	...	(W4) (W8)
S_b	Bolt design stress at design temperature	MPa	ksi	304.5.1 A304.5.1	...	...
S_b	Bending stress range due to displacement strains	MPa	ksi	319.4.4	...	(17) (18)
S_b	Stress due to sustained bending moments	MPa	ksi	320.2	...	(23a) (23b)
S_c	Basic allowable stress at minimum metal temperature expected during the displacement cycle under analysis	MPa	ksi	302.3.5 K302.3.5 S301.7	...	(1a) (1b) (32)
S_d	Allowable stress from Table A-1 or Table A-1M for the material at design temperature	MPa	ksi	V303.1.1 V304	...	(V1)
S_E	Computed displacement stress range	MPa	ksi	300.2 302.3.5 319.2.3 319.4.4 319.5.1 K302.3.5 S301.7 S303.7	S301.7 S303.7.1 S303.7.2 S303.7.3	(17) (22)
S_{Ei}	Computed displacement stress range for condition i corresponding to cycles N_i	MPa	ksi	W302.1	W302.1-1 W302.1-2	(W1)
$S_{Ei,\ max}$	Computed maximum displacement stress for condition i corresponding to stress range S_{Ei} and cycles N_i	MPa	ksi	W302.1	...	...
$S_{Ei,\ min}$	Computed minimum displacement stress for condition i corresponding to stress range S_{Ei} and cycles N_i	MPa	ksi	W302.1	...	...
S_{EW}	Computed maximum stress range due to wave motion	MPa	ksi	W302.2 W305.1	...	(W3)
S_F	Separation distance between the outer extent of a flaw and the nearest surface	mm	in.	R307	R307	...
S_f	Allowable stress for flange material or pipe	MPa	ksi	304.5.1 A304.5.1	...	...
S_H	Mean long-term hydrostatic strength (LTHS)	kPa	psi	A328.2.5	...	(27)
S_h	Basic allowable stress at maximum metal temperature expected during the displacement cycle under analysis	MPa	ksi	302.3.5 319.5.1 K302.3.5 S301.6 S301.7	S301.6 S302.6.3.1	(1a) (1b) (22) (32)

Symbol	Definition	Units [Note (1)] SI	U.S. Customary	Reference Paragraph	Table/Fig./App.	Equation
S_i	A computed displacement stress range smaller than S_E (i = 1, 2, ...)	MPa	ksi	302.3.5	...	(1d)
S_i	Equivalent stress during service condition, i (the higher of S_{pi} and S_L)	MPa	ksi	V303.1.1 V303.1.2 V304	...	...
S_L	Stress due to sustained loads	MPa	ksi	302.3.5 302.3.6 320.1 320.2 K302.3.5 K302.3.6 S301.3 S301.6 S301.7 S302.6.1 S302.6.3 S303.6 V303.1.1 V303.1.4 V304	S301.6 S302.6.3.1 S303.7.3	(1b) (23a)
S_{pi}	Equivalent stress for pressure during service condition, i	MPa	ksi	V303.1.1 V304	...	(V1)
S_S	Mean short-term burst stress	kPa	psi	A328.2.5	...	(27)
S_T	Specified minimum tensile strength at room temperature	MPa	ksi	302.3.2 K302.3.2	...	(31d)
S_T	Allowable stress at test temperature	MPa	ksi	345.4.2 A345.4.2 K345.4.2	...	(24) (38)
S_t	Torsional stress range due to displacement strains	MPa	ksi	319.4.4	...	(17)
S_t	Stress due to sustained torsional moment	MPa	ksi	320.2	...	(23a) (23c)
S_{ut}	Tensile strength at temperature	MPa	ksi	K302.3.2	...	(31b) (31d)
S_Y	Specified minimum yield strength at room temperature	MPa	ksi	302.3.2 K302.3.2 K328.2.1	...	(31c)
S_y	Yield strength (ASME BPVC)	MPa	ksi	302.2.4	...	...
S_{yi}	Yield strength of the component under consideration for condition i	MPa	ksi	W302.1	...	...
S_{yT}	Yield strength at test temperature	MPa	ksi	X302.2.3	...	...

Symbol	Definition	Units [Note (1)] SI	U.S. Customary	Reference Paragraph	Table/Fig./App.	Equation
S_{yt}	Yield strength at temperature	MPa	ksi	K302.3.1 K302.3.2 K304.7.2 K304.8.3 K345.2.1	...	(31a) (31b) (31c)
S_{yt}	Yield strength at bellows design temperature	MPa	ksi	X302.2.3	...	...
T	Pipe wall thickness (measured or minimum in accordance with purchase specification)	mm	in.	304.1.1 304.2.3 306.4.2 A304.1.1 K304.1.1 K304.1.2 K304.8.3 S301.2 S301.7	302.3.3D 304.2.3 323.3.1 K323.3.1	(4a) (4b) (4c) (35a) (35b) (37)
T_1	Maximum temperature (for stress analysis)	°C	°F	S301.7 S302.5	S301.3.1	...
T_2	Minimum temperature (for stress analysis)	°C	°F	S301.7 S302.5	S301.3.1	...
T_2	Minimum thickness of fabricated lap	mm	in.	...	328.5.5	...
T_b	Branch pipe wall thickness (measured or minimum in accordance with purchase specification)	mm	in.	304.3.3 304.3.4	304.3.3 304.3.4 App. H	(8) (11) (12)
T_{cr}	Critical temperature	°C	°F	300.2	302.3.5	...
T_E	Effective temperature for service condition, i (temperature corresponding to S_i, Table A-1 and Table A-1M)	°C	°F	V303.1.2 V303.1.3 V304	...	(V2)
T_E	Effective component thickness at weld joint	mm	in.	W302.1	W302.1-1 W302.1-2	(W1) (W9)
T_h	Header pipe wall thickness (measured or minimum in accordance with purchase specification)	mm	in.	304.3.1 304.3.3 304.3.4	304.3.3 304.3.4 App. H	(7) (10)
T_i	Temperature of the component for the coincident operating pressure–temperature condition, i, under consideration	°C	°F	V303.1.4 V303.2	302.3.5	(V3)
T_j	Pipe metal temperature for the condition being considered; the as-installed and operating conditions are subscripted as j = 1, 2, 3, ...	°C	°F	S300.1 S301 S302 S303	S301.1 S301.3.1 S302.1	...
T_r	Minimum thickness of reinforcing ring or saddle made from pipe (nominal thickness if made from plate)	mm	in.	304.3.3 H304 H312 H314	304.3.3	...

Symbol	Definition	Units [Note (1)] SI	U.S. Customary	Reference Paragraph	Table/Fig./App.	Equation
T_s	Effective branch wall thickness	mm	in.	319.4.4	...	...
T_x	Corroded finished thickness of extruded outlet	mm	in.	304.3.4	304.3.4	(12)
$\overline{T}$	Nominal wall thickness of pipe	mm	in.	A328.2.5 S301.2 V304	323.2.2A 328.5.2B 328.5.2C 328.5.5 K302.3.3D	(27)
$\overline{T}$	Component nominal thickness at welded joint	mm	in.	W302.1	...	...
$\overline{T}_b$	Nominal branch pipe wall thickness	mm	in.	319.4.4 328.5.4 331.1.3	304.3.3 328.5.4D 328.5.4F App. H	...
$\overline{T}_h$	Nominal header pipe wall thickness	mm	in.	319.4.4 328.5.4 331.1.3	304.3.3 328.5.4D	...
$\overline{T}_m$	Nominal thickness of branch weld for integrally reinforced branch connection fittings [see para. 328.5.4(c) for further details]	mm	in.	328.5.4(c) 331.1.3	328.5.4F	...
$\overline{T}_r$	Nominal thickness of reinforcing ring or saddle	mm	in.	328.5.4 331.1.3 H302	328.5.4D	...
$\overline{T}_w$	Nominal wall thickness, thinner of components joined by butt weld	mm	in.	344.6.2 R304 R307 R308	341.3.2 K341.3.2 R307 R308.1 R308.2	...
t	Pressure design thickness	mm	in.	304.1.1 304.1.2 304.1.3 304.2.1 304.3.3 304.4.1 304.5.2 A304.1.1 A304.1.2 A304.1.3 K304.1.1 K304.1.2 K304.1.3 K304.5.2 S301.2	304.1.1 App. A Notes	(2) (3a) (3b) (3c) (13) (14) (25) (26a) (26b) (26c) (33) (34a) (34b) (36)
t_b	Pressure design thickness of branch	mm	in.	304.3.3 304.3.4	304.3.3 304.3.4 App. H	(8) (11)

Symbol	Definition	Units [Note (1)] SI	U.S. Customary	Reference Paragraph	Table/Fig./App.	Equation
t_c	Throat thickness of cover fillet weld	mm	in.	328.5.4 331.1.3	328.5.4D 328.5.4F App. H	...
t_h	Pressure design thickness of header	mm	in.	304.3.3 304.3.4	304.3.3 304.3.4 App. H	(6) (7) (9) (10)
t_i	Total duration of service condition, i, at pressure, P_i, and temperature, T_i	h	hr	V303.2 V304	...	(V4)
t_m	Minimum required thickness, including mechanical, corrosion, and erosion allowances	mm	in.	304.1.1 304.2.1 304.4.1 304.5.2 304.5.3 328.4.2 A304.1.1 A304.2.1 K304.1.1 K304.2.1 K304.5.2 K328.4.2 S301.2	304.5.3 328.3.2 328.4.3 K341.3.2 U304.5.3	(2) (13) (14) (15) (25) (33) (36)
t_{min}	For branch, the smaller of $\overline{T}_b$ or $\overline{T}_r$	mm	in.	328.5.4	328.5.4D	...
t_{ri}	Rupture life of a component subjected to repeated service conditions, i, and stress, S_i	h	hr	V303.1.4 V303.2 V304	...	(V3) (V4)
U	Straight line distance between anchors	m	ft	319.4.1	...	(16)
u	Creep-rupture usage factor, summed up from individual usage factors, t_i/t_{ri}	...	...	V303.2 V303.3 V304	...	(V4)
V_a	Average zero-crossing frequency	Hz	Hz	W302.2 W302.3	...	(W6) (W7)
W	Weld joint strength reduction factor	...	. .	302.2.2 302.3.5 304.1.1 304.1.2 304.2.1 304.2.3 304.3.3 304.4.1 304.5.1 304.5.2 304.5.3 V303.1.1 V304	302.3.5 App. H	(3a) (3b) (3c) (4a) (4b) (4c) (15)
X_1	Ring reinforcement area	mm^2	$in.^2$	H304	...	...
X_2	Fillet weld reinforcement area	mm^2	$in.^2$	H304	...	...

Symbol	Definition	Units [Note (1)] SI	U.S. Customary	Reference Paragraph	Table/Fig./App.	Equation
x_{min}	Size of fillet weld to slip-on or socket welding flange	mm	in.	...	328.5.2B	...
Y	Coefficient for effective stressed diameter	...	...	304.1.1 304.1.2 S301.2 V304	304.1.1	(3a) (3b) (3c)
Y+	Single acting support — a pipe support that provides support to the piping system in only the vertically upward direction	...	...	S300.1 S302 S302.1 S302.6.2	S302.5.1 S302.6.3.1	...
y	Resultant of total displacement	mm	in.	319.4.1	...	(16)
Z	Section modulus of pipe	mm^3	in.^{3}	319.4.4	...	(18)
Z	Sustained section modulus of pipe	mm^3	in.^{3}	320.2	...	(21b) (23c)
α	Angle of change in direction at miter joint	deg	deg	304.2.3 306.3.2 306.3.3 M306.3	304.2.3	...
β	Smaller angle between axes of branch and run	deg	deg	304.3.1 304.3.3	304.3.3	(6) (8)
Γ	Gamma function	...	...	...	W301-1	(W8)
γ	Span of the pipe bend	deg	deg	304.2.1	304.2.1	...
θ	Angle of miter cut	deg	deg	304.2.3	304.2.3	(4a) (4c) (5)
σ	Standard deviation	...	...	...	W302.1-1 W302.1-2	...

GENERAL NOTE: For Code reference to this Appendix, see para. 300.3.

NOTE: (1) Note that the use of these units is not required by the Code. They represent sets of consistent units (except where otherwise stated) that may be used in computations, if stress values in ksi and MPa are multiplied by 1,000 for use in equations that also involve pressure in psi and kPa values.

APPENDIX K
ALLOWABLE STRESSES FOR HIGH PRESSURE PIPING (20)

See next page.

Specification Index for Appendix K

Spec. No.	Title
ASTM	
A53	Pipe, Steel, Black and Hot-Dipped, Zinc-Coated, Welded and Seamless
A105	Carbon Steel Forgings for Piping Applications
A106	Seamless Carbon Steel Pipe for High-Temperature Service
A182	Forged or Rolled Alloy and Stainless Steel Pipe Flanges, Forged Fittings, and Valves and Parts for High-Temperature Service
A210	Seamless Medium-Carbon Steel Boiler and Superheater Tubes
A234	Piping Fittings of Wrought Carbon Steel and Alloy Steel for Moderate and High Temperature Service
A312	Seamless, Welded, and Heavily Cold Worked Austenitic Stainless Steel Pipes
A333	Seamless and Welded Steel Pipe for Low-Temperature Service and Other Applications with Required Notch Toughness
A334	Seamless and Welded Carbon and Alloy-Steel Tubes for Low-Temperature Service
A335	Seamless Ferritic Alloy-Steel Pipe for High-Temperature Service
A350	Carbon and Low-Alloy Steel Forgings, Requiring Notch Toughness Testing for Piping Components
A358	Electric-Fusion-Welded Austenitic Chromium-Nickel Stainless Steel Pipe for High-Temperature Service and General Applications
A403	Wrought Austenitic Stainless Steel Piping Fittings
A420	Piping Fittings of Wrought Carbon Steel and Alloy Steel for Low-Temperature Service
A508	Quenched and Tempered Vacuum-Treated Carbon and Alloy Steel Forgings for Pressure Vessels
A694	Carbon and Alloy Steel Forgings for Pipe Flanges, Fittings, Valves, and Parts for High-Pressure Transmission Service
A723	Alloy Steel Forgings for High-Strength Pressure Component Application
A789	Seamless and Welded Ferritic/Austenitic Stainless Steel Tubing for General Service
A790	Seamless and Welded Ferritic/Austenitic Stainless Steel Pipe
A815	Wrought Ferritic, Ferritic/Austenitic, and Martensitic Stainless Steel Piping Fittings
A928	Ferritic/Austenitic (Duplex) Stainless Steel Pipe Electric Fusion Welded with Addition of Filler Metal
B164	Nickel-Copper Alloy Rod, Bar and Wire
B165	Nickel-Copper Alloy (UNS N04400) Seamless Pipe and Tube
B166	Nickel-Chromium-Iron Alloys (UNS N06600, N06601, N06603, N06690, N06693, N06025, N06045, and N06696), Nickel-Chromium-Cobalt-Molybdenum Alloy (UNS N06617), and Nickel-Iron-Chromium-Tungsten Alloy (UNS N06674) Rod, Bar, and Wire
B167	Nickel-Chromium-Iron Alloys (UNS N06600, N06601, N06603, N06690, N06693, N06025, N06045, and N06696), Nickel-Chromium-Cobalt-Molybdenum Alloy (UNS N06617), and Nickel-Iron-Chromium-Tungsten Alloy (UNS N06674) Seamless Pipe and Tube
B338	Seamless and Welded Titanium and Titanium Alloy Tubes for Condensers and Heat Exchangers
B363	Seamless and Welded Unalloyed Titanium and Titanium Alloy Welding Fittings
B366	Factory-Made Wrought Nickel and Nickel Alloy Fittings
B381	Titanium and Titanium Alloy Forgings
B564	Nickel Alloy Forgings
B574	Low-Carbon Nickel-Chromium-Molybdenum, Low-Carbon Nickel-Molybdenum-Chromium, Low-Carbon Nickel-Molybdenum-Chromium-Tantalum, Low-Carbon Nickel-Chromium-Molybdenum-Copper, and Low-Carbon Nickel-Chromium-Molybdenum-Tungsten Alloy Rod
B622	Seamless Nickel and Nickel-Cobalt Alloy Pipe and Tube
B861	Titanium and Titanium Alloy Seamless Pipe
API	
5L	Line Pipe

GENERAL NOTE: It is not practical to refer to a specific edition of each standard throughout the Code text. Instead, the approved edition references, along with the names and addresses of the sponsoring organizations, are shown in Appendix E.

NOTES FOR TABLE K-1 (20)

GENERAL NOTES:

(a) The allowable stress values and P-Number assignments in Table K-1, together with the referenced Notes, are requirements of Chapter IX.

(b) Notes (1) through (4) are referenced in column headings. Notes (5) through (20) are referenced in the Notes column for specific materials.

(c) At this time, SI units equivalents have not been provided in Table K-1. To convert stress values in Table K-1 to MPa at a given temperature in °C, determine the equivalent temperature in °F and interpolate to calculate the stress value in ksi at the given temperature. Multiply by 6.895 to determine allowable stress in MPa at the given temperature.

(d) The following abbreviations are used in the Condition and Size or Thickness Range columns: ann., annealed; A.W., as worked; C.W., cold worked; H.W., hot worked; hex., hexagons; O.D., outside diameter; rd., rounds; rec., rectangles; rel., relieved; sq., squares; and str., stress.

(e) Samples representative of all piping components, as well as their fabrication welds, shall be impact tested in accordance with para. K323.3.

(f) A product analysis of the material shall be performed. See para. K323.1.5.

(g) Material defects may be repaired by welding only in accordance with para. K323.1.6.

(h) The following abbreviations are used in the Product Form column: ftgs., fittings; smls., seamless; and wld., welded.

NOTES:

(1) See the ASME BPVC, Section IX, QW-200.3 for a description of P-Number groupings. P-Numbers are indicated by number or by a number followed by a letter (e.g., 8, 5B, and 11A).

(2) The stress values in Table K-1 are allowable stresses in tension in accordance with para. K302.3.1(a). Stress values in shear and bearing are stated in para. K302.3.1(b); those in compression in para. K302.3.1(c).

(3) The lower temperature limit for listed materials shall be in accordance with para. K323.2.2.

(4) The upper temperature limit for listed materials shall be in accordance with para. K323.2.1.

(5) Pipe and tubing shall be examined for longitudinal defects in accordance with Table K305.1.2.

(6) DELETED.

(7) Galvanized pipe furnished to this specification is not permitted for pressure containing service. See para. K323.4.2(b).

(8) If this grade is cold expanded, the most severely deformed portion of a representative sample shall be impact tested in accordance with para. K323.3.

(9) DELETED.

(10) DELETED.

(11) No welding is permitted on this material.

(12) DELETED.

(13) Welds shall be of a design that permits fully interpretable radiographic examination; joint quality factor, E_j, shall be 1.00 in accordance with para. K302.3.4.

(14) Pipe furnished to this specification shall be supplied in the solution heat treated condition.

(15) This unstabilized grade of stainless steel increasingly tends to precipitate intergranular carbides as the carbon content increases above 0.03%. See also para. F323.4(c)(2).

(16) For material thickness >127 mm (5 in.), the specified minimum tensile strength is 448 MPa (65 ksi).

(17) For material thickness >127 mm (5 in.), the specified minimum tensile strength is 483 MPa (70 ksi).

(18) Stress values shown are for the lowest strength base material permitted by the specification to be used in the manufacture of this grade of fitting. If a higher strength base material is used, the higher stress values for that material may be used in design.

(19) Stress values shown are applicable for both product specification levels (PSL 1 and PSL 2) and any delivery condition and service condition allowed for the applicable pipe strength level in API 5L.

(20) This steel may develop embrittlement in service above 260°C (500°F).

(20)

Table K-1 Allowable Stresses in Tension for Metals for Chapter IX

Numbers in Parentheses Refer to Notes for Appendix K Table; Specifications Are ASTM Unless Otherwise Indicated

Nominal Composition	Product Form	Spec. No.	Type or Grade	UNS No.	P-No. (1)	Notes	Specified Min. Strength, ksi Tensile	Specified Min. Strength, ksi Yield
Carbon steel	Smls. pipe	A53	B	K03005	1	(5) (7)	60	35
Carbon steel	Smls. pipe	A106	B	K03006	1	(5)	60	35
Carbon steel	Smls. pipe	A333	6	K03006	1	(5)	60	35
Carbon steel	Smls. tube	A334	6	K03006	1	(5)	60	35
Carbon steel	Smls. pipe	API 5L	B	...	1	(5) (8)	60	35
Carbon steel	Smls. tube	A210	A-1	K02707	1	(5)	60	37
Carbon steel	Smls. pipe	A106	C	K03501	1	(5)	70	40
Carbon steel	Smls. tube	A210	C	K03501	1	(5)	70	40
Carbon steel	Smls. pipe	API 5L	X42	...	1	(5) (8) (19)	60.2	42.1
Carbon steel	Smls. pipe	API 5L	X46	...	1	(5) (8) (19)	63.1	46.4
Carbon steel	Smls. pipe	API 5L	X52	...	1	(5) (8) (19)	66.7	52.2
Carbon steel	Smls. pipe	API 5L	X56	...	1	(5) (8) (19)	71.1	56.6
Carbon steel	Smls. pipe	API 5L	X60	...	1	(5) (8) (19)	75.4	60.2
Carbon steel	Smls. pipe	API 5L	X65	...	1	(5) (8) (19)	77.6	65.3
Carbon steel	Smls. pipe	API 5L	X70	...	1	(5) (8) (19)	82.7	70.3
Carbon steel	Smls. pipe	API 5L	X80	...	1	(5) (8) (19)	90.6	80.5
Carbon steel	Smls. ftgs.	A234	WPB	K03006	1	...	60	35
Carbon steel	Smls. ftgs.	A420	WPL6	K03006	1	...	60	35
Carbon steel	Forgings	A105	...	K03504	1	...	70	36
Carbon steel	Forgings	A350	LF2	K03011	1	...	70	36
Carbon steel	Smls. ftgs.	A234	WPC	K03501	1	...	70	40
Carbon steel	Forgings	A694	F42	K03014	1	...	60	42
Carbon steel	Forgings	A694	F46	K03014	1	...	60	46
Carbon steel	Forgings	A694	F48	K03014	1	...	62	48
Carbon steel	Forgings	A694	F50	K03014	1	...	64	50
Carbon steel	Forgings	A694	F52	K03014	1	...	66	52
Carbon steel	Forgings	A694	F56	K03014	1	...	68	56
Carbon steel	Forgings	A694	F60	K03014	1	...	75	60
Carbon steel	Forgings	A694	F65	K03014	1	...	77	65
Carbon steel	Forgings	A694	F70	K03014	1	...	82	70
C–$\frac{1}{2}$Mo	Smls. pipe	A335	P1	K11522	3	(5)	55	30
1Cr–$\frac{1}{2}$Mo	Smls. pipe	A335	P12	K11562	4	(5)	60	32
1$\frac{1}{4}$Cr–$\frac{1}{2}$Mo–Si	Smls. pipe	A335	P11	K11597	4	(5)	60	30
2$\frac{1}{4}$Cr–1Mo	Smls. pipe	A335	P22	K21590	5A	(5)	60	30
5Cr–$\frac{1}{2}$Mo	Smls. pipe	A335	P5	K41545	5B	(5)	60	30
3$\frac{1}{2}$Ni	Smls. pipe	A333	3	K31918	9B	(5)	65	35
3$\frac{1}{2}$Ni	Smls. tube	A334	3	K31918	9B	(5)	65	35

Table K-1 Allowable Stresses in Tension for Metals for Chapter IX

Numbers in Parentheses Refer to Notes for Appendix K Table; Specifications Are ASTM Unless Otherwise Indicated

Allowable Stress, ksi (Multiply by 1000 to Obtain psi), for Metal Temperature, °F, Not Exceeding [Notes (2)–(4)]									
Min. Temp. to 100	200	300	400	500	600	650	700	Type or Grade	Spec. No.
28.0	25.7	24.8	23.9	22.8	21.4	20.7	19.4	B	A53
28.0	25.7	24.8	23.9	22.8	21.4	20.7	20.1	B	A106
28.0	25.7	24.8	23.9	22.8	21.4	20.7	20.1	6	A333
28.0	25.7	24.8	23.9	22.8	21.4	20.7	20.1	6	A334
28.0	25.7	24.8	23.9	22.8	21.4	20.7	20.1	B	API 5L
29.6	27.1	26.2	25.3	24.2	22.7	21.9	21.2	A-1	A210
32.0	29.3	28.3	27.4	26.1	24.6	23.7	22.9	C	A106
32.0	29.3	28.3	27.4	26.1	24.6	23.7	22.9	C	A210
33.7	30.1	27.4	25.2	23.8	22.7	22.2	21.8	X42	API 5L
36.5	33.2	30.2	27.8	26.2	25.0	24.6	24.1	X46	API 5L
39.6	37.4	34.0	31.3	29.4	28.2	27.6	27.0	X52	API 5L
42.6	40.5	36.8	33.9	31.9	30.6	29.9	29.3	X56	API 5L
45.2	43.0	39.1	36.1	33.9	32.5	31.8	31.2	X60	API 5L
47.6	45.3	42.5	39.1	36.8	35.2	34.6	33.8	X65	API 5L
51.0	48.5	45.8	42.2	...	...	...	...	X70	API 5L
57.0	54.2	52.0	48.2	...	...	...	...	X80	API 5L
28.0	25.7	24.8	23.9	22.8	21.4	20.7	20.1	WPB	A234
28.0	25.7	24.8	23.9	22.8	21.4	20.7	20.1	WPL6	A420
28.8	26.4	25.4	24.6	23.4	22.1	21.4	20.6	...	A105
28.8	26.4	25.4	24.6	23.4	22.1	21.4	20.6	LF2	A350
32.0	29.3	28.3	27.4	26.1	24.6	23.7	22.9	WPC	A234
33.6	29.7	27.2	25.3	23.8	...	...	...	F42	A694
35.3	32.5	29.8	27.7	26.0	...	...	...	F46	A694
36.7	33.9	31.0	28.9	27.1	...	...	...	F48	A694
38.0	35.3	32.3	30.1	28.2	...	...	...	F50	A694
39.3	36.7	33.7	31.3	29.4	...	...	...	F52	A694
41.3	39.1	36.2	33.7	31.7	...	...	...	F56	A694
45.0	42.4	38.8	36.1	33.9	...	...	...	F60	A694
47.3	44.8	42.1	39.1	36.7	...	...	...	F65	A694
50.7	47.9	45.3	42.2	...	...	...	...	F70	A694
24.0	22.6	21.7	20.9	20.2	19.6	19.3	18.9	P1	A335
25.6	23.1	21.8	20.8	20.1	19.5	19.2	19.0	P12	A335
24.0	22.2	21.0	20.2	19.5	18.8	18.5	18.1	P11	A335
24.0	22.4	21.8	21.5	21.5	21.5	21.5	21.5	P22	A335
24.0	21.7	20.9	20.6	20.5	20.2	19.9	19.6	P5	A335
28.0	25.7	24.7	23.9	22.7	21.0	20.0	18.9	3	A333
28.0	25.7	24.7	23.9	22.7	21.0	20.0	18.9	3	A334

Table K-1 Allowable Stresses in Tension for Metals for Chapter IX (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix K Table; Specifications Are ASTM Unless Otherwise Indicated

							Specified Min. Strength, ksi	
Nominal Composition	Product Form	Spec. No.	Type or Grade	UNS No.	P-No. (1)	Notes	Tensile	Yield
9Ni	Smls. pipe	A333	8	K81340	11A	(5)	100	75
9Ni	Smls. tube	A334	8	K81340	11A	(5)	100	75
C–½Mo	Forgings	A182	F1	K12822	3	...	70	40
1Cr–½Mo	Forgings	A182	F12, Cl. 2	K11564	4	...	70	40
1¼Cr–½Mo–Si	Forgings	A182	F11, Cl. 2	K11572	4	...	70	40
2¼Cr–1Mo	Forgings	A182	F22, Cl. 3	K21590	5A	...	75	45
5Cr–½Mo	Forgings	A182	F5	K41545	5B	...	70	40
2Ni–1½Cr–¼Mo–V	Forgings	A723	1, Cl. 1	K23550	...	(11)	115	100
2Ni–1½Cr–¼Mo–V	Forgings	A723	1, Cl. 2	K23550	...	(11)	135	120
2Ni–1½Cr–¼Mo–V	Forgings	A723	1, Cl. 3	K23550	...	(11)	155	140
2¾Ni–1½Cr–½Mo–V	Forgings	A723	2, Cl. 1	K23550	...	(11)	115	100
2¾Ni–1½Cr–½Mo–V	Forgings	A723	2, Cl. 2	K23550	...	(11)	135	120
2¾Ni–1½Cr–½Mo–V	Forgings	A723	2, Cl. 3	K23550	...	(11)	155	140
3½Ni	Smls ftgs.	A420	WPL3	K31918	9B	...	65	35
3½Ni	Forgings	A350	LF3	K32025	9B	...	70	37.5
3½Ni–1¾Cr–½Mo–V	Forgings	A508	4N, Cl. 2	K22375	11B	...	115	100
4Ni–1½Cr–½Mo–V	Forgings	A723	3, Cl. 1	K23550	...	(11)	115	100
4Ni–1½Cr–½Mo–V	Forgings	A723	3, Cl. 2	K23550	...	(11)	135	120
4Ni–1½Cr–½Mo–V	Forgings	A723	3, Cl. 3	K23550	...	(11)	155	140
9Ni	Smls. ftgs.	A420	WPL8	K81340	11A	...	100	75

Table K-1 Allowable Stresses in Tension for Metals for Chapter IX (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix K Table; Specifications Are ASTM Unless Otherwise Indicated

Allowable Stress, ksi (Multiply by 1000 to Obtain psi), for Metal Temperature, °F, Not Exceeding [Notes (2)–(4)]									
Min. Temp. to 100	200	300	400	500	600	650	700	Type or Grade	Spec. No.
58.3	57.3	53.6	...	...	...	...	...	8	A333
58.3	57.3	53.6	...	...	...	...	...	8	A334
32.0	30.1	28.9	27.8	27.0	26.2	25.7	25.2	F1	A182
32.0	29.0	27.2	26.0	25.1	24.4	24.1	23.7	F12, Cl. 2	A182
32.0	29.5	28.1	27.0	26.0	25.1	24.6	24.2	F11, Cl. 2	A182
36.0	33.0	31.5	30.5	29.8	29.2	28.9	28.5	F22, Cl. 3	A182
32.0	29.0	27.8	27.5	27.3	26.9	26.6	26.1	F5	A182
71.7	70.3	69.5	69.0	68.5	68.0	66.9	65.5	1, Cl. 1	A723
85.0	83.4	82.4	81.8	81.3	80.6	79.4	77.6	1, Cl. 2	A723
98.3	96.5	95.3	94.6	94.0	93.2	91.8	89.8	1, Cl. 3	A723
71.7	70.3	69.5	69.0	68.5	68.0	66.9	65.5	2, Cl. 1	A723
85.0	83.4	82.4	81.8	81.3	80.6	79.4	77.6	2, Cl. 2	A723
98.3	96.5	95.3	94.6	94.0	93.2	91.8	89.8	2, Cl. 3	A723
28.0	25.7	24.7	23.9	22.7	21.0	20.0	...	WPL3	A420
30.0	27.4	26.6	25.6	24.3	22.6	21.4	...	LF3	A350
71.7	69.7	68.7	67.7	66.9	65.9	65.1	...	4N, Cl. 2	A508
71.7	70.3	69.5	69.0	68.5	68.0	66.9	65.5	3, Cl. 1	A723
85.0	83.4	82.4	81.8	81.3	80.6	79.4	77.6	3, Cl. 2	A723
98.3	96.5	95.3	94.6	94.0	93.2	91.8	89.8	3, Cl. 3	A723
58.3	57.3	53.6	...	...	...	...	...	WPL8	A420

Table K-1 Allowable Stresses in Tension for Metals for Chapter IX (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix K Table; Specifications Are ASTM Unless Otherwise Indicated

Nominal Composition	Product Form	Spec. No.	Type or Grade	UNS No.	Thickness Range, in.	P-No. (1)	Notes	Specified Min. Strength, ksi Tensile	Specified Min. Strength, ksi Yield
16Cr–12Ni–2Mo	Smls. & wld. pipe	A312	TP316L	S31603	...	8	(5) (13)	70	25
16Cr–12Ni–2Mo	Wld. pipe	A358	316L, Cl. 1 & 3	S31603	...	8	(5) (13) (14)	70	25
16Cr–12Ni–2Mo–N	Smls. & wld. pipe	A312	TP316LN	S31653	...	8	(5) (13)	75	30
16Cr–12Ni–2Mo–N	Wld. pipe	A358	316LN, Cl. 1 & 3	S31653	...	8	(5) (13) (14)	75	30
18Cr–8Ni	Smls. & wld. pipe	A312	TP304L	S30403	...	8	(5) (13)	70	25
18Cr–8Ni	Wld. pipe	A358	304L, Cl. 1 & 3	S30403	...	8	(5) (13) (14)	70	25
18Cr–8Ni–N	Smls. & wld. pipe	A312	TP304LN	S30453	...	8	(5) (13)	75	30
18Cr–8Ni–N	Wld. pipe	A358	304LN, Cl. 1 & 3	S30453	...	8	(5) (13) (14)	75	30
18Cr–10Ni–Ti	Smls. pipe	A312	TP321	S32100	>3/8	8	(5)	70	25
18Cr–10Ni–Ti	Smls. pipe	A312	TP321	S32100	≤3/8	8	(5)	75	30
18Cr–10Ni–Ti	Wld. pipe	A312	TP321	S32100	...	8	(5) (13)	75	30
18Cr–10Ni–Ti	Wld. pipe	A358	321, Cl. 1 & 3	S32100	...	8	(5) (13) (14)	75	30
18Cr–8Ni	Smls. & wld. pipe	A312	TP304	S30400	...	8	(5) (13) (15)	75	30
18Cr–8Ni	Wld. pipe	A358	304, Cl. 1 & 3	S30400	...	8	(5) (13) (14) (15)	75	30
16Cr–12Ni–2Mo	Smls. & wld. pipe	A312	TP316	S31600	...	8	(5) (13) (15)	75	30
16Cr–12Ni–2Mo	Wld. pipe	A358	316, Cl. 1 & 3	S31600	...	8	(5) (13) (14) (15)	75	30
18Cr–13Ni–3Mo	Smls. & wld. pipe	A312	TP317	S31700	...	8	(5) (13) (15)	75	30
18Cr–10Ni–Cb	Smls. & wld. pipe	A312	TP347	S34700	...	8	(5) (13)	75	30
18Cr–10Ni–Cb	Wld. pipe	A358	347, Cl. 1 & 3	S34700	...	8	(5) (13) (14)	75	30
18Cr–8Ni–N	Smls. & wld. pipe	A312	TP304N	S30451	...	8	(5) (13) (15)	80	35
18Cr–8Ni–N	Wld. pipe	A358	304N, Cl. 1 & 3	S30451	...	8	(5) (13) (14) (15)	80	35
16Cr–12Ni–2Mo–N	Smls. & wld. pipe	A312	TP316N	S31651	...	8	(5) (13) (15)	80	35
16Cr–12Ni–2Mo–N	Wld. pipe	A358	316N, Cl. 1 & 3	S31651	...	8	(5) (13) (14) (15)	80	35
22Cr–5Ni–3Mo–N	Smls. & wld. tube	A789	...	S31803	...	10H	(5) (13) (20)	90	65
22Cr–5Ni–3Mo–N	Smls. & wld. pipe	A790	...	S31803	...	10H	(5) (13) (20)	90	65
22Cr–5Ni–3Mo–N	Smls. & wld. pipe	A790	2205	S32205	...	10H	(5) (13) (20)	95	65
22Cr–5Ni–3Mo–N	Wld. pipe	A928	Cl. 1, 3, & 4	S31803	...	10H	(5) (13) (20)	90	65
22Cr–5Ni–3Mo–N	Wld. pipe	A928	2205, Cl. 1, 3, & 4	S32205	...	10H	(5) (13) (20)	95	65
22Cr–5Ni–3Mo–N	Smls. & wld. tube	A789	...	S32205	...	10H	(5) (13) (20)	95	70

Table K-1 Allowable Stresses in Tension for Metals for Chapter IX (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix K Table; Specifications Are ASTM Unless Otherwise Indicated

Allowable Stress, ksi (Multiply by 1000 to Obtain psi), for Metal Temperature, °F, Not Exceeding [Notes (2)–(4)]									
Min. Temp. to 100	200	300	400	500	600	650	700	Type or Grade	Spec. No.
20.0	17.0	15.2	14.0	13.1	12.5	12.2	12.0	TP316L	A312
20.0	17.0	15.2	14.0	13.1	12.5	12.2	12.0	316L, Cl. 1 & 3	A358
24.0	20.4	18.3	16.8	15.6	14.6	14.2	13.8	TP316LN	A312
24.0	20.4	18.3	16.8	15.6	14.6	14.2	13.8	316LN, Cl. 1 & 3	A358
20.0	17.1	15.4	14.0	13.1	12.4	12.2	12.0	TP304L	A312
20.0	17.1	15.4	14.0	13.1	12.4	12.2	12.0	304L, Cl. 1 & 3	A358
24.0	20.0	17.9	16.6	15.5	14.7	14.4	14.1	TP304LN	A312
24.0	20.0	17.9	16.6	15.5	14.7	14.4	14.1	304LN, Cl. 1 & 3	A358
20.0	18.0	16.6	15.4	14.3	13.5	13.2	13.0	TP321	A312
24.0	21.6	19.8	18.4	17.2	16.2	15.8	15.5	TP321	A312
24.0	21.6	19.8	18.4	17.2	16.2	15.8	15.5	TP321	A312
24.0	21.6	19.8	18.4	17.2	16.2	15.8	15.5	321, Cl. 1 & 3	A358
24.0	20.0	17.9	16.6	15.5	14.7	14.4	14.1	TP304	A312
24.0	20.0	17.9	16.6	15.5	14.7	14.4	14.1	304, Cl. 1 & 3	A358
24.0	20.7	18.7	17.1	16.0	15.1	14.8	14.6	TP316	A312
24.0	20.7	18.7	17.1	16.0	15.1	14.8	14.6	316, Cl. 1 & 3	A358
24.0	20.7	18.7	17.1	16.0	15.1	14.8	14.6	TP317	A312
24.0	22.1	20.6	19.2	18.1	17.2	16.9	16.6	TP347	A312
24.0	22.1	20.6	19.2	18.1	17.2	16.9	16.6	347, Cl. 1 & 3	A358
28.0	22.9	20.0	18.1	16.8	15.9	15.6	15.3	TP304N	A312
28.0	22.9	20.0	18.1	16.8	15.9	15.6	15.3	304N, Cl. 1 & 3	A358
28.0	24.8	22.8	21.1	19.8	18.7	18.2	17.8	TP316N	A312
28.0	24.8	22.8	21.1	19.8	18.7	18.2	17.8	316N, Cl. 1 & 3	A358
51.7	46.2	43.0	41.0	39.7	...	...	...	...	A789
51.7	46.2	43.0	41.0	39.7	...	...	...	...	A790
52.0	46.2	43.0	41.0	39.7	...	...	...	2205	A790
51.7	46.2	43.0	41.0	39.7	...	...	...	Cl. 1, 3, & 4	A928
52.0	46.2	43.0	41.0	39.7	...	...	...	2205, Cl. 1, 3, & 4	A928
55.0	49.8	46.3	44.2	42.7	...	...	...	...	A789

Table K-1 Allowable Stresses in Tension for Metals for Chapter IX (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix K Table; Specifications Are ASTM Unless Otherwise Indicated

Nominal Composition	Product Form	Spec. No.	Type or Grade	UNS No.	Thick-ness Range, in.	P-No. (1)	Notes	Specified Min. Strength, ksi Tensile	Yield
25Cr–7Ni–4Mo–N	Smls. & wld. tube	A789	...	S32750	...	10H	(5) (13) (20)	116	80
25Cr–7Ni–4Mo–N	Smls. & wld. pipe	A790	2507	S32750	...	10H	(5) (13) (20)	116	80
25Cr–7Ni–4Mo–N	Wld. pipe	A928	2507, Cl. 1, 3, & 4	S32750	...	10H	(5) (13) (20)	116	80
16Cr–12Ni–2Mo	Forgings	A182	F316L	S31603	...	8	(16)	70	25
16Cr–12Ni–2Mo	Smls. & wld. ftgs.	A403	WP316L, Cl. S & WX	S31603	...	8	(13)	70	25
16Cr–12Ni–2Mo–N	Forgings	A182	F316LN	S31653	...	8	(17)	75	30
16Cr–12Ni–2Mo–N	Smls. & wld. ftgs.	A403	WP316LN, Cl. S & WX	S31653	...	8	(13)	75	30
18Cr–8Ni	Forgings	A182	F304L	S30403	...	8	(16)	70	25
18Cr–8Ni	Smls. & wld. ftgs.	A403	WP304L, Cl. S & WX	S30403	...	8	(13)	70	25
18Cr–8Ni–N	Forgings	A182	F304LN	S30453	...	8	(17)	75	30
18Cr–8Ni–N	Smls. & wld. ftgs.	A403	WP304LN, Cl. S & WX	S30453	...	8	(13)	75	30
18Cr–10Ni–Ti	Forgings	A182	F321	S32100	...	8	(17)	75	30
18Cr–10Ni–Ti	Smls. & wld. ftgs.	A403	WP321, Cl. S & WX	S32100	...	8	(13)	75	30
18Cr–8Ni	Forgings	A182	F304	S30400	...	8	(15) (17)	75	30
18Cr–8Ni	Smls. & wld. ftgs.	A403	WP304, Cl. S & WX	S30400	...	8	(13) (15)	75	30
16Cr–12Ni–2Mo	Forgings	A182	F316	S31600	...	8	(15) (17)	75	30
16Cr–12Ni–2Mo	Smls. & wld. ftgs.	A403	WP316, Cl. S & WX	S31600	...	8	(13) (15)	75	30
18Cr–13Ni–3Mo	Smls. & wld. ftgs.	A403	WP317, Cl. S & WX	S31700	...	8	(13) (15)	75	30
18Cr–10Ni–Cb	Forgings	A182	F347	S34700	...	8	(17)	75	30
18Cr–10Ni–Cb	Smls. & wld. ftgs.	A403	WP347, Cl. S & WX	S34700	...	8	(13)	75	30
18Cr–8Ni–N	Forgings	A182	F304N	S30451	...	8	(15)	80	35
18Cr–8Ni–N	Smls. & wld. ftgs.	A403	WP304N, Cl. S & WX	S30451	...	8	(13) (15)	80	35
16Cr–12Ni–2Mo–N	Forgings	A182	F316N	S31651	...	8	(15)	80	35
16Cr–12Ni–2Mo–N	Smls. & wld. ftgs.	A403	WP316N, Cl. S & WX	S31651	...	8	(13) (15)	80	35
22Cr–5Ni–3Mo–N	Forgings	A182	F51	S31803	...	10H	(20)	90	65
22Cr–5Ni–3Mo–N	Smls. & wld. ftgs.	A815	WPS31803, Cl. WP-S & WP-WX	S31803	...	10H	(13) (20)	90	65
22Cr–5Ni–3Mo–N	Forgings	A182	F60	S32205	...	10H	(20)	95	65

Table K-1 Allowable Stresses in Tension for Metals for Chapter IX (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix K Table; Specifications Are ASTM Unless Otherwise Indicated

Allowable Stress, ksi (Multiply by 1000 to Obtain psi), for Metal Temperature, °F, Not Exceeding [Notes (2)–(4)]									
Min. Temp. to 100	200	300	400	500	600	650	700	Type or Grade	Spec. No.
64.0	56.4	51.8	48.6	46.6	...	...	...	...	A789
64.0	56.4	51.8	48.6	46.6	...	...	...	2507	A790
64.0	56.4	51.8	48.6	46.6	...	...	...	2507, Cl. 1, 3, & 4	A928
20.0	17.0	15.2	14.0	13.1	12.5	12.2	12.0	F316L	A182
20.0	17.0	15.2	14.0	13.1	12.5	12.2	12.0	WP316L, Cl. S & WX	A403
24.0	20.4	18.3	16.8	15.6	14.6	14.2	13.8	F316LN	A182
24.0	20.4	18.3	16.8	15.6	14.6	14.2	13.8	WP316LN, Cl. S & WX	A403
20.0	17.1	15.4	14.0	13.1	12.4	12.2	12.0	F304L	A182
20.0	17.1	15.4	14.0	13.1	12.4	12.2	12.0	WP304L, Cl. S & WX	A403
24.0	20.0	17.9	16.6	15.5	14.7	14.4	14.1	F304LN	A182
24.0	20.0	17.9	16.6	15.5	14.7	14.4	14.1	WP304LN, Cl. S & WX	A403
24.0	21.6	19.8	18.4	17.2	16.2	15.8	15.5	F321	A182
24.0	21.6	19.8	18.4	17.2	16.2	15.8	15.5	WP321, Cl. S & WX	A403
24.0	20.0	17.9	16.6	15.5	14.7	14.4	14.1	F304	A182
24.0	20.0	17.9	16.6	15.5	14.7	14.4	14.1	WP304, Cl. S & WX	A403
24.0	20.7	18.7	17.1	16.0	15.1	14.8	14.6	F316	A182
24.0	20.7	18.7	17.1	16.0	15.1	14.8	14.6	WP316, Cl. S & WX	A403
24.0	20.7	18.7	17.1	16.0	15.1	14.8	14.6	WP317, Cl. S & WX	A403
24.0	22.1	20.6	19.2	18.1	17.2	16.9	16.6	F347	A182
24.0	22.1	20.6	19.2	18.1	17.2	16.9	16.6	WP347, Cl. S & WX	A403
28.0	22.9	20.0	18.1	16.8	15.9	15.6	15.3	F304N	A182
28.0	22.9	20.0	18.1	16.8	15.9	15.6	15.3	WP304N, Cl. S & WX	A403
28.0	24.8	22.8	21.1	19.8	18.7	18.2	17.8	F316N	A182
28.0	24.8	22.8	21.1	19.8	18.7	18.2	17.8	WP316N, Cl. S & WX	A403
51.7	46.2	43.0	41.0	39.7	...	...	...	F51	A182
51.7	46.2	43.0	41.0	39.7	...	...	...	WPS31803, Cl. WP-S & WP-WX	A815
52.0	46.2	43.0	41.0	39.7	...	...	...	F60	A182

Table K-1 Allowable Stresses in Tension for Metals for Chapter IX (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix K Table; Specifications Are ASTM Unless Otherwise Indicated

Nominal Composition	Product Form	Spec. No.	Type or Grade	UNS No.	Thick-ness Range, in.	P-No. (1)	Notes	Specified Min. Strength, ksi	
								Tensile	Yield
22Cr–5Ni–3Mo–N	Smls. & wld. ftgs.	A815	WPS32205, Cl. WP-S & WP-WX	S32205	...	10H	(13) (20)	95	65
25Cr–7Ni–4Mo–N	Forgings	A182	F53	S32750	...	10H	(20)	116	80
25Cr–7Ni–4Mo–N	Smls. & wld. ftgs.	A815	WPS32750, Cl. S & WX	S32750	...	10H	(13) (20)	116	80

Table K-1 Allowable Stresses in Tension for Metals for Chapter IX (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix K Table; Specifications Are ASTM Unless Otherwise Indicated

Allowable Stress, ksi (Multiply by 1000 to Obtain psi), for Metal Temperature, °F, Not Exceeding [Notes (2)–(4)]									
Min. Temp. to 100	200	300	400	500	600	650	700	Type or Grade	Spec. No.
52.0	46.2	43.0	41.0	39.7	...	...	...	WPS32205, Cl. WP-S & WP-WX	A815
64.0	56.4	51.8	48.6	46.6	...	...	...	F53	A182
64.0	56.4	51.8	48.6	46.6	...	...	...	WPS32750, Cl. S & WX	A815

Table K-1 Allowable Stresses in Tension for Metals for Chapter IX (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix K Table; Specifications Are ASTM Unless Otherwise Indicated

Nominal Composition	Product Form	Spec. No.	P-No. (1)	UNS Number	Condition	Size or Thickness Range, in.	Notes	Specified Min. Strength, ksi Tensile	Specified Min. Strength, ksi Yield
67Ni–30Cu	Smls. pipe & tube	B165	42	N04400	Annealed	>5 O.D.	(5)	70	25
72Ni–15Cu–8Fe	Smls. pipe & tube	B167	43	N06600	H.W.	>5 O.D.	(5)	75	25
72Ni–15Cu–8Fe	Smls. pipe & tube	B167	43	N06600	H.W. ann.	>5 O.D.	(5)	75	25
67Ni–30Cu	Smls. pipe & tube	B165	42	N04400	Annealed	≤5 O.D.	(5)	70	28
72Ni–15Cu–8Fe	Smls. pipe & tube	B167	43	N06600	H.W.	≤5 O.D.	(5)	80	30
72Ni–15Cu–8Fe	Smls. pipe & tube	B167	43	N06600	H.W. ann.	≤5 O.D.	(5)	80	30
72Ni–15Cu–8Fe	Smls. pipe & tube	B167	43	N06600	C.W. ann.	>5 O.D.	(5)	80	30
72Ni–15Cu–8Fe	Smls. pipe & tube	B167	43	N06600	C.W. ann.	≤5 O.D.	(5)	80	35
54Ni–16Mo–15Cr	Smls. pipe & tube	B622	43	N10276	...	All	(5)	100	41
67Ni–30Cu	Smls. pipe & tube	B165	42	N04400	Str. rel.	All	(5)	85	55
67Ni–30Cu	Smls. & wld. ftgs.	B366	42	N04400	...	All	(13) (18)	70	25
67Ni–30Cu	Forgings	B564	42	N04400	Annealed	All	...	70	25
72Ni–15Cu–8Fe	Smls. & wld. ftgs.	B366	43	N06600	...	All	(13) (18)	75	25
72Ni–15Cu–8Fe	Forgings	B564	43	N06600	Annealed	All	...	80	35
54Ni–16Mo–15Cr	Smls. & wld. ftgs.	B366	43	N10276	...	All	(13)	100	41
54Ni–16Mo–15Cr	Forgings	B564	43	N10276	Annealed	All	...	100	41
67Ni–30Cu	Rod and bar	B164	42	N04400	Annealed	All	...	70	25
72Ni–15Cu–8Fe	Rod and bar	B166	43	N06600	C.W. ann. & H.W. ann.	All	...	80	35
72Ni–15Cu–8Fe	Rod and bar	B166	43	N06600	H.W., A.W.	Sq., rec. & hex.	...	85	35
72Ni–15Cu–8Fe	Rod and bar	B166	43	N06600	H.W., A.W.	>3 rd.	...	85	35
67Ni–30Cu	Rod and bar	B164	42	N04400	H.W.	Rod, sq. & rec. ≤12, hex. ≤2⅛	...	80	40
72Ni–15Cu–8Fe	Rod and bar	B166	43	N06600	H.W., A.W.	½ to 3 rd.	...	90	40
54Ni–16Mo–15Cr	Rod	B574	43	N10276	...	All	...	100	41
72Ni–15Cu–8Fe	Rod and bar	B166	43	N06600	H.W., A.W.	¼ to ½ rd.	...	95	45

Table K-1 Allowable Stresses in Tension for Metals for Chapter IX (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix K Table; Specifications Are ASTM Unless Otherwise Indicated

Allowable Stress, ksi (Multiply by 1000 to Obtain psi), for Metal Temperature, °F, Not Exceeding [Notes (2)–(4)]									
Min. Temp. to 100	200	300	400	500	600	650	700	UNS Number	Spec. No.
20.0	17.5	16.3	15.8	15.8	15.8	15.8	15.7	N04400	B165
20.0	19.0	18.2	17.5	16.8	16.2	15.9	15.7	N06600	B167
20.0	19.0	18.2	17.5	16.8	16.2	15.9	15.7	N06600	B167
22.4	19.6	18.2	17.7	17.6	17.6	17.6	17.5	N04400	B165
24.0	22.9	21.9	21.0	20.2	19.4	19.1	18.8	N06600	B167
24.0	22.9	21.9	21.0	20.2	19.4	19.1	18.8	N06600	B167
24.0	22.9	21.9	21.0	20.2	19.4	19.1	18.8	N06600	B167
28.0	25.6	25.0	24.6	24.2	23.9	23.8	23.5	N06600	B167
32.8	29.8	27.6	25.6	23.8	22.4	21.8	21.4	N10276	B622
44.0	41.4	40.3	39.8	39.4	...	...	...	N04400	B165
20.0	17.5	16.3	15.8	15.8	15.8	15.8	15.7	N04400	B366
20.0	17.5	16.3	15.8	15.8	15.8	15.8	15.7	N04400	B564
20.0	19.0	18.2	17.5	16.8	16.2	15.9	15.7	N06600	B366
28.0	25.6	25.0	24.6	24.2	23.9	23.8	23.5	N06600	B564
32.8	29.8	27.6	25.6	23.8	22.4	21.8	21.4	N10276	B366
32.8	29.8	27.6	25.6	23.8	22.4	21.8	21.4	N10276	B564
20.0	17.5	16.3	15.8	15.8	15.8	15.8	15.7	N04400	B164
28.0	25.6	25.0	24.6	24.2	23.9	23.8	23.5	N06600	B166
28.0	26.6	25.8	25.5	25.5	25.4	25.4	25.2	N06600	B166
28.0	26.6	25.8	25.5	25.5	25.4	25.4	25.2	N06600	B166
32.0	31.0	29.7	28.7	28.2	27.8	27.5	27.2	N04400	B164
32.0	30.4	29.6	29.1	29.1	29.1	28.9	28.7	N06600	B166
32.8	29.8	27.6	25.6	23.8	22.4	21.8	21.4	N10276	B574
36.0	34.2	33.4	32.8	32.7	32.7	32.5	32.3	N06600	B166

Table K-1 Allowable Stresses in Tension for Metals for Chapter IX (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix K Table; Specifications Are ASTM Unless Otherwise Indicated

Nominal Composition	Product Form	Spec. No.	Grade	UNS No.	P-No. (1)	Notes	Specified Min. Strength, ksi Tensile	Specified Min. Strength, ksi Yield
Ti	Smls. pipe	B861	2	R50400	51	(5)	50	40
Ti	Smls. tube	B338	2	R50400	51	(5)	50	40
Ti–Pd	Smls. pipe	B861	7	R52400	51	(5)	50	40
Ti–Pd	Smls. tube	B338	7	R52400	51	(5)	50	40
Ti	Smls. pipe	B861	3	R50550	52	(5)	65	55
Ti	Smls. tube	B338	3	R50550	52	(5)	65	55
Ti	Smls. ftgs.	B363	WPT2	R50400	51	...	50	40
Ti	Forgings	B381	F-2	R50400	51	...	50	40
Ti–Pd	Forgings	B381	F-7	R52400	51	...	50	40
Ti	Smls. ftgs.	B363	WPT3	R50550	52	...	65	55
Ti	Forgings	B381	F-3	R50550	52	...	65	55

Table K-1 Allowable Stresses in Tension for Metals for Chapter IX (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix K Table; Specifications Are ASTM Unless Otherwise Indicated

Allowable Stress, ksi (Multiply by 1000 to Obtain psi), for Metal Temperature, °F, Not Exceeding [Notes (2)–(4)]									
Min. Temp. to 100	**200**	**300**	**400**	**500**	**600**	**650**	**700**	**Grade**	**Spec. No.**
30.0	25.0	20.5	15.7	11.8	9.1	...	...	2	B861
30.0	25.0	20.5	15.7	11.8	9.1	...	...	2	B338
30.0	25.0	20.5	15.7	11.8	9.1	...	...	7	B861
30.0	25.0	20.5	15.7	11.8	9.1	...	...	7	B338
40.0	33.1	26.8	21.6	17.4	13.7	...	...	3	B861
40.0	33.1	26.8	21.6	17.4	13.7	...	...	3	B338
30.0	25.0	20.5	15.7	11.8	9.1	...	...	WPT2	B363
30.0	25.0	20.5	15.7	11.8	9.1	...	...	F-2	B381
30.0	25.0	20.5	15.7	11.8	9.1	...	...	F-7	B381
40.0	33.1	26.8	21.6	17.4	13.7	...	...	WPT3	B363
40.0	33.1	26.8	21.6	17.4	13.7	...	...	F-3	B381

APPENDIX L
ALUMINUM ALLOY PIPE FLANGES

L300 GENERAL

This Appendix covers pressure–temperature ratings, materials, dimensions, and marking of forged aluminum alloy flanges, as an alternative to applying the rules in paras. 304.5.1(b) and 304.5.2(b). DN 15 (NPS ½) through DN 600 (NPS 24) flanges may be welding neck, slip-on, socket welding, lapped, or blind in ratings of Classes 150, 300, and 600.

Requirements and recommendations regarding bolting and gaskets are included.

L301 PRESSURE–TEMPERATURE RATINGS

L301.1 Ratings Basis

Ratings are maximum allowable working gage pressures at the temperatures shown in Tables L301.2M and L301.2U for the applicable material and pressure Class. For intermediate temperatures, linear interpolation is permitted.

L301.2 Ratings of Flanged Joints

(a) In addition to the considerations in para. F312.1, consideration must be given to the low modulus of elasticity of aluminum alloys. External moments should be limited, and controlled bolt tightening or other techniques may be necessary to achieve and maintain a leak-free joint.

(b) For ratings of slip-on and socket welding flanges made of Alloy 6061-T6, see Tables L301.2M and L301.2U, Note (3).

L301.3 Temperature Considerations

Application of the ratings in this Appendix to flanged joints at both high and low temperatures shall take into consideration the risk of leakage due to forces and moments developed in the connected piping or equipment. The following provisions are intended to minimize these risks.

L301.3.1 Flange Attachment. Slip-on and socket welding flanges are not recommended for service below −50°F if flanges are subject to thermal cycling.

L301.3.2 Differential Thermal Expansion and Conductivity. Because aluminum alloys have thermal expansion coefficients approximately twice those for steel, and thermal conductivity approximately three times that of steel, it may be necessary to provide for differential expansion and expansion rates between components of the flanged joint. Consideration shall be given to thermal transients (e.g., startup, shutdown, and upset) in addition to the operating temperature of the joint.

L301.4 Hydrostatic Test

A flange shall be capable of withstanding a hydrostatic test at 1.5 times its 100°F pressure rating.

L302 MARKING

Marking shall be in accordance with MSS SP-25, except as follows. Marking shall be stamped on the edge of each flange.

L302.1 Name

The manufacturer's name or trademark shall be applied.

L302.2 Material

The marking ASTM B247 shall be applied, followed by the applicable alloy and temper designations.

L302.3 Rating

The marking shall be the applicable rating Class — 150, 300, or 600.

L302.4 Designation

The marking B31.3L shall be applied.

L302.5 Size

The marking of NPS shall be applied. A reducing size shall be designated by its two nominal pipe sizes. See examples in Note (4) of Table 6, ASME B16.5.

Table L301.2M Pressure–Temperature Ratings (SI Units)

Material ASTM B247 Alloy and Temper	Class 150 Temperature [Note (1)]				Class 300 Temperature [Note (1)]				Class 600 Temperature [Note (1)]			
	38	66	93	121	38	66	93	121	38	66	93	121
3003-H112	275	275	240	240	725	690	655	655	1 415	1 380	1 345	1 275
6061-T6 [Note (2)]	1 895	1 860	1 825	1 795	4 965	4 895	4 825	4 655	9 930	9 790	9 655	9 345
6061-T6 [Note (3)]	1 265	1 240	1 215	1 195	3 310	3 265	3 215	3 105	6 620	6 525	6 435	6 230

GENERAL NOTE: Pressures are in kPa; temperatures are in °C.

NOTES:
(1) The minimum temperature is −269°C (−425°F). The maximum rating below 38°C (100°F) shall be the rating shown for 38°C.
(2) Ratings apply to welding neck, lapped, and blind flanges.
(3) Ratings apply to slip-on and socket welding flanges.

L303 MATERIALS

L303.1 Flange Material

Flanges shall be forgings conforming to ASTM B247. For specific alloys and tempers, see Tables L301.2M and L301.2U. For precautions in use, see para. 323.5 and Appendix F, para. F323.

L303.1.1 Repair Welding of Flanges. Repair welding of flanges manufactured to this Appendix shall be restricted to any damaged areas of the weld bevel of welding neck flanges unless specifically approved by the Purchaser after consideration of the extent, location, and effect on temper and ductility. Repair welding of any area other than the weld bevel on 6061-T6 welding neck flanges shall restrict the pressure/temperature ratings to those specified for slip-on and socket welding flanges in Tables L301.2M and L301.2U. Any repair welding shall be performed in accordance with para. 328.6.

L303.2 Bolting Materials

Bolting listed in Table L303.2 and in ASME B16.5, Table 1B, may be used subject to the following limitations.

L303.2.1 High Strength Bolting. Bolting materials listed as high strength in ASME B16.5, Table 1B, may be used in any flanged joints. See para. L305.

L303.2.2 Intermediate Strength Bolting. Bolting materials in Table L303.2, and bolting listed as intermediate strength in ASME B16.5, Table 1B, may be used in any flanged joints. See para. L305.

L303.2.3 Low Strength Bolting. Bolting materials listed as low strength in ASME B16.5, Table 1B, may be used in Classes 150 and 300 flanged joints. See para. L305.

L303.3 Gaskets

Gaskets listed in ASME B16.5, Nonmandatory Appendix B, Table B-1, Group Ia may be used with any rating Class and bolting.

L303.3.1 Gaskets for Low-Strength Bolting. If bolting listed as low strength (see para. L303.2.3) is used, gaskets listed in ASME B16.5, Nonmandatory Appendix B, Table B-1, Group Ia shall be used.

Table L301.2U Pressure–Temperature Ratings (U.S. Customary Units)

Material ASTM B247 Alloy and Temper	Class 150 Temperature [Note (1)]				Class 300 Temperature [Note (1)]				Class 600 Temperature [Note (1)]			
	100	150	200	250	100	150	200	250	100	150	200	250
3003-H112	40	40	35	35	105	100	95	95	205	200	195	185
6061-T6 [Note (2)]	275	270	265	260	720	710	700	675	1 440	1 420	1 400	1 355
6061-T6 [Note (3)]	185	180	175	175	480	475	465	450	960	945	935	905

GENERAL NOTE: Pressures are in psig; temperatures are in °F.

NOTES:
(1) The minimum temperature is −269°C (−425°F). The maximum rating below 38°C (100°F) shall be the rating shown for 38°C.
(2) Ratings apply to welding neck, lapped, and blind flanges.
(3) Ratings apply to slip-on and socket welding flanges.

Table L303.2 Aluminum Bolting Materials

ASTM Specification	Alloy	Temper
B211	2014	T6, T261
B211	2024	T4
B211	6061	T6, T261

GENERAL NOTE Repair welding of bolting material is prohibited.

L303.3.2 Gaskets for Class 150 Flanged Joints. It is recommended that only gaskets listed in ASME B16.5, Nonmandatory Appendix B, Table B-1, Group Ia be used.

L303.3.3 Gaskets for Class 300 and Higher Flanged Joints. It is recommended that only gaskets listed in ASME B16.5, Nonmandatory Appendix B, Table B-1, Group I be used. For gaskets in Group Ib, line flanges should be of the welding neck or lapped joint type; controlled-torque tightening practices should be used.

L304 DIMENSIONS AND FACINGS

(a) Flanges shall meet the dimensional and tolerance requirements of ASME B16.5.

(b) Flange facing and facing finish shall be in accordance with ASME B16.5, except that small male and female facings (on ends of pipe) shall not be used.

L305 DESIGN CONSIDERATIONS

The following design considerations are applicable to all flanged joints that incorporate a flange manufactured to this Appendix:

(a) The differential expansion within a flanged joint must be considered; also, see para. F312.

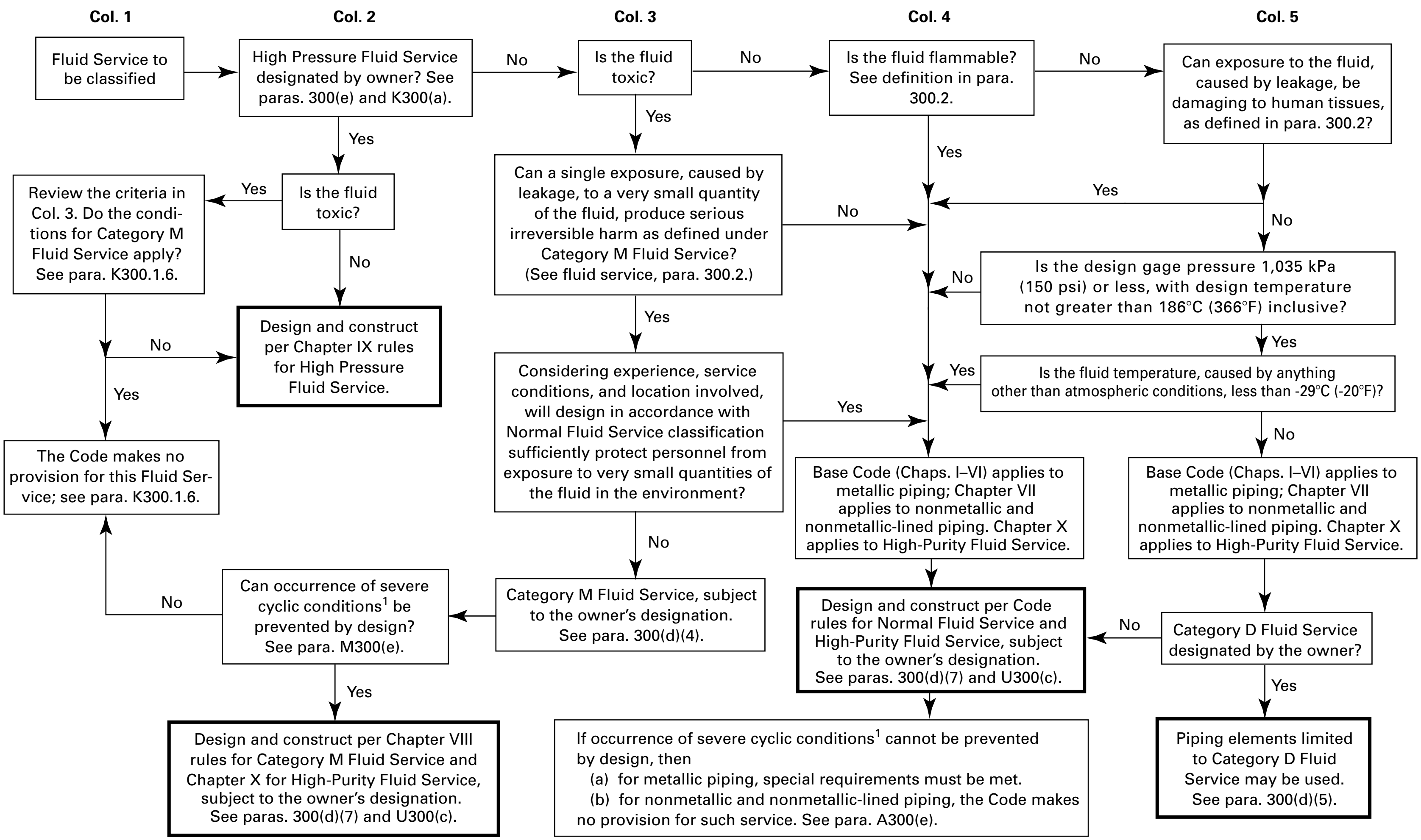
(b) Where a gasket other than those recommended in para. L303.3 is specified, the designer shall verify by calculations the ability of the selected bolting to seat the selected gasket and maintain a sealed joint under the expected operating conditions without over-stressing the components.

APPENDIX M
GUIDE TO CLASSIFYING FLUID SERVICES

See Figure M300.

(20)

Figure M300 Guide to Classifying Fluid Services



GENERAL NOTES:

(a) See paras. 300(b)(1), 300(d)(4) and (5), and 300(e) for decisions the owner must make. Other decisions are the designer's responsibility; see para. 300(b)(2).

(b) The term "fluid service" is defined in para. 300.2.

NOTE: (1) Severe cyclic conditions are defined in para. 300.2. Requirements are found in Chapter II, Parts 3 and 4, and in paras. 323.4.2 and 341.4.3.

APPENDIX N
APPLICATION OF ASME B31.3 INTERNATIONALLY

N100 INTRODUCTION

The ASME B31.3 Process Piping Code is an internationally recognized code for pressure piping. ISO 15649, Petroleum and natural gas industries — Piping, incorporates ASME B31.3 by normative reference and contains provisions for agreed common international practice that are additional to B31.3. ISO 15649 was prepared by Technical Committee TC 67, Subcommittee SC 6, Working Group WG 5.

N200 COMPLIANCE WITH THE EUROPEAN PRESSURE EQUIPMENT DIRECTIVE (PED)

The European Pressure Equipment Directive 97/23/EC is mandatory throughout all Member States of the European Union (EU) and the rest of the European Economic Area, effective May 30, 2002. The PED contains essential safety requirements that must be satisfied before a manufacturer can declare conformity with the Directive and place its product on the market anywhere in the European Community.

Some articles of the PED and its essential safety requirements are either not satisfied or are not addressed by ASME B31.3, and aspects of ASME B31.3 differ from the PED and the essential safety requirements.

Examples of where essential safety requirements are not fully satisfied by ASME B31.3 are as follows:

(a) decomposition of unstable fluids
(b) draining and venting
(c) short duration pressure surge
(d) temperature monitoring devices
(e) external fire
(f) marking and labeling
(g) operating instructions
(h) route of underground piping
(i) joint coefficients
(j) listed materials

To assist industry in using ASME B31.3, the Engineering Equipment and Materials Users' Association (EEMUA) has cooperated with the European Petroleum Industry Association (Europia) to publish CEN/TR 14549 — Guide to the use of ISO 15649 and ANSI/ASME B31.3 for piping in Europe in compliance with the Pressure Equipment Directive.

The format of the guide is that of a set of additional and modified requirements to ISO 15649 and ASME B31.3 that are required by the PED. It also gives a more-detailed explanation of the principal aspects and processes that require attention in order to be in compliance with the PED, especially where different from industry practice that was current before May 2002.

The full text of the PED can be found at http://ec.europa.eu/growth/sectors/pressure-gas/pressure-equipment/directive_en.

APPENDIX Q
QUALITY SYSTEM PROGRAM

[This Appendix is a Code requirement only when specified by the owner in accordance with para. 300(b)(1).]

Design, construction, inspection, examination, testing, manufacture, fabrication, and erection of piping in accordance with this Code shall be performed under a Quality System Program following the principles of an appropriate standard such as the ISO 9000 series.[1] The details describing the quality system shall be documented and shall be available upon request. A determination of the need for registration and/or certification of the quality system program shall be the responsibility of the owner.

[1] The series is also available from the American National Standards Institute (ANSI) and the American Society for Quality (ASQ) as American National Standards that are identified by similar "9000" numbers, sometimes with the prefix "Q" replacing the prefix "ISO." Each standard of the series is listed in Appendix E.

APPENDIX R
USE OF ALTERNATIVE ULTRASONIC ACCEPTANCE CRITERIA

R300 GENERAL

(a) This Appendix provides alternative fracture-mechanics-based acceptance criteria for ultrasonic examination that may be used for Code piping in lieu of those described in para. 344.6.

(b) The acceptance criteria within this Appendix are applicable to $\overline{T}_w$ having a thickness equal to or greater than 25 mm (1.0 in.). The acceptance criteria stated in para. 344.6.2 shall be used for all thicknesses less than 25 mm (1.0 in.).

(20) R301 SCOPE

(a) The examination shall be conducted using automated or semiautomated techniques utilizing computer-based data acquisition.

(b) The examination shall be performed in accordance with a written procedure approved by UT (ultrasonic testing) Level III personnel [see para. R303(a)] and conforming to the requirements of ASME BPVC, Section V, Article 4.

R302 EQUIPMENT

A mechanical guided scanner capable of maintaining a fixed and consistent search unit position relative to the weld centerline shall be used.

R303 PERSONNEL

(a) Personnel performing nondestructive examination to the requirements of this Appendix shall be qualified and certified in the ultrasonic testing method in accordance with a procedure as described in ASME BPVC, Section V, Article 1, T-120(e) or (f).

(b) Setup and scanning of welds shall be performed by personnel certified as UT Level II or III (or by Level I personnel under the direct supervision of Level II or Level III personnel).

(c) Interpretation and evaluation of data shall be performed by UT Level II or III personnel.

(d) Personnel demonstration requirements shall be as stated in ASME BPVC, Section V, Article 4, Mandatory Appendix VIII.

R304 EXAMINATION

(a) The initial straight beam scan for reflectors that could interfere with the angle beam examination shall be performed (1) manually, (2) as part of a previous manufacturing process, or (3) during the weld examination, provided detection of these reflectors is included in the demonstration as required in para. R301(c).

(b) The examination area shall include the volume of the weld, plus the lesser of 25 mm (1.0 in.) or $\overline{T}_w$ of adjacent base metal on each side of the weld. Alternatively, the examination volume may be reduced to include the actual heat-affected zone (HAZ) plus 6 mm (0.25 in.) of base material beyond the heat-affected zone on each side of the weld, provided the extent of the weld HAZ is measured and documented.

R305 DATA RECORDING AND CAPTURE

Data shall be recorded in the unprocessed form as specified in ASME BPVC, Section V, Article 4, V-471.6. The data record shall include the complete examination area as specified in para. R304(b).

R306 DATA ANALYSIS

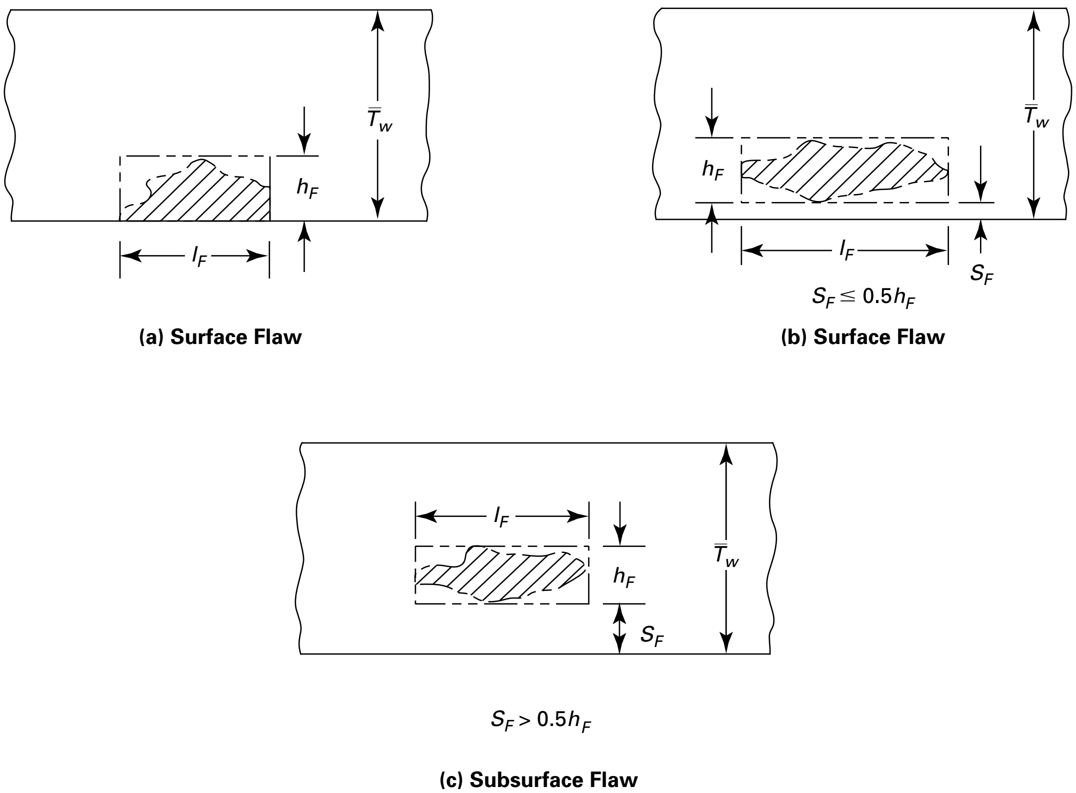
(a) Reflectors exceeding the limits of (1) or (2) shall be investigated to determine whether the indication originates from a flaw or is a geometric indication as described in (b).

(1) For amplitude-based techniques, the location, amplitude, and extent of all reflectors that produce a response greater than 20% of the reference level shall be evaluated.

(2) For non-amplitude-based techniques, the location and extent of all images that have an indicated length greater than 4.0 mm (0.16 in.) shall be investigated.

(b) Ultrasonic indications of geometric and metallurgical origin shall be classified as specified in ASME BPVC, Section V, Article 4, T-481. Alternatively, other techniques or nondestructive examination methods may be used to classify an indication as geometric (e.g., alternative beam angles, radiography). The method employed is for information only to classify the indication as geometric, and the Code requirements for examination techniques are only required to the extent that they are applicable.

Figure R307 Surface and Subsurface Flaws



R307 FLAW EVALUATION

(a) Dimensions. The dimensions of the flaw(s) shall be determined by the rectangle that fully contains the area of the flaw(s). Refer to Figure R307.

(1) The length, l_F, of the flaw shall be drawn parallel to the inside pressure-retaining surface of the component.

(2) The height, h_F, of the flaw shall be drawn normal to the inside pressure-retaining surface of the component.

(3) The flaw shall be characterized as a surface or subsurface flaw, as shown in Figure R307.

(4) A subsurface flaw shall be considered as a surface flaw if the separation (S_F in Figure R307) of the flaw from the nearest surface of the component is equal to or less than half the through-wall dimension [h_F in Figure R307, illustration (b)] of the subsurface flaw.

(b) Multiple Flaws

(1) Discontinuous flaws that are oriented primarily in parallel planes shall be considered to lie in a single plane if the distance between the adjacent planes is equal to or less than 13 mm (0.50 in.) or $0.5\overline{T}_w$, whichever is less.

(2) If the space between two flaws aligned along the axis of weld is less than the height of the flaw of greater height, the two flaws shall be considered a single flaw.

(3) If the space between two flaws aligned in the through-thickness dimension is less than the height of the flaw of greater height, the two flaws shall be considered a single flaw.

R308 FLAW ACCEPTANCE CRITERIA

Flaws shall be evaluated using the applicable criteria of Table R308.1 or Table R308.2. Regardless of flaw height or aspect ratio, flaw length shall not exceed $4\overline{T}_w$.

Table R308.1 Acceptance Criteria for Surface Flaws

Aspect Ratio, h_F/l_F	Maximum $h_F/\overline{T}_w$ for Nominal Weld Thickness: 25 mm to 65 mm (1.0 in. to 2.5 in.)	Maximum $h_F/\overline{T}_w$ for Nominal Weld Thickness: 100 mm to 300 mm (3.9 in. to 11.8 in.)
0.00	0.031	0.019
0.05	0.033	0.020
0.10	0.036	0.022
0.15	0.041	0.025
0.20	0.047	0.028
0.25	0.055	0.033
0.30	0.064	0.038
0.35	0.074	0.044
0.40	0.083	0.050
0.45	0.085	0.051
0.50	0.087	0.052

GENERAL NOTES:

(a) Aspect ratio (h_F/l_F) used may be determined by rounding the calculated h_F/l_F down to the nearest 0.05 increment value within the column, or by linear interpolation.

(b) For intermediate thickness $\overline{T}_w$ [thicknesses greater than 65 mm (2.5 in.) and less than 100 mm (3.9 in.)], linear interpolation is permitted to obtain $h_F/\overline{T}_w$ values. Otherwise, the lower values shall be used.

Table R308.2 Acceptance Criteria for Subsurface Flaws

Aspect Ratio, h_F/l_F	Maximum $h_F/\overline{T}_w$ for Nominal Weld Thickness: 25 mm to 65 mm (1.0 in. to 2.5 in.)	Maximum $h_F/\overline{T}_w$ for Nominal Weld Thickness: 100 mm to 300 mm (3.9 in. to 11.8 in.)
0.00	0.068	0.040
0.10	0.076	0.044
0.20	0.086	0.050
0.30	0.108	0.058
0.40	0.132	0.066
0.50	0.156	0.080
0.60	0.180	0.094
0.70	0.206	0.108
0.80	0.232	0.122
0.90	0.258	0.138
1.00	0.286	0.152

GENERAL NOTES:

(a) Aspect ratio (h_F/l_F) used may be determined by rounding the calculated h_F/l_F down to the nearest 0.10 increment value within the column, or by linear interpolation.

(b) For intermediate thickness $\overline{T}_w$ [thicknesses greater than 65 mm (2.5 in.) and less than 100 mm (3.9 in.)], linear interpolation is permitted to obtain $h_F/\overline{T}_w$ values. Otherwise, the lower values shall be used.

APPENDIX S
(20) # PIPING SYSTEM STRESS ANALYSIS EXAMPLES

S300 INTRODUCTION

The examples in this Appendix are intended to illustrate the application of the rules and definitions in Chapter II, Part 5, Flexibility and Support; and the stress limits of para. 302.3.5. The loadings and conditions necessary to comply with the intent of the Code are presented.

S300.1 Definitions and Nomenclature

global axes: these are Cartesian X, Y, and Z axes. In this Appendix, vertically upward is taken to be the +Y direction with gravity acting in the −Y direction.

P_j*:* piping internal pressure; see para. 301.2; when more than one condition exists for the piping system, each is subscripted (e.g., P_1, P_2, ...).

T_j*:* pipe maximum or minimum metal temperature; see paras. 301.3 and 319.3.1(a); when more than one condition exists for the piping system, each is subscripted (e.g., T_1, T_2, ...).

Y+*:* a "single acting support" that provides support in only the vertically upward direction and is considered to be "active" when the pipe exerts a downward force on the support. The pipe is free to move upward, i.e., the pipe "lifts off" the support; the support in the "lift-off" situation is considered to be "removed" from providing support, i.e., inactive, during the load condition considered.

S301 EXAMPLE 1: CODE-COMPLIANT PIPING SYSTEM

S301.1 Example Description

This example is intended to illustrate the design of an adequately supported and sufficiently flexible piping system. The piping system in Figure S301.1 is fabricated from ASTM A106 Grade B seamless pipe (i.e., E = 1.00); the pipe is DN 400 (NPS 16) with a nominal wall thickness of 9.53 mm (0.375 in.), 127 mm (5 in.) thickness of calcium silicate insulation, and 1.59 mm (0.063 in.) corrosion allowance; the fluid has a specific gravity of 1.0. The equivalent number of full displacement cycles expected for the piping system is fewer than 7 000 [i.e., f = 1.00 in accordance with para. 302.3.5(d)].

The piping system is in normal fluid service. The reference modulus of elasticity used for the piping analysis is 202.3 GPa (29.4 Msi) from Appendix C, Tables C-6 and C-6M in accordance with paras. 319.3.2 and 319.4.4, and Poisson's ratio is 0.3 in accordance with para. 319.3.3.

The piping internal pressures and temperatures expected during normal operation and the design conditions are listed in Table S301.1; see paras. 319.2.3(b) and 319.3.1(a). The design conditions are set sufficiently in excess of the operating conditions so as to provide additional margin on the allowable stress for pressure design as required by the owner.

S301.2 Design Conditions

The design conditions establish the pressure rating, flange ratings, component ratings, and minimum required pipe wall thickness in accordance with para. 301.2.1. For example, ASME B16.5 requires a minimum of Class 300 for ASTM A105 flanges. Also, the minimum required pipe wall thickness, t_m, is determined from the design conditions by inserting eq. (3a) into eq. (2); terms are defined in para. 304.1.1 and Appendix J.

E = 1.0
P = design pressure
= 3 800 kPa (550 psi)
S = allowable stress from Appendix A, Tables A-1 and A-1M
= 127.4 MPa (18.4 ksi) at design temperature 288°C (550°F)
W = 1.0 for carbon steel at any temperature in accordance with Table 302.3.5, Note (9)
Y = 0.4 from Table 304.1.1

Insert eq. (3a) into eq. (2).

Figure S301.1 Simple Code-Compliant Model

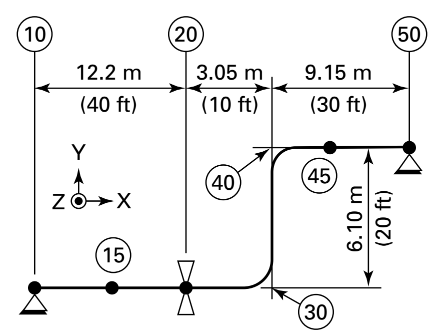


Table S301.1 Pressure–Temperature Combinations

Conditions	Pressure	Temperature
Design conditions	3 800 kPa (550 psi)	288°C (550°F)
Operating (P_1,T_1) maximum metal temperature	3 450 kPa (500 psi)	260°C (500°F)
Minimum metal temperature	0 kPa (0 psi)	−1°C (30°F)
Ambient (as-installed) temperature	0 kPa (0 psi)	−1°C (30°F)

$$t_m = t + c$$

$$t = \frac{\left(\frac{3\,800}{1\,000}\text{ MPa}\right)(406.4\text{ mm})}{2\left[(127.4\text{ MPa})(1.00)(1.00) + \left(\frac{3\,800}{1\,000}\text{ MPa}\right)(0.4)\right]}$$

$$c = 1.59\text{ mm}$$

$$t_m = 5.99\text{ mm} + 1.59\text{ mm} = 7.58\text{ mm }(0.299\text{ in.})$$

In accordance with para. 304.1.2(a), t must be less than $D/6$ for eq. (3a) to be appropriate without considering additional factors to compute the pressure design thickness, t (i.e., $t < D/6$, or 7.58 mm < 406.4 mm/6). Since 7.58 mm (0.299 in.) < 67.7 mm (2.67 in.), eq. (3a) is applicable without special consideration of factors listed in para. 304.1.2(b).

Now select a pipe schedule of adequate thickness. Determine the specified minimum pipe wall thickness, T, from nominal pipe wall thickness, $\overline{T}$, considering a mill tolerance of 12.5%.

Select DN 400 (NPS 16) Schedule 30/STD nominal wall thickness from ASME B36.10M.

$\overline{T}$ = 9.53 mm (0.375 in.)

T = (9.53 mm)(1.00 − 0.125) = 8.34 mm (0.328 in.)

Since $T > t_m$ [i.e., 8.34 mm (0.328 in.) > 7.58 mm (0.299 in.)], the selection of the nominal pipe wall thickness, $\overline{T}$, for Schedule 30/STD pipe is acceptable. The long radius elbows specified for this piping system are in accordance with ASME B16.9 and are specified to be for use with Schedule 30/STD wall thickness pipe.

S301.3 Computer Model Input

Tables S301.3.1 and S301.3.2 list the "node numbers," lengths, etc., for each piping element displayed in Figure S301.1. A bend radius of 1.5 times the nominal pipe diameter [i.e., 609.6 mm (24 in.)] and nominal wall thickness of 9.53 mm (0.375 in.) are used for the elbows in the computer model. Generic computer program options are as follows:

(a) include pressure stiffening on elbows

(b) exclude pressure thrust and Bourdon effects

(c) use nominal section properties for both the stiffnesses, forces, moments, and deflections calculation

(d) use "nominal less allowances" section properties for the stress due to sustained loads, S_L, calculation

(e) use nominal section properties for displacement stress range, S_E, calculation

S301.4 Pressure Effects

For the operating, sustained, and displacement stress range load cases, the effect of pressure stiffening on the elbows is included to determine the end reactions in accordance with ASME B31J, Table 1-1, Note (4). The effects of pressure-induced elongation and Bourdon effects are not included, as both are deemed negligible for this particular example.

S301.5 The Operating Load Case

The operating load case is used to determine the operating position of the piping and reaction loads for any attached equipment, anchors, supports, guides, or stops. The operating load case is based on the temperature range from the ambient (as-installed) temperature of −1°C (30°F) to the maximum operating metal temperature of 260°C (500°F), in accordance with paras. 319.2.3(b) and 319.3.1(b). Tables C-1 and C-1M values used for Row A and Row B expansion coefficients are listed below.

(a) Row A = 13.1 × 10^{-6} mm/mm/°C (7.30 × 10^{-6} in./in./°F)

(b) Row B = 3.43 mm/m (4.00 in./100 ft)

Table S301.3.1 Generic Pipe Stress Model Input

Term	Value
Operating conditions:	
internal pressure, P_1	3 450 kPa (500 psi)
maximum metal temp., T_1	260°C (500°F)
minimum metal temp., T_2	−1°C (30°F)
ambient (as-installed) temp	−1°C (30°F)
Line size	DN 400 (NPS 16)
Pipe	Schedule 30/STD, 9.53 mm (0.375 in.)
Mechanical allowance, c	1.59 mm (0.063 in.)
Mill tolerance	12.5%
Elbows	Long radius
Fluid specific gravity	1.0
Insulation thickness	127 mm (5 in.)
Insulation density	176 kg/m^3 (11.0 lbm/ft^3)
Pipe material	ASTM A106 Grade B
Pipe density	7 833.4 kg/m^3 (0.283 lbm/in.^{3})

Table S301.3.2 Element Connectivity, Type, and Lengths

From	To	D_X, m (ft)	D_Y, m (ft)	Element Type
10	15	6.10 (20)	...	10 anchor 15 bisection node
15	20	6.10 (20)	...	20 Y support
20	30	3.05 (10)	...	Three-node elbow [Note (1)]
30	40	...	6.10 (20)	Three-node elbow [Note (1)]
40	45	3.05 (10)	...	Informational node
45	50	6.10 (20)	...	50 anchor

GENERAL NOTE: This piping system is planar, i.e., D_Z = 0 m (ft) for each piping element.

NOTE: (1) The specified element lengths are measured to and/or from each elbow's tangent intersection point.

The operating load case in this example also includes the effects of internal pressure, pipe weight, insulation weight, and fluid weight on the piping system. Both pipe stiffness and displacement stress range are based on the nominal thickness of the pipe. Pipe deflections and internal reaction loads for the operating load case are listed in Table S301.5.1. Piping loads acting on the anchors and support structure are listed in Table S301.5.2.

S301.6 The Sustained Load Case

Stresses due to the sustained loads, such as axial forces, internal pressure, and intensified bending moments in this example, are combined in accordance with para. 320 to determine S_L. The sustained load case excludes thermal effects and includes the effects of internal pressure [P_1 = 3 450 kPa (500 psi)], pipe weight, insulation weight, and fluid weight on the piping system.

Nominal section properties are used to generate the stiffness matrix and sustained loads for the computer model in accordance with para. 319.3.5. The nominal thickness, less allowances, is used to calculate the section properties for S_L in accordance with para. 320.

A summary of the sustained load case internal reaction forces, moments, and stress due to sustained loads, S_L, is provided in Table S301.6. Since this example model lies in only one plane, only the stress due to sustained bending moments due to the in-plane bending moment is not zero. The in-plane bending moment is intensified at each elbow by the sustained in-plane moment index for an unflanged elbow, I_i. Note that S_L for the nodes listed in Table S301.6 do not exceed the 130.8 MPa (19.0 ksi) sustained allowable stress, S_h, for A106 Grade B piping at the operating maximum metal temperature, T_1 = 260°C (500°F), from Appendix A, Tables A-1 and A-1M. By limiting S_L to S_h in accordance with para. 302.3.5(c), the piping system is deemed adequately protected against collapse.

Table S301.5.1 Operating Load Case Results: Internal Loads and Deflections

Node Number	Axial Force (Structural Only), N (lb) (Unsigned) [Notes (1), (2)]	Bending Moment, N-m (ft-lb) (Unsigned) [Note (1)]	Horizontal Deflection, mm (in.) [Note (1)]	Vertical Deflection, mm (in.) [Note (1)]
10	29 700 (6,670)	22 100 (16,300)	0.00	0.00
15	29 700 (6,670)	11 000 (8,110))	21 (0.8)	−1 (−0.1)
20	29 700 (6,670)	46 400 (34,200))	42 (1.6)	0.00
30 near	29 700 (6,670)	64 700 (47,700)	50 (1.9)	−3 (−0.1)
30 mid	50 700 (11,400)	77 500 (57,100)	51 (2.0)	−2 (−0.1)
30 far	40 200 (9,040)	72 000 (53,100)	47 (1.8)	2 (0.1)
40 near	28 400 (6,380)	72 600 (53,600)	−26 (−1.0)	18 (0.7)
40 mid	40 100 (9,050)	80 400 (59,400)	−30 (−1.2)	21 (0.8)
40 far	29 700 (6,670)	74 300 (54,900)	−29 (−1.1)	23 (0.9)
45	29 700 (6,670)	18 100 (13,400)	−21 (−0.8)	16 (0.6)
50	29 700 (6,670)	59 000 (43,600)	0.00	0.00

NOTES:
(1) Forces, moments, and deflections are averaged from commercial programs' results and are obtained by analyzing the piping system in both U.S. Customary and SI units.
(2) No operating axial pressure force is included in the axial forces listed above.

Table S301.5.2 Operating Load Case Results: Reactions on Supports and Anchors

Node	Global Axis Forces and Moments [Note (1)] F_X, N (lb) (Signed) [Note (2)]	F_Y, N (lb) (Signed) [Note (2)]	M_Z, N-m (ft-lb) (Signed) [Note (2)]
10 anchor	−29 700 (−6,670)	−12 900 (−2,890)	−22 100 (−16,300)
20 support	...	−65 300 (−14,700)	...
50 anchor	+29 700 (+6,670)	+5 300 (+1,180)	−59 000 (−43,600)

NOTES:
(1) Reactions are averaged from commercial programs' results and are obtained by analyzing the piping system in both U.S. Customary and SI units.
(2) Reaction forces and moments are those acting on the restraints and are signed based on their vectors acting along and about the selected coordinate system.

Table S301.6 Sustained Forces, Moments, and Stresses [Allowable S_h = 130.8 MPa (19.0 ksi)]

Node	Axial Force, (Structural Only), N (lb) (Unsigned) [Notes (1), (2)]	Bending Moment, N·m (ft-lb) (Unsigned) [Note (1)]	Sustained Stress, S_L, MPa (ksi) [Notes (1)–(3)]
10 anchor	3 270 (735)	17 300 (12,700)	59.0 (8.60)
20 support	3 270 (735)	56 100 (41,400)	98.9 (14.4)
30 near	3 270 (735)	5 280 (3,900)	52.7 (7.50)
30 mid	17 200 (3,860)	14 000 (10,300)	69.1 (9.90)
30 far	19 900 (4,480)	16 300 (12,000)	73.3 (10.5)
40 near	8 000 (1,800)	370 (270)	42.0 (6.00)
40 mid	7 170 (1,610)	250 (185)	42.1 (6.00)
40 far	3 270 (735)	2 350 (1,720)	46.0 (6.70)
50 anchor	3 270 (735)	37 800 (27,900)	79.5 (11.6)

NOTES:
(1) Forces, moments, and stresses are averaged from commercial programs' results and are obtained by analyzing the piping system in both U.S. Customary and SI units.
(2) Both the unsigned sustained axial forces (listed above) and the unsigned sustained axial pressure force, 413 000 N (92,800 lb), are summed to calculate the stresses due to sustained loads, S_L, in accordance with para. 320.
(3) The sustained longitudinal indices, I_a, are defaulted to 1.0 for all piping components in the absence of more applicable data, in accordance with para. 320.2, and are applied to both the stresses due to sustained axial reactions and axial pressure force.

Table S301.7 Displacement Stress Range [Allowable, Eq. (1a), S_A = 205.2 MPa (29.75 ksi)]

Node Number	Axial Force Range, N (lb) (Unsigned) [Notes (1), (2)]	In-Plane Bending Moment Range, N·m (ft-lb) (Unsigned) [Notes (1)]	Displacement Stress Range, S_E, From Eq. (17), MPa (ksi) [Notes (1), (2)]
10	26 400 (5,940)	4 840 (3,570)	6.43 (0.93)
20	26 400 (5,940)	9 740 (7,190)	10.7 (1.55)
30 near	26 400 (5,940)	59 400 (43,800)	137 (19.9)
30 mid	32 200 (7,200)	63 400 (46,800)	147 (21.3)
30 far	20 400 (4,580)	55 700 (41,100)	128 (18.6)
40 near	20 400 (4,580)	72 900 (53,900)	168 (24.4)
40 mid	33 200 (7,420)	80 800 (59,600)	187 (27.1)
40 far	26 400 (5,940)	76 700 (56,600)	177 (25.7)
50	26 400 (5,940)	97 000 (71,500)	86.4 (12.4)

NOTES:

(1) All ranges listed above are averaged from commercial programs' results and are obtained by analyzing the piping system in both U.S. Customary and SI units.

(2) Axial force ranges do not have their sign retained, do not include axial pressure force ranges, and are included in the displacement stress range, S_E, in accordance with para. 319.4.4.

S301.7 The Displacement Stress Range Load Case

The displacement stress range, S_E, in this example is based on the temperature range from the minimum metal (as-installed) temperature, −1°C (30°F), to maximum metal temperature for the thermal cycles under analysis [T_1 = 260°C (500°F)], in accordance with paras. 319.2.3(b) and 319.3.1(a). The displacement stress range, S_E, for each element is calculated in accordance with eq. (17) and is listed in Table S301.7, along with the internal reaction loads. Nominal section properties are used to generate the stiffness matrix and displacement stress ranges in the piping in accordance with para. 319.3.5. Since this example model lies in only one plane, only the in-plane bending moment range is not zero. The in-plane moment range is intensified at each elbow in accordance with ASME B31J, Table 1-1 stress intensification factor, i_i, for an unflanged elbow.

For simplicity, the allowable displacement stress range, S_A, is calculated in accordance with eq. (1a). Though eq. (1a) is used in this example, it is also acceptable to calculate S_A in accordance with eq. (1b), which permits S_A to exceed the eq. (1a) value for each piping element, based on the magnitude of each element's S_L.

The following terms are as defined in para. 302.3.5(d) and Appendix J:

f = 1.00 for 7 000 equivalent full displacement cycles, from Figure 302.3.5 or eq. (1c)

$S_A = f(1.25S_c + 0.25S_h)$
$= (1.00)[(1.25)(138\text{ MPa}) + (0.25)(130.8\text{ MPa})]$
$= 205.2$ MPa (29.75 ksi)

S_c = allowable stress from Appendix A, Tables A-1 and A-1M
= 138 MPa (20.0 ksi) at ambient (as-installed) temperature

S_h = allowable stress from Appendix A, Tables A-1 and A-1M
= 130.8 MPa (19.0 ksi) at T_1

T_1 = maximum metal temperature
= 260°C (500°F)

Note that each piping element's displacement stress range based on minimum to maximum metal temperature for the thermal cycles under analysis, S_E, does not exceed the eq. (1a) allowable, S_A. By limiting S_E to S_A, the piping system is deemed adequate to accommodate up to 7 000 equivalent full displacement cycles.

Considering both the stress due to sustained loads and displacement stress range load cases, the piping system is compliant with the requirements of the Code; redesign of the piping system is not required unless the sustained or operating reaction loads at either anchor data point 10 or 50 exceed the allowable loads for the attached equipment nozzle or the support structure at node 20 is overloaded. The nozzle load and support structure analyses are beyond the scope of this Appendix and are not addressed.

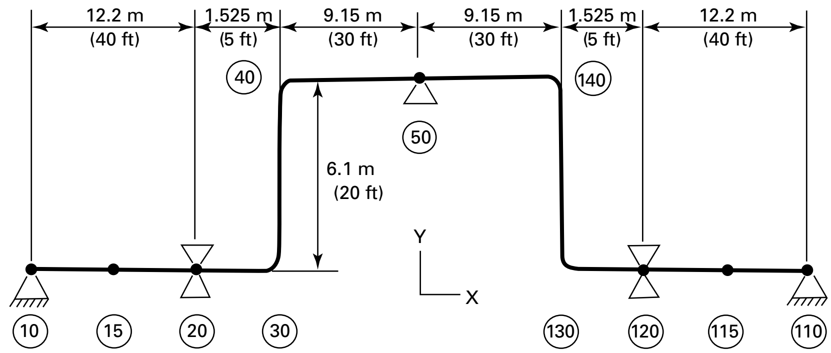
S302 EXAMPLE 2: ANTICIPATED SUSTAINED CONDITIONS CONSIDERING PIPE LIFT-OFF

S302.1 Example Description

This example is intended to illustrate the analysis of a piping system in which a portion of the piping lifts off at least one Y+ support in at least one operating condition. The emphasis of this example is to describe the effect this removal of support has on the determination of anticipated sustained conditions. The same principles utilized for this example would also apply for guides and stops (that are single directional or gap-type) that are not engaged during any anticipated operating condition.

The examples in this Appendix are intended for illustration purposes only and are not intended to portray the same as either adequate or even acceptable piping geometries and/or support scenarios. The piping system in Figure S302.1 is the same in material properties as in Example 1; see para. S301.1. Note that the distance from node 20 to the elbow node 30 and from nodes 120 to 130 in Example 2's model is 1.52 m (5 ft). Also, note that both the design and operating conditions are well below the creep regime; therefore, the piping system will not develop any permanent creep-related displacements, relaxation, or sag.

Figure S302.1 Lift-Off Model



S302.2 Design Conditions

The design conditions are similar to those in the Example 1 model; see para. S301.2 and Table S302.2. Note that the nominal thickness remains unchanged from Example 1 even though the design temperature and corrosion allowance have increased; the corrosion allowance in this example model is 3.18 mm (0.125 in.).

S302.3 Computer Model Input

Table S302.3 lists the node numbers, lengths, etc., for each piping component that is displayed in Figure S302.1. The computer-based options are the same as those for the Example 1 model; see para. S301.3.

S302.4 Pressure Effects

The pressure effect considerations are the same as those for Example 1; see para. 301.4.

S302.5 The Operating Load Case

The operating case evaluated and discussed in this example includes the effects of pipe weight, insulation weight, fluid weight, internal pressure [P_1 = 3 040 kPa (440 psi)], and temperature [T_1 = 288°C (550°F)]. Tables C-1 and C-1M values used for Row A and Row B expansion coefficients are listed below.

(a) Row A = 13.2 × 10^{-6} mm/mm/°C (7.35 × 10^{-6} in./in./°F)

(b) Row B = 3.80 mm/m (4.5 in./100 ft)

An operating load case is evaluated to determine the operating position of the piping and determine the reaction loads for any attached equipment, anchors, supports, guides, or stops. In particular, each operating load case's support scenario is evaluated or assessed by the designer in order to determine whether any anticipated sustained conditions need to be evaluated with one or more Y+ supports removed. Further operating load case discussion can be found in para. S301.5.

Piping loads acting on the anchors and support structure for the operating load case are listed in Table S302.5. Note that only nodes 10 through 50 are listed in the following tables; this is for convenience since the model is symmetric; the reactions, deflections, and stresses for nodes 10 through 40 are the same as for nodes 110 through 140 except that some signs may be reversed.

S302.6 Sustained Conditions

S302.6.1 The Stress Due to Sustained Loads, S_L, Calculations. The stress due to (long-term) sustained loads, S_L, is computed in accordance with para. 320.2 for each sustained condition that is evaluated; see para. S302.6.2.

S302.6.2 Anticipated Sustained Conditions. All anticipated sustained conditions utilizing all possible support scenarios should be considered. The designer has identified three anticipated sustained conditions for the piping system; each is listed in Table S302.6.2, along with the support status of the node 50 Y+ support, as either assessed by analysis or determined by the designer. The designer has deemed the Sustained Condition 3 as both controlling the sustained design and requiring evaluation.

Table S302.2 Pressure–Temperature Combinations

Conditions	Pressure	Temperature
Design	3 230 kPa (465 psi)	302°C (575°F)
Operating (P_1, T_1) maximum metal temperature	3 040 kPa (440 psi)	288°C (550°F)
Minimum metal temperature	0 kPa (0 psi)	−1°C (30°F)
Ambient (as-installed) temperature	0 kPa (0 psi)	−1°C (30°F)

Table S302.3 Generic Pipe Stress Model Input: Component Connectivity, Type, and Lengths

From	To	D_X, m (ft)	D_Y, m (ft)	Component Type
10	15	6.10 (20)	...	10 anchor 15 informational node
15	20	6.10 (20)	...	20 Y support
20	30	1.52 (5)	...	Three-node elbow [Note (1)]
30	40	...	6.10 (20)	Three-node elbow [Note (1)]
40	45	3.05 (10)	...	Informational node
45	50	6.10 (20)	...	50 Y+ support
110	115	−6.10 (−20)	...	110 anchor
115	120	−6.10 (−20)	...	120 Y support
120	130	−1.52 (−5)	...	Three-node elbow [Note (1)]
130	140	...	6.10 (20)	Three-node elbow [Note (1)]
140	145	−3.05 (−10)	...	Informational node
145	50	−6.10 (−20)	...	...

NOTE: (1) The specified component lengths are measured to and/or from each elbow's tangent intersection point.

Table S302.5 Results for Operating Case: Reactions on Support and Anchors

	Global Axis Forces and Moments [Note (1)]		
Node	F_x, N (lb) (Signed) [Note (2)]	F_y, N (lb) (Signed) [Note (2)]	M_z, N·m (ft-lb) (Signed) [Note (2)]
10 anchor	−24 400 (−5,500)	−20 200 (−4,500)	−51 700 (−38,100)
20 support	...	−49 000 (−11,000)	...
50 Y+	...	0 [Note (3)]	...

NOTES:

(1) Reactions are averaged from commercial programs' results and are obtained by analyzing the piping system in both U.S. Customary and SI units.

(2) Reactions are signed based on their directions relative to the selected coordinate system's positive directions. Reactions F_x and M_z are positive in sign for anchor 110.

(3) No support is provided at the node 50 Y+ restraint for the operating case. Sustained Condition 2's support load at node 50 Y+ is 26 300 N (5,900 lb); see Table S302.6.2 and para. S302.6.3.

S302.6.3 Results for the Evaluated Sustained Condition. Table S302.6.2's Sustained Conditions 1 and 2 reflect the ambient temperature support scenario. Sustained Condition 3 reflects the support scenario of the operating case. All three sustained conditions exclude thermal effects. Sustained Conditions 2 and 3 include the effects of internal pressure [P_1 = 3 040 kPa (440 psi)], pipe weight, insulation weight, and fluid weight on the piping system. A summary of the Sustained Condition 3 reactions and stresses due to sustained loads, S_L, appears in Table S302.6.3.

In the determination of S_L, the sustained longitudinal force index, I_a, is defaulted to 1.0 in the absence of more applicable data in accordance with para. 320. The in-plane bending moment is indexed at each elbow by the appropriate I_i calculated for this example by multiplying 0.75 times i_i determined from ASME B31J, Table 1-1. See para. S301.6 for additional information concerning the stress due to sustained loads determination.

S302.7 Displacement Stress Range Load Cases

The displacement stress range load cases are not listed, since they are not the subject of this example.

S302.8 Code Compliance — Satisfying the Intent of the Code

The Sustained Condition 3 results indicate that the piping system is not protected against collapse for the cycles under analysis when considering the operating case support scenario. Note the greatest Stresses due

Table S302.6.2 Sustained Load Condition Listing

Sustained Condition	Node 50's Support Status (Active/Inactive)
1: Ambient (as-installed) [Note (1)]	Active
2: P_1 [Note (2)]	Active
3: P_1 [Note (3)]	Inactive

NOTES:
(1) Sustained Condition 1, the ambient condition, includes only pipe weight and insulation weight without fluid contents or internal pressure.
(2) Sustained Condition 2 reflects the support scenario of the ambient condition, excludes thermal effects, and includes internal pressure, pipe weight, insulation weight, and fluid weight.
(3) Sustained Condition 3 reflects the support scenario of the operating condition, excludes thermal effects, and includes internal pressure, pipe weight, insulation weight, and fluid weight.

to sustained loads, S_L, are at elbow nodes 40 and 140 and "Lift-Off" support location, node 50. Therefore, redesign of the piping system is required.

If the piping system is redesigned such that it is compliant with the intent of the Code, then the piping system would require no further attention unless the sustained, hydrostatic leak test, or operating reaction loads at either anchor data point 10 or 110 exceed the allowable loads for the attached equipment nozzle, or the support structure at either node 20 or 120 is overloaded. The nozzle loads and support structure analyses are beyond the scope of this Appendix and are not addressed. Although the occasional load cases are important to the design and analysis of a piping system, they are not discussed in this example.

S303 EXAMPLE 3: MOMENT REVERSAL

S303.1 Example Description

This example is intended to illustrate the flexibility analysis required for a piping system that is designed for more than one operating condition and also experiences a "reversal of moments" between any two of the anticipated operating conditions. The examples in this Appendix are intended for illustration purposes only and are not intended to portray the same as either adequate or even acceptable piping geometries and/or

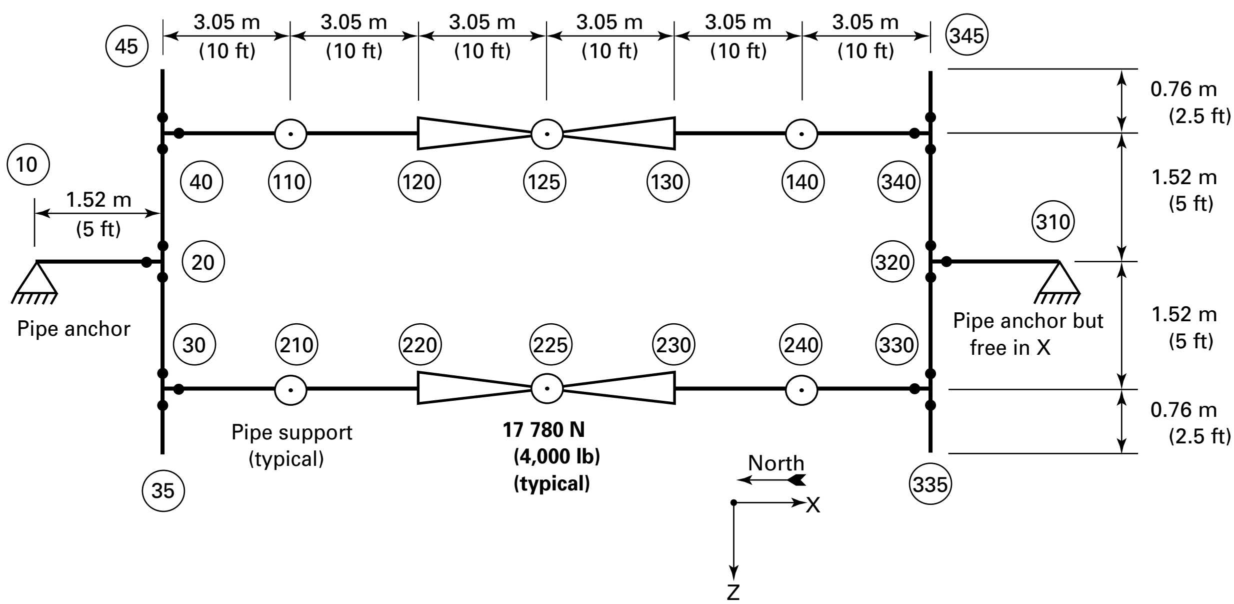
Table S302.6.3 Sustained Forces, Moments, and Stresses for Sustained Condition 3 With Node 50's Y+ Support Inactive [Allowable S_h = 127 MPa (18.4 ksi): Fails]

Node	Axial Force, (Structural Only), N (lb) (Signed) [Notes (1)–(3)]	Bending Moment, N·m (ft-lb) (Unsigned) [Note (1)]	Sustained Stress, S_L, MPa (ksi) [Notes (1)–(3)]
10 anchor	+9 000 (+2,000)	25 400 (18,800)	77.5 (11.3)
20 support	+9 000 (+2,000)	39 600 (29,200)	95.6 (13.9)
30 near	+9 000 (+2,000)	4 500 (3,300)	55.9 (8.14)
30 mid	+32 000 (+7,200)	9 700 (7,150)	67.1 (9.77)
30 far	+35 000 (+7,850)	12 200 (9,000)	73.2 (10.6)
40 near	+23 100 (+5,200)	31 400 (23,200)	124 (18.0)
40 mid	+22 500 (+5,050)	31 200 (23,000)	123 (17.9)
40 far	+9 000 (+2,000)	23 600 (17,500)	106 (15.3)
50 Y+	−9 000 (−2,000)	64 900 (47,800)	128 (18.6)

GENERAL NOTE: No support is provided at the node 50 Y+ restraint for Sustained Condition 3; see Table S302.6.2 and para. S302.6.3. The stress due to sustained loads, S_L, at node 50 Y+ when active is 76.3 MPa (11.0 ksi) for Sustained Condition 2.

NOTES:
(1) Forces, moments, and stresses are averaged from commercial programs' results and are obtained by analyzing the piping system in both U.S. Customary and SI units. The magnitude of loads and stresses for nodes 10 through 40 are the same for nodes 110 through 140, though the loads may differ in sign.
(2) The sustained longitudinal force indices, I_a, are defaulted to 1.0 for all piping components in the absence of more applicable data in accordance with para. 320.2.
(3) Both the sustained axial forces listed above and sustained axial pressure force, +370 000 N (+83,000 lb), are summed in accordance with para. 320 to calculate the stresses due to sustained loads, S_L.

Figure S303.1 Moment Reversal Model



support scenarios. Both the design and operating conditions are well below the creep regime.

The piping system in Figure S303.1 consists of two headers and two branches, which are referred to as gas "meter runs." Only one of the branches is in service (operating) at a given time; the out-of-service branch is purged and at ambient (as-installed) condition. The design specification calls for each of the meter run branches to alternate in and out of service five times every 2 weeks for the piping system's planned 30-yr service life (N = 3,900 equivalent full displacement cycles), i.e., f = 1.15 in accordance with para. 302.3.5(d). The piping system is fabricated from ASTM A53 Grade B pipe (E = 1.00), both piping headers are DN 600 (NPS 24) and the branches are DN 500 (NPS 20), and both branch and header are 9.53 mm (0.375 in.) thick. For simplicity, each piping segment or component is 1.524 m (5 ft) in length.

The piping system is in normal fluid service. The fluid is gaseous, is considered to add no weight and to be neither a corrosive nor an erosive hazard, i.e., there is no corrosion allowance. The line is not insulated. The ambient (as -installed) temperature is 4°C (40°F). The reference modulus of elasticity used is 202.3 GPa (29.4 Msi) and Poisson's ratio is 0.3. Consideration is given to the close proximity of the three tees in each header in accordance with the guidance in para. 319.3.6, and the stress intensification factors from ASME B31J are considered to adequately represent the header tees for this piping system. The piping internal pressure and minimum to maximum metal temperature range expected during normal operation for each meter run and the design conditions are listed in Table S303.1. The design conditions are set sufficiently in excess of the operating conditions so as to provide additional margin on the allowable as required by the owner.

S303.2 Design Conditions

The design conditions establish the pressure rating, flange ratings, components ratings, and minimum required pipe wall thickness. ASME B16.5 requires a minimum of Class 300 for ASTM A105 flanges. The minimum required wall thickness for both the branch and header is 4.4 mm (0.171 in.), considering a 12.5% mill tolerance; therefore, selection of the standard wall thickness of 9.5 mm (0.375 in.) is acceptable.

S303.3 Computer Model Input

Table S303.3 lists the node numbers, lengths, etc., for each piping component that is displayed in Figure S303.1. Note that flanges and valve components are not explicitly included in the model listing in Table S303.3. For simplicity, an entire branch (from tee centerline to tee centerline) is considered to be at the operating conditions listed in Table S303.1, e.g., the East meter run branch from nodes 40 through 340 operates at 1 724 kPa (250 psi) and 121°C (250°F) for Operating Case 2. The computer-based options are the same as those for the Example 1 model, except that pressure stiffening is not included in the analyses for this example; see para. S301.3.

Table S303.1 Pressure–Temperature Combinations

Condition	Header(s) Pressure	Header(s) Temperature	West Branch Pressure	West Branch Temperature	East Branch Pressure	East Branch Temperature
Design	2 069 kPa (300 psi)	149°C (300°F)	2 069 kPa (300 psi)	149°C (300°F)	2 069 kPa (300 psi)	149°C (300°F)
Operating Case 1 [Note (1)]	1 724 kPa (250 psi)	121°C (250°F)	1 724 kPa (250 psi)	121°C (250°F)	0 kPa (0 psi)	4°C (40°F)
Operating Case 2 [Note (2)]	1 724 kPa (250 psi)	121°C (250°F)	0 kPa (0 psi)	4°C (40°F)	1 724 kPa (250 psi)	121°C (250°F)
Ambient (as-installed) temperature	...	4°C (40°F)	...	4°C (40°F)	...	4°C (40°F)

GENERAL NOTE: For computer-based temperature and pressure data input, consider the West Branch temperature and pressure to be in effect from nodes 30 through 330 as listed in Table S303.3. Likewise, consider the East Branch temperature and pressure to be in effect from nodes 40 through 340 as listed in Table S303.3; see para. S303.3.

NOTES:
(1) East Branch is at ambient (as-installed) conditions.
(2) West Branch is at ambient (as-installed) conditions.

S303.4 Pressure Effects

Neither pressure stiffening nor Bourdon effects are included in the analyses.

S303.5 Operating Load Case(s)

The operating load case is used to determine the operating position of the piping and reaction loads for any attached equipment, anchors, supports, guides, or stops. The owner has mandated in the design specification that the meter runs and piping be more than adequately supported. Therefore, the operating load case, while necessary to set the limits of the strain ranges, does not contribute to the emphasis of this example, and its output is not included. Tables C-1 and C-1M values used for Row A and Row B expansion coefficients are listed below.

(a) Row A = 12.3 × 10^{-6} mm/mm/°C (6.80 × 10^{-6} in./in./°F)

(b) Row B = 1.34 mm/m (1.68 in./100 ft)

S303.6 Sustained Load Case

Stresses due to the sustained loads, such as axial forces, internal pressure, and intensified bending moments in this example, are combined in accordance with para. 320 to determine S_L. For reasons similar to those expressed for the operating load case, the sustained load case output is not included.

S303.7 Displacement Stress Range Load Cases

The displacement stress range, S_E, is computed in accordance with paras. 319.2.3(b) and 319.3.1(a), in which the strains evaluated for the ambient temperature (which is also the as-installed and minimum metal temperature condition for this particular example) are algebraically subtracted from the strains evaluated for Operating Case 1 as listed in Table S303.1. Similarly, the displacement stress range, S_E, is computed from the algebraic strain difference evaluated from the ambient (as-installed) condition to Operating Case 2 as listed in Table S303.1. The individual displacement stress range, S_E, along with the internal reaction loads, is evaluated for each piping component in accordance with eq. (17), is listed in Table S303.7.1 (Operating Case 1), and has the same results as listed in Table S303.7.2 (Operating Case 2), with the exception that some signs differ (indicating the moment reversal range between the two conditions).

The algebraic strain difference between the two resultant case evaluations discussed above produces the greatest displacement stress range for the piping system in accordance with paras. 319.2.1(d), 319.2.3(b), and 319.3.1 (a), i.e., S_E, the "stress range corresponding to the total displacement strains." The resulting reactions' combination and S_E for each piping component are listed in Table S303.7.3.

The values in the tables listed in this paragraph consist of averaged and truncated results originally obtained from commercial pipe stress analysis vendors. In spite of the averaging and truncation processes, as well as the various methods in which each vendor has chosen to perform the modeling of branch connections, each vendor's results are within ±6% of the values listed in Tables S303.7.1, S303.7.2, and S303.7.3.

S303.8 Code Compliance — Satisfying the Intent of the Code

The piping system is compliant with the sustained load requirements of the Code. The displacement stress range from the ambient (as-installed) condition to each of the operating cases indicates the piping system is in

Table S303.3 Generic Pipe Stress Model Input: Component Connectivity, Type, and Lengths

From	To	D_X, m (ft)	D_Z, m (ft)	Component Type
10	20	1.52 (5)	...	10 anchor (DN 600 Header)
				20 welding tee
20	30	...	1.52 (5)	30 welding tee
30	35	...	0.76 (2.5)	35 simulated end cap
20	40	...	−1.52 (−5)	40 welding tee
40	45	...	−0.76 (−2.5)	45 end cap
40	110	3.05 (10)	...	(East DN 500 Branch)
				110 Y support
110	120	3.05 (10)	...	120 pipe segment
120	125	3.05 (10)	...	8 890 N (2,000 lb) meter
				125 Y support
125	130	3.05 (10)	...	8 890 N (2,000 lb) meter
130	140	3.05 (10)	...	140 pipe segment
140	340	3.05 (10)	...	340 welding tee
30	210	3.05 (10)	...	(West DN 500 Branch)
				210 Y support
210	220	3.05 (10)	...	220 pipe segment
220	225	3.05 (10)	...	8 890 N (2,000 lb) meter
				225 Y support
225	230	3.05 (10)	...	8 890 N (2,000 lb) meter
230	240	3.05 (10)	...	240 pipe segment
240	330	3.05 (10)	...	330 welding tee
310	320	3.05 (10)	...	(DN 600 Header)
				310 anchor [free in the X (axial) direction]
				320 welding tee
320	330	...	1.52 (5)	330 welding tee
330	335	...	0.76 (2.5)	335 end cap
320	340	...	−1.52 (−5)	340 welding tee
340	345	...	−0.76 (−2.5)	345 end cap

GENERAL NOTE: This piping system is planar, i.e., D_Y = 0 m (0 ft) for each piping component.

compliance with the intent of the Code even when limited to the eq. (1a) allowable, S_A. But the "stress range corresponding to the total displacement strains," which considers the algebraic strain difference between the two operating cases, indicates that the piping system is not protected against fatigue failure for the cycles under analysis even when considering the eq. (1b) allowable, S_A. Therefore, redesign of the piping system is required.

If the piping system is redesigned such that it is compliant with the intent of the Code, then the piping system would require no further attention unless the sustained, hydrostatic leak test, or operating reaction loads at either anchor data point 10 or 310, or meter runs 130 or 230, exceeded the allowable loads for the attached equipment, nozzles, or support structure. The meter loads, nozzle loads, and support structure analyses are beyond the scope of this example. Although the occasional load cases are important to the design and analysis of a piping system, they are not discussed in this example.

Table S303.7.1 Operating Case 1: Displacement Stress Range [Eq. (1b) Allowable S_A = 364 MPa (52.7 ksi): Passes]

Node	Global Axis Forces and Moments [Note (1)]		
	F_x, N (lb) (Signed) [Notes (2), (3)]	M_y, N·m (ft-lb) (Unsigned) [Note (2)]	Eq. (17), S_E, MPa (ksi) [Note (3)]
10 anchor	0	180 000 (132,000)	68.0 (9.9)
20 tee	0	180 000 (132,000)	224 (32.4)
30 tee	−94 000 (−21,000)	52 800 (38,800)	110 (15.7)
40 tee	+94 000 (+21,000)	52 800 (38,800)	110 (15.7)
110 Y	+94 000 (+21,000)	52 800 (38,800)	35.2 (5.1)
120 meter	+94 000 (+21,000)	52 800 (38,800)	35.2 (5.1)
125 Y	−94 000 (−21,000)	52 800 (38,800)	35.2 (5.1)
130 meter	+94 000 (+21,000)	52 800 (38,800)	35.2 (5.1)
140 Y	+94 000 (+21,000)	52 800 (38,800)	35.2 (5.1)
310 anchor	0	180 000 (132,000)	68.0 (9.9)
320 tee	0	180 000 (132,000)	224 (32.4)
330 tee	−94 000 (−21,000)	52 800 (38,800)	110 (15.7)
340 tee	+94 000 (+21,000)	52 800 (38,800)	110 (15.7)
210 Y	−94 000 (−21,000)	52 800 (38,800)	35.2 (5.1)
220 meter	+94 000 (+21,000)	52 800 (38,800)	35.2 (5.1)
225 Y	+94 000 (+21,000)	52 800 (38,800)	35.2 (5.1)
230 meter	−94 000 (−21,000)	52 800 (38,800)	35.2 (5.1)
240 Y	−94 000 (−21,000)	52 800 (38,800)	35.2 (5.1)

GENERAL NOTE: The stress due to sustained load used in determining the eq. (1b) allowable displacement stress range, S_A, for nodes 20 and 320 is 28.4 MPa (4.12 ksi).

NOTES:

(1) Force ranges, moment ranges, and displacement stress ranges are averaged from commercial programs' results, are obtained by analyzing the piping system in both U.S. Customary and SI units, and are directly affected by the stiffness chosen for valves, flanges, other relatively stiff components, and branch connections.

(2) Each force range and moment range is signed based on its direction relative to the selected coordinate system's positive direction.

(3) In accordance with para. 319.4.4, no operating pressure force range is included in the force ranges and displacement stress ranges listed above.

Table S303.7.2 Operating Case 2: Displacement Stress Range [Eq. (1b) Allowable S_A = 364 MPa (52.7 ksi): Passes]

Node	Global Axis Forces and Moments [Note (1)]		Eq. (17), S_E, MPa (ksi) [Note (3)]
	F_x, N (lb) (Signed) [Notes (2), (3)]	M_y, N·m (ft-lb) (Unsigned) [Note (2)]	
10 anchor	0	180 000 (132,000)	68.0 (9.9)
20 tee	0	180 000 (132,000)	224 (32.4)
30 tee	+94 000 (+21,000)	52 800 (38,800)	110 (15.7)
40 tee	−94 000 (−21,000)	52 800 (38,800)	110 (15.7)
110 Y	−94 000 (−21,000)	52 800 (38,800)	35.2 (5.1)
120 meter	+94 000 (+21,000)	52 800 (38,800)	35.2 (5.1)
125 Y	−94 000 (−21,000)	52 800 (38,800)	35.2 (5.1)
130 meter	−94 000 (−21,000)	52 800 (38,800)	35.2 (5.1)
140 Y	−94 000 (−21,000)	52 800 (38,800)	35.2 (5.1)
310 anchor	0	180 000 (132,000)	68.0 (9.9)
320 tee	0	180 000 (132,000)	224 (32.4)
330 tee	+94 000 (+21,000)	52 800 (38,800)	110 (15.7)
340 tee	−94 000 (−21,000)	52 800 (38,800)	110 (15.7)
210 Y	−94 000 (−21,000)	52 800 (38,800)	35.2 (5.1)
220 meter	−94 000 (−21,000)	52 800 (38,800)	35.2 (5.1)
225 Y	−94 000 (−21,000)	52 800 (38,800)	35.2 (5.1)
230 meter	−94 000 (−21,000)	52 800 (38,800)	35.2 (5.1)
240 Y	−94 000 (−21,000)	52 800 (38,800)	35.2 (5.1)

GENERAL NOTE: The stress due to sustained load used in determining the eq. (1b) allowable displacement stress range, S_A, for nodes 20 and 320 is 28.4 MPa (4.12 ksi).

NOTES:

(1) Force ranges, moment ranges, and displacement stress ranges are averaged from commercial programs' results, are obtained by analyzing the piping system in both U.S. Customary and SI units, and are directly affected by the stiffness chosen for valves, flanges, other relatively stiff components, and branch connections.

(2) Each force range and moment range is signed based on its direction relative to the selected coordinate system's positive direction.

(3) In accordance with para. 319.4.4, no operating pressure force range is included in the force ranges and displacement stress ranges listed above.

Table S303.7.3 Moment Reversal Load Combination Considering Operating Cases 1 and 2, Total Strain Based: Displacement Stress Range [Eq. (1b) Allowable S_A = 364 MPa (52.7 ksi): Fails]

Node	Global Axis Forces and Moments [Note (1)]: F_x, N (lb) (Unsigned) [Notes (2), (3)]	Global Axis Forces and Moments [Note (1)]: M_y, N·m (ft-lb) (Unsigned) [Note (3)]	Eq. (17), S_E, MPa (ksi) [Notes (2), (3)]
10 and 310 anchor	0	361 000 (265,000)	136 (19.7)
20 and 320 tee	0	361 000 (265,000)	448 (64.7)
30 and 330 tee	188 000 (42,100)	106 000 (77,600)	220 (31.4)
40 and 340 tee	188 000 (42,100)	106 000 (77,600)	220 (31.4)
110 and 210 Y	188 000 (42,100)	106 000 (77,600)	70.4 (10.2)
120 and 220 meter	188 000 (42,100)	106 000 (77,600)	70.4 (10.2)
125 and 225 Y	188 000 (42,100)	106 000 (77,600)	70.4 (10.2)
130 and 230 meter	188 000 (42,100)	106 000 (77,600)	70.4 (10.2)
140 and 240 Y	188 000 (42,100)	106 000 (77,600)	70.4 (10.2)

GENERAL NOTE: The stress due to sustained load used in determining the eq. (1b) allowable displacement stress range, S_A, for nodes 20 and 320 is 28.4 MPa (4.12 ksi).

NOTES:

(1) Force ranges, moment ranges, and displacement stress ranges are averaged from commercial programs' results, are obtained by analyzing the piping system in both U.S. Customary and SI units, and are directly affected by the stiffness chosen for valves, flanges, other relatively stiff components, and branch connections.

(2) In accordance with para. 319.4.4, no operating pressure force range is included in the force ranges and displacement stress ranges listed above.

(3) Signs are not listed for F_x and M_y listed above since signs are irrelevant following the load combination summation; see paras. 319.2.3(b), 319.3.1(a), 319.4.4, and 302.3.5(d) in determining the greatest displacement stress range, S_E.

APPENDIX V
ALLOWABLE VARIATIONS IN ELEVATED TEMPERATURE SERVICE

V300 APPLICATION

(a) This Appendix covers application of the Linear Life Fraction Rule, which provides a method for evaluating variations at elevated temperatures above design conditions where material creep properties [see para. V302(c)] control the allowable stress at the temperature of the variation. This Appendix is a Code requirement only when specified by the owner in accordance with the last sentence of para. 302.2.4(f)(1).

(b) Life Fraction analysis addresses only the gross strength of piping components; it does not consider local stress effects. It is the designer's responsibility to provide construction details suitable for elevated temperature design.

V300.1 Definitions

duration :

(a) the extent of any service condition, hours

(b) the cumulative extent of all repetitions of a given service condition during service life, hours

excursion : any condition under which pressure, temperature, or both exceed the design conditions.

operating condition : any condition of pressure and temperature under which the design conditions are not exceeded.

service condition: any operating condition or excursion.

service life: the life assigned to a piping system for design purposes, hours.

V301 DESIGN BASIS

Life Fraction analysis shall be performed in accordance with one of the following design basis options selected by the owner:

(a) All service conditions in the creep range and their durations are included.

(b) To simplify the analysis, less severe service conditions need not be individually evaluated if their durations are included with the duration of a more severe service condition.

V302 CRITERIA

(a) All of the criteria in para. 302.2.4 shall be met.

(b) Only carbon steels, low and intermediate alloy steels, austenitic stainless steels, and high nickel alloys are included.

(c) Service conditions are considered only in the calculation of the usage factors in accordance with para. V303 when the allowable stress at the temperature of those conditions in Table A-1 or Table A-1M is based on the creep criteria stated in para. 302.3.2.

(d) Creep–fatigue interaction effects shall be considered when the number of cycles exceeds 100.

V303 PROCEDURE

The cumulative effect of all service conditions during the service life of the piping is determined by the Linear Life Fraction Rule in accordance with the following procedure.

V303.1 Calculations for Each Service Condition *i*

The following steps shall be repeated for each service condition considered.

V303.1.1 Equivalent Stress for Pressure

(a) Using eq. (V1), compute a pressure-based equivalent stress, S_{pi}

$$S_{pi} = S_d P_i / P_{\max} \tag{V1}$$

where

P_i = gage pressure, kPa (psig), during service condition i

$P_{\max}$ = maximum allowable gage pressure, kPa (psig), for continuous operation of pipe or component at design temperature, considering allowances, c, and mill tolerance, but without considering weld joint strength reduction factor, W; weld joint quality factors, E_j; or casting quality factor, E_c

S_d = allowable stress, MPa (ksi), at design temperature, °C (°F)

S_{pi} = pressure-based equivalent stress, MPa (ksi) *(b)* Compute the maximum stress due to sustained loads, S_L, during service condition i, in accordance with para. 302.3.5(c).

(c) The equivalent stress, S_i, for use in para. V303.1.2 is the greater of the values calculated in (a) and (b), divided by their respective weld joint strength reduction factor, W, in accordance with para. 302.3.5(e).

V303.1.2 Effective Temperature. From Table A-1 or Table A-1M, find the temperature corresponding to a basic allowable stress equal to the equivalent stress, S_i, using linear interpolation if necessary. This temperature, T_E, is the effective temperature for service condition i.

V303.1.3 Larson–Miller Parameter. Compute the LMP for the basic design life for service condition i, using eq. (V2)

(SI Units)

$$LMP = (C + 5)(T_E + 273) \tag{V2}$$

(U.S. Customary Units)

$$LMP = (C + 5)(T_E + 460) \tag{V2}$$

where

C = Larson-Miller constant
= 30 for 9Cr–1Mo–V
= 20 for carbon, low, and intermediate alloy steels, except 9Cr–1Mo–V
= 15 for austenitic stainless steel and high nickel alloys

T_E = effective temperature, °C (°F); see para. V303.1.2

V303.1.4 Rupture Life. Compute the rupture life, t_{ri}, h, using eq. (V3)

$$t_{ri} = 10^a \tag{V3}$$

where

(SI Units)

$$a = \frac{LMP}{T_i + 273} - C$$

(U.S. Customary Units)

$$a = \frac{LMP}{T_i + 460} - C$$

and

T_i = temperature, °C (°F), of the component for the coincident operating pressure–temperature condition i under consideration

t_{ri} = allowable rupture life, h, associated with a given service condition i and stress, S_i

LMP and C are as defined in para. V303.1.3.

V303.2 Determine Creep-Rupture Usage Factor

The usage factor, u, is the summation of individual usage factors, t_i / t_{ri}, for all service conditions considered in para. V303.1. See eq. (V4).

$$u = \sum (t_i / t_{ri}) \tag{V4}$$

where

i = as a subscript, 1 for the prevalent operating condition; i = 2, 3, etc., for each of the other service conditions considered

t_i = total duration, h, associated with any service condition, i, at pressure, P_i, and temperature, T_i

t_{ri} = as defined in para. V303.1.4

V303.3 Evaluation

The calculated value of u indicates the nominal amount of creep-rupture life expended during the service life of the piping system. If $u \leq 1.0$, the usage factor is acceptable including excursions. If $u > 1.0$, the designer shall either increase the design conditions (selecting piping system components of a higher allowable working pressure if necessary) or reduce the number and/or severity of excursions until the usage factor is acceptable.

V304 EXAMPLE (20)

The following example illustrates the application of the procedure in para. V303:

Pipe material: ASTM A691, Gr. 2¼CR Cl. 32 pipe
Pipe size: NPS 30 (30 in. O.D.)
Nominal pipe wall thickness: 0.85 in.
Corrosion allowance: 0.0625 in.
Mill tolerance: 0.01 in.
Design pressure: 250 psig
Design temperature: 1,025°F
Allowable stress at 1,025°F: 6.85 ksi
Allowable stress at 1,050°F: 5.7 ksi
Total service life: 175,200 hr
Three service conditions are considered.

(a) Normal operation is 157,200 hr at design conditions of 250 psig, 1,025°F.

(b) Excursion 1 condition is up to 16,000 hr at excursion condition of 250 psig, 1,050°F. [This is a 20% reduction in allowable stress (6.85 ksi to 5.7 ksi), and, with the owner's approval, it complies with the criteria of para. 302.2.4. As a simplification, and in accordance with para. V301(b), this 16,000-hr total includes less severe excursions.]

(c) Excursion 2 condition is up to 2,000 hr at excursion condition of 330 psig, 1,025°F. [This is a 32% variation above the design pressure, and, with the owner's approval, it complies with the criteria of para. 302.2.4. As a simplification, and in accordance with para. V301(b), this 2,000-hr total includes less severe excursions.]

Compute pressure-based equivalent stress, S_{pi}, from eq. (V1).

From Table A-1, S_d = 6.85 ksi at 1,025°F

$$P_{max} = \frac{2(\overline{T} - c - \text{mill tol.}) \times SEW}{D - 2(\overline{T} - c - \text{mill tol.}) \times Y}$$

Letting $S = S_d$ and, in accordance with the definition of P_{max} in para. V303.1.1, E = 1 and W = 1, and for all the service temperatures Y = 0.7,

$$P_{max} = 368 \text{ psi}$$

$$\begin{aligned} S_{p1} &= 6.85(250/368) = 4.65 \text{ ksi} \\ S_{p2} &= 6.85(250/368) = 4.65 \text{ ksi} \\ S_{p3} &= 6.85(330/368) = 6.14 \text{ ksi} \end{aligned}$$

NOTE: In eq. (V1), design pressure could be used in this example for P_{max}, as this will always be conservative. Here the actual P_{max} of the piping system is used.

The stress due to sustained loads, S_L, for each condition i, calculated in accordance with para. 320.2, is

$$\begin{aligned} S_{L1} &= 3.0 \text{ ksi} \\ S_{L2} &= 3.0 \text{ ksi} \\ S_{L3} &= 3.7 \text{ ksi} \end{aligned}$$

For pipe with a longitudinal weld (E = 1), W is 0.8, 0.77, and 1.0 for S_{p1}, S_{p2}, and S_{p3}, respectively. Note that condition 3 is short term, so W = 1. Also note that with the owner's approval, and in accordance with para. 302.3.5(f)(2), W may be larger than the W factors listed in Table 302.3.5. The designer chooses not to apply W for girth welds, so W is 1.00 for S_{L1}, S_{L2}, and S_{L3}. The equivalent stress, S_i, is the greater of S_{pi}/W and S_{Li}/W. Therefore, S_i is as follows:

$$\begin{aligned} S_1 &= \text{MAX}\left(S_{p1}/W,\ S_{L1}/W\right) \\ &= \text{MAX}\ (4.65/0.8,\ 3.0/1.0) \\ &= \text{MAX}\ (5.81,\ 3.00) = 5.81 \text{ ksi} \end{aligned}$$

$$\begin{aligned} S_2 &= \text{MAX}\left(S_{p2}/W,\ S_{L2}/W\right) \\ &= \text{MAX}\ (4.65/0.77,\ 3.0/1.0) \\ &= \text{MAX}\ (6.04,\ 3.00) = 6.04 \text{ ksi} \end{aligned}$$

$$\begin{aligned} S_3 &= \text{MAX}\left(S_{p3}/W,\ S_{L3}/W\right) \\ &= \text{MAX}\ (6.14/1.0,\ 3.7/1.0) \\ &= \text{MAX}\ (6.14,\ 3.70) = 6.14 \text{ ksi} \end{aligned}$$

From Table A-1, find the temperature, T_E, corresponding to each S_i.

$$\begin{aligned} T_{E1} &= 1{,}048°\text{F} \\ T_{E2} &= 1{,}043°\text{F} \\ T_{E3} &= 1{,}040°\text{F} \end{aligned}$$

Compute the LMP for each condition i using eq. (V2).

$$\begin{aligned} LMP &= (20 + 5)(1{,}048 + 460) = 37{,}700 \\ LMP &= (20 + 5)(1{,}043 + 460) = 37{,}575 \\ LMP &= (20 + 5)(1{,}040 + 460) = 37{,}500 \end{aligned}$$

Compute the rupture life, t_{ri}, using eq. (V3).

$$a = 37{,}700/(1{,}025 + 460) - 20 = 5.39$$
$$t_{r1} = 10^{5.39} = 245{,}471 \text{ hr}$$

$$a = 37{,}575/(1{,}050 + 460) - 20 = 4.88$$
$$t_{r2} = 10^{4.88} = 75{,}858 \text{ hr}$$

$$a = 37{,}500/(1{,}025 + 460) - 20 = 5.25$$
$$t_{r3} = 10^{5.25} = 177{,}828 \text{ hr}$$

Compute the usage factor, u, the summation of t_i/t_{ri}, for all service conditions using eq. (V4).

$$\begin{aligned} t_1/t_{r1} &= 157{,}200/245{,}471 = 0.640 \\ t_2/t_{r2} &= 16{,}000/75{,}858 = 0.211 \\ t_3/t_{r3} &= 2{,}000/177{,}828 = 0.011 \end{aligned}$$

$$u = 0.640 + 0.211 + 0.011 = 0.862 < 1.0$$

Therefore, the excursion is acceptable.

APPENDIX W
HIGH-CYCLE FATIGUE ASSESSMENT OF PIPING SYSTEMS

W300 APPLICATION

This Appendix addresses the fatigue evaluation of Code piping subjected to cyclic loadings when the total number of significant stress cycles due to all causes exceeds 100,000. The Appendix may be used subject to the owner's approval. When it is used, the details shall be documented in the engineering design.

A significant stress cycle is defined as a cycle with a computed stress range, in accordance with para. 319, greater than 20.7 MPa (3.0 ksi) for ferritic steels and austenitic stainless steels. For other materials, or corrosive environments, all cycles shall be considered significant, unless otherwise documented in the engineering design. The allowable displacement stress range requirements of para. 302, using the computed stress range in accordance with para. 319, provide an acceptable method of evaluating piping systems for fatigue when the number of significant stress cycles is less than or equal to 100,000. The piping cyclic loadings may be due to thermal expansion, anchor motion, vibration, inertial loads, wave motion or other sources.

Fatigue due to pressure cycling is not addressed in this Appendix, but it shall be considered in the engineering design. The methods in Chapter IX or ASME BPVC, Section VIII, Division 2 may be applied to address pressure cycling.

The design, fabrication, examination, and testing requirements of this Appendix are in addition to the requirements of Chapters I through VI.

W301 NOMENCLATURE

CF = welded joint fatigue curve coefficient, SI (U.S. Customary) units
d_t = fatigue damage due to thermal stress with constant amplitude
d_w = fatigue damage due to wave stress with variable amplitude
E = modulus of elasticity at operating temperature
e = base of natural logarithm
E_{CSA} = modulus of elasticity of carbon steel at ambient temperature or 21°C (70°F)
f_E = environmental correction factor (see Table W302.1-4)
f_I = fatigue improvement factor from ASME BPVC, Section VIII, Division 2
$f_{M,k}$ = fatigue factor for stress ratio
f_t = temperature correction factor
h = Weibull stress range shape distribution parameter
k = fatigue strength thickness exponent (see Tables W302.1-1 through W302.1-3)
L_d = piping cyclic design life, yr
L_w = design storm period of occurrence, yr
m = welded joint fatigue curve exponent
N_d = design number of pipe stress cycles
N_i = number of cycles for loading condition i
N_{ti} = allowable number of cycles for loading condition i
N_w = design storm wave height associated cycles
q = Weibull stress range scale distribution parameter that can be expressed in terms of stress range
S_{aw} = allowable maximum probable stress range during N_w wave cycles, MPa (ksi)
S_{Ei} = computed displacement stress range for condition i corresponding to cycles N_i, MPa (ksi)
$S_{Ei,\ max}$ = computed maximum displacement stress for condition i corresponding to stress range S_{Ei} and cycles N_i, MPa (ksi)
$S_{Ei,\ min}$ = computed minimum displacement stress for condition i corresponding to stress range S_{Ei} and cycles N_i, MPa (ksi)
S_{EW} = computed maximum stress range due to wave motion, MPa (ksi)
S_{yi} = yield strength of the component under consideration for condition i
T_E = effective component thickness at weld joint, mm (in.)
$\overline{T}$ = component nominal thickness at weld joint, mm (in.)
V_o = average zero-crossing frequency, Hz
$\Gamma(1 + m/h)$ = gamma function of argument $1 + m/h$ [see Table W301-1 and eq. (W8)]
σ = standard deviation; -2σ is a 95% prediction interval and -3σ is a 99% prediction interval on a statistical basis

Table W301-1 Gamma Function Evaluation

1 + m/h	$\Gamma(1 + m/h)$	1 + m/h	$\Gamma(1 + m/h)$
3.00	2.00	5.00	24.00
3.05	2.10	5.05	25.88
3.10	2.20	5.10	27.93
3.15	2.31	5.15	30.16
3.20	2.42	5.20	32.58
3.25	2.55	5.25	35.21
3.30	2.68	5.30	38.08
3.35	2.83	5.35	41.20
3.40	2.98	5.40	44.60
3.45	3.15	5.45	48.30
3.50	3.32	5.50	52.34
3.55	3.51	5.55	56.75
3.60	3.72	5.60	61.55
3.65	3.94	5.65	66.80
3.70	4.17	5.70	72.53
3.75	4.42	5.75	78.78
3.80	4.69	5.80	85.62
3.85	4.99	5.85	93.10
3.90	5.30	5.90	101.27
3.95	5.64	5.95	110.21
4.00	6.00	6.00	120.00
4.05	6.39	6.05	130.72
4.10	6.81	6.10	142.45
4.15	7.27	6.15	155.31
4.20	7.76	6.20	169.41
4.25	8.29	6.25	184.86
4.30	8.86	6.30	201.81
4.35	9.47	6.35	220.41
4.40	10.14	6.40	240.83
4.45	10.85	6.45	263.26
4.50	11.63	6.50	287.89
4.55	12.47	6.55	314.95
4.60	13.38	6.60	344.70
4.65	14.37	6.65	377.42
4.70	15.43	6.70	413.41
4.75	16.59	6.75	453.01
4.80	17.84	6.80	496.61
4.85	19.20	6.85	544.61
4.90	20.67	6.90	597.49
4.95	22.27	6.95	655.77

GENERAL NOTE: This Table shows the evaluation of the gamma function, Γ, for values between 3 and 6.95, e.g., Γ(3) = 2. Gamma function for values of (1 + m/h) not listed here may be computed directly from the mathematical definition of the gamma function or computed from the following approximation:

$$\Gamma(1 + m/h) \cong \sqrt{2\pi(m/h)}\,[(m/h)/e]^{m/h}$$

W302 DESIGN FOR FATIGUE

The fatigue design procedure in this Appendix addresses two types of cyclic loading — fatigue loading where the loading spectrum may be reduced to a series of stress range–cycle pairs, and fatigue loading where the loading spectrum may be represented by a two-parameter Weibull distribution. Fatigue damage is the summation based on the linear damage rule. The fatigue design analysis method in this Appendix is based on the following general requirements:

(a) In the absence of more directly applicable data, the stress intensification factors shown in Appendix D for elbows, bends, and ASME B16.9 tees may be used. The stress intensification factors for other components are the responsibility of the designer and their validity shall be documented in the engineering design.

(b) Integral construction is recommended. Fabricated components such as branch connections and miter elbows are not recommended.

(c) The maximum stress range from all sources of loadings shall not exceed the displacement stress range requirements of para. 302.3.5 with f = 1.0.

(d) Inertial forces due to wave loading shall be considered as occasional loads and shall satisfy the requirements of para. 302.3.6.

W302.1 Fatigue Damage Due to Cyclic Stress Range From Other Than Wave Motion

The maximum stress range, S_E, shall be computed in accordance with para. 319 and meet the allowable displacement stress range requirements of para. 302.3.5 with f = 1.0. The stress range–cycle pairs (S_{Ei}, N_i) shall be established from a stress–cycle histogram by the Rainflow method of ASME BPVC, Section VIII, Division 2, Annex 5-B. Fatigue damage shall be computed as follows:

Allowable fatigue cycles for load case i

$$N_{ti} = \frac{f_I}{f_E}\left(\frac{CF \cdot f_{M,k} \cdot f_t}{S_{Ei} \cdot T_E^k}\right)^m \qquad \text{(W1)}$$

where

f_I = 1.0 unless otherwise documented in the engineering design

$f_{M,k}$ = 1.0 unless ($S_{Ei,\ max}$ + $S_{Ei,\ min}$) > S_{yi}, in which case $f_{M,k} = (1 - S_{Ei,\ min}/S_{Ei,\ max})^{0.2778}$

f_t = temperature correction factor
= E/E_{CSA}

T_E = 16 mm (0.625 in.) for $\overline{T}$ ≤ 16 mm (0.625 in.)
= $\overline{T}$ for 16 mm (0.625 in.) < $\overline{T}$ < 150 mm (6 in.)
= 150 mm (6 in.) for $\overline{T}$ ≥ 150 mm (6 in.)

Fatigue damage due to displacement loadings

Table W302.1-1 Fatigue Material Coefficients (−3σ)

Material	CF SI Units	CF U.S. Customary Units	m	k
Ferritic steels and austenitic stainless steels	14 137	999.1	3.13	0.222
Aluminum	2 303	162.8	3.61	0.222

GENERAL NOTES:
(a) SI units include S_{Ei} (MPa) and T_E (mm) in eq. (W1).
(b) U.S. Customary units include S_{Ei} (ksi) and T_E (in.) in eq. (W1).

$$d_t := \sum \frac{N_i}{N_{ti}} \tag{W2}$$

where d_t must be less than 1.0. When computing fatigue damage in accordance with eq. (W2), cycles associated with a stress range less than 20.7 MPa (3 ksi) need not be considered.

The fatigue material coefficients used in eq. (W1) shall be in accordance with Table W302.1-1. Alternatively, when specified in the engineering design and approved by the owner, the fatigue material coefficients may be in accordance with Table W302.1-2. The maximum temperature limits for Table W302.1-1 and Table W302.1-2 are 371°C (700°F) for ferritic steels, 427°C (800°F) for austenitic stainless steels, and 204°C (400°F) for aluminum. The fatigue material coefficients for temperatures in excess of these limits or for materials not listed in Table W302.1-1 or Table W302.1-2 shall be specified and the basis documented in the engineering design.

When the number of cycles, N_{ti}, exceeds 10^7, and with approval of the owner, the fatigue material coefficients in Table W302.1-3 may be used instead of the coefficients in Table W302.1-1 or Table W302.1-2 when applying eq. (W1). Alternatively, when specified in the engineering design and approved by the owner, optional fatigue material coefficients may be developed for $N_{ti} > 10^6$.

Table W302.1-2 Fatigue Material Coefficients (−2σ)

Material	CF SI Units	CF U.S. Customary Units	m	k
Ferritic steels and austenitic stainless steels	16 942	1,198	3.13	0.222
Aluminum	2 828	199.9	3.61	0.222

GENERAL NOTES:
(a) SI units include S_{Ei} (MPa) and T_E (mm) in eq. (W1).
(b) U.S. Customary units include S_{Ei} (ksi) and T_E (in.) in eq. (W1).

The environmental fatigue factor, f_E, is typically a function of the fluid environment, loading frequency, temperature, and material variables, e.g., grain size and chemical composition. In the absence of more directly applicable data, the values of f_E provided in Table W302.1-4 may be used for the effect of the environment on the fatigue life of carbon steel piping at temperatures less than or equal to 93°C (200°F). The values of f_E for other materials, temperatures, or environments may be assumed to be 4.0 if more-specific data is not available. Alternative environmental fatigue factors may be used when justified based on applicable data, and shall be specified and the basis documented in the engineering design.

W302.2 Fatigue Damage Due to Cyclic Stress Range From Wave Motion

This paragraph addresses variable amplitude random loadings where the long-term stress range distribution may be represented by a two-parameter Weibull distribution. The specific requirements are written for wave loadings for applications such as floating offshore platforms; however, the method may be applied to other applications where the Weibull distribution applies. In this Appendix, a "sea state" is defined as the general condition of the free surface on a large body of water with respect to wind waves and swell at a certain location and time. A sea state is characterized by statistics, including the wave height and period, and represented here by parameters h and V_o.

When designing for wave motion, the design sea state shall be specified by the owner. The sea state shall be characterized by a two-parameter wave-scatter diagram of significant wave height and zero upcrossing period. The stress range is assumed proportional to wave height, and the Weibull stress range shape distribution parameter and average zero crossing frequency are determined from the data.

The long-term stress range distribution may be represented by a two-parameter Weibull distribution as follows:

Table W302.1-3 Optional Fatigue Material Coefficients When $N_{ti} > 10^7$

Material	CF	m	k
Ferritic steels and austenitic stainless steels	$CFa[(f_E/f_i)10^7]^{ax}$	5.0	0.222

GENERAL NOTES:
(a) CFa is CF from Table W302.1-1 or Table W302.1-2 in SI or U.S. Customary units.
(b) $ax = (1/m_2 - 1/m_1)$, where
m_1 = value of m from Table W302.1-1 or Table W302.1-2
m_2 = value of m from Table W302.1-3
(For ferritic and austenitic stainless steels, $ax = -0.1195$.)

(20) **Table W302.1-4 Environmental Fatigue Factors for Carbon Steel Piping, $T \le 93°C$ (200°F)**

Environment	f_E
Air	1.0
Seawater with cathodic protection	2.51
Seawater with free corrosion	3.0

$$F = e^{-(S_{EW}/q)^h} \quad \text{(W3)}$$

$$q = \frac{S_{aw}}{[\ln(N_w)]^{1/h}} \quad \text{(W4)}$$

where

F = probability for exceeding the stress range, S_{EW}

The design fatigue curve is represented by a single equation of the form given by eq. (W1).

Allowable fatigue damage for variable wave loadings

$$d_w = 1 - d_t \quad \text{(W5)}$$

Design storm wave height associated cycles

$$N_w = 3.156 \times 10^7 \times V_o \times L_w \quad \text{(W6)}$$

Design number of pipe stress cycles

$$N_d = 3.156 \times 10^7 \times V_o \times L_d \quad \text{(W7)}$$

The maximum probable stress range shall be determined from the maximum probable wave height based on a two-parameter Weibull model. The maximum probable wave height (or maximum probable stress range) will be exceeded, on average, once every N_w design wave cycles.

Allowable maximum probable stress range during N_w wave cycles

$$S_{aw} = \left(\frac{d_w a}{N_d}\right)^{1/m} \times \frac{[\ln(N_w)]^{1/h}}{\left[\Gamma\left(1 + \frac{m}{h}\right)\right]^{1/m}} \quad \text{(W8)}$$

where

$$a = \left(\frac{f_I}{f_E}\right) \times \left(\frac{CF \cdot f_{M,k} \cdot f_t}{T_E^k}\right)^m \quad \text{(W9)}$$

f_I = 1.0 unless otherwise documented in the engineering design

The fatigue material coefficients, CF, m, and k, shall be in accordance with Table W302.1-1, unless the alternative analysis methods of para. W302.3 are applied.

The computed maximum stress range, S_{EW}, is assumed to be proportional to the maximum probable wave height (trough to peak). The stress range shall be computed in accordance with para. 319 from the imposed displacements created by the maximum probable wave height and shall not exceed the allowable maximum probable stress range, S_{aw}.

This Appendix does not prescribe specific values for h, V_o, L_w, or L_d. These design parameters shall be specified by the owner or regulatory authority, as applicable. The values for h and V_o are determined by statistical data based on the specific sea state. The design life of the piping, L_d, and the design maximum probable wave height based on the design storm period of occurrence, L_w, shall be based on the intended life of the piping and acceptable risk.

In the absence of more-applicable data for the specific sea state, the following typical values may be used:

(a) h = 1.0
(b) V_o = 0.159 Hz
(c) L_d = 20 yr
(d) L_w = 100 yr

W302.3 Alternative Analysis Methods

The fatigue analysis method presented in para. W302.1 is based on a design fatigue curve with a single linear slope on a log-log stress-cycles plot, except when the optional coefficients of Table W302.1-3 are applied for a bilinear fatigue curve. The fatigue analysis method presented in para. W302.2 is based on a two-parameter Weibull model for a design fatigue curve with a single linear slope on a log-log stress-cycles plot and a single sea state, represented by parameters h and V_o. With the owner's approval, the designer may apply more-applicable data or more rigorous analysis methods for fatigue of piping, e.g., a bilinear fatigue curve with a change in slope of the fatigue curve at cycles $>10^7$ or an endurance limit.

The fatigue analysis method of ASME BPVC, Section VIII, Division 2 may be used for piping as an alternative to the method of this Appendix.

W305 FLUID SERVICE REQUIREMENTS

W305.1 General

The requirements in Chapters I through VI apply in addition to the requirements of this Appendix. When the fatigue damage, d_t, computed in accordance with para. W302.1 exceeds 0.5 or when S_{EW}, computed in accordance with para. W302.2, exceeds $0.8S_{aw}$, the requirements for severe cyclic conditions in Chapters I through VI shall apply. For special applications, e.g., offshore piping, the owner may elect to require the supplemental requirements of para. W305.3.

W305.3 Optional Supplemental Requirements

When these supplemental requirements are specified, the requirements for para. W305.1 also apply.

W305.3.1 Examination. The following additional examination is required:

All longitudinal welds shall be fully radiographed in accordance with para. 344.5 with acceptance criteria in accordance with Table 341.3.2 for Normal Fluid Service.

The extent of examination of circumferential groove welds shall be as follows:

(a) At least 10% of the welds shall be randomly examined using the liquid penetrant method (para. 344.4) or, for magnetic materials, the magnetic particle method (para. 344.3) with acceptance criteria in accordance with para. 341.3.2.

(b) When the requirements for severe cyclic conditions do not apply, a minimum of 10% of the welds shall be fully radiographed in accordance with para. 344.5 with acceptance criteria in accordance with Table 341.3.2 for Normal Fluid Service.

Piping specified as critical by the owner shall be subjected to 100% radiography and 100% liquid penetrant or magnetic particle examination using the methods and acceptance criteria described above.

W305.3.2 Leak Testing. Leak testing of the system shall be in accordance with the requirements of para. 345, except that the test duration for hydrostatic testing shall be a minimum of 30 min after the test pressure has been adequately stabilized.

APPENDIX X
METALLIC BELLOWS EXPANSION JOINTS

(Design requirements of Appendix X are dependent on and compatible with EJMA standards.)

X300 GENERAL

The intent of this Appendix is to set forth design, manufacturing, and installation requirements and considerations for bellows type expansion joints, supplemented by the EJMA standards. It is intended that applicable provisions and requirements of Chapters I through VI of this Code shall be met, except as modified herein. This Appendix does not specify design details. The detailed design of all elements of the expansion joint is the responsibility of the manufacturer. This Appendix is not applicable to expansion joints in piping designed in accordance with Chapter IX.

X301 PIPING DESIGNER RESPONSIBILITIES

The piping designer shall specify the design conditions and requirements necessary for the detailed design and manufacture of the expansion joint in accordance with para. X301.1 and the piping layout, anchors, restraints, guides, and supports required by para. X301.2.

X301.1 Expansion Joint Design Conditions

The piping designer shall specify all necessary design conditions including the following.

X301.1.1 Static Design Conditions. The design conditions shall include any possible variations of pressure or temperature, or both, above operating levels. Use of a design metal temperature other than the fluid temperature for any component of the expansion joint shall be verified by computation, using accepted heat transfer procedures, or by test or measurement on similarly designed equipment in service under equivalent operating conditions.

X301.1.2 Cyclic Design Conditions. These conditions shall include coincident pressure, temperature, imposed end displacements and thermal expansion of the expansion joint itself, for cycles during operation. Cycles due to transient conditions (startup, shutdown, and abnormal operation) shall be stated separately. (See EJMA standards, 4.12.1.5 on fatigue life expectancy, for guidance in defining cycles.)

X301.1.3 Other Loads. Other loads, including dynamic effects (e.g., wind, thermal shock, vibration, seismic forces, and hydraulic surge); and static loads, e.g., weight (insulation, snow, ice, etc.), shall be stated.

X301.1.4 Fluid Properties. Properties of the flowing medium pertinent to design requirements, including the owner-designated fluid service category, flow velocity and direction, for internal liners, etc., shall be specified.

X301.1.5 Other Design Conditions. Other conditions that may affect the design of the expansion joint, such as use of shrouds, external or internal insulation, limit stops, other constraints, and connections in the body (e.g., drains or bleeds) shall be stated.

X301.2 Piping Design Requirements

X301.2.1 General. Piping layout, anchorage, restraints, guiding, and support shall be designed to avoid imposing motions and forces on the expansion joint other than those for which it is intended. For example, a bellows expansion joint is not normally designed to absorb torsion. Pipe guides, restraints, and anchorage shall conform to the EJMA standards. Anchors and guides shall be provided to withstand expansion joint thrust forces when not self-restrained by tie rods, hinge bars, pins, etc. (See para. X302.1.) Column buckling of the piping (e.g., due to internal fluid pressure) shall also be considered.

X301.2.2 Design of Anchors

(a) Main Anchors. Main anchors shall be designed to withstand the forces and moments listed in (b), and pressure thrust, defined as the product of the effective thrust area of the bellows and the maximum pressure to which the joint will be subjected in operation. Consideration shall be given to the increase of pressure thrust loads on anchors due to unrestrained expansion joints during leak testing if supplemental restraints are not used during the test (see para. 345.3.3). For convoluted, omega, or disk type joints, the effective thrust area recommended by the manufacturer shall be used. If this information is unavailable, the area shall be based on the mean diameter of the bellows.

(b) Intermediate Anchors. Anchors shall be capable of withstanding the following forces and moments:

(1) those required to compress, extend, offset, or rotate the joint by an amount equal to the calculated linear or angular displacement

(2) static friction of the pipe in moving on its supports between extreme extended and contracted positions (with calculated movement based on the length of pipe between anchor and expansion joint)

(3) operating and transient dynamic forces caused by the flowing medium

(4) other piping forces and moments

X302 EXPANSION JOINT MANUFACTURER RESPONSIBILITIES

The expansion joint manufacturer shall provide the detailed design and fabrication of all elements of the expansion joint in accordance with the requirements of the Code and the engineering design. This includes

(a) all piping within the end connections of the assembly supplied by the manufacturer, including pipe, flanges, fittings, connections, bellows, and supports or restraints of piping

(b) specifying the need for supports or restraints external to the assembly as required, and of the data for their design

(c) determining design conditions for all components supplied with the expansion joint that are not in contact with the flowing medium

X302.1 Expansion Joint Design

The design of bellows-type expansion joints shall be based on recognized and accepted analysis methods and design conditions stated in para. X301.1. These joints shall be designed so that permanent deformation of the expansion joint and pressure-restraint hardware will not occur during leak testing. Convoluted-type bellows shall be designed in accordance with the EJMA standards, except as otherwise required or permitted herein. Design of other types of bellows shall be qualified as required by para. 304.7.2.

X302.1.1 Factors of Safety. The factor of safety on squirm pressure shall be not less than 2.25. The factor of safety on ultimate rupture pressure shall be not less than 3.0.

X302.1.2 Design Stress Limits. For convoluted type bellows, stresses shall be calculated either by the formulas shown in the EJMA standards or by other methods acceptable to the owner.

(a) The circumferential and meridional membrane stress in the bellows, the tangent end, and reinforcing ring members (including tensile stress in fasteners) due to design pressure shall not exceed the allowable stress values given in Table A-1 or Table A-1M.

(b) Meridional membrane and bending stresses at design pressure shall be of a magnitude that will not result in permanent deformation of the convolutions at test pressure. Correlation with previous test data may be used to satisfy this requirement.

For an unreinforced bellows, annealed after forming, the meridional membrane plus bending stress in the bellows shall not exceed 1.5 times the allowable stress given in Table A-1 or Table A-1M.

(c) Stresses shall be calculated in restraints (tie rods, hinge bars, pins, etc.) in self-restrained expansion joints and in the attachments of the restraining devices to the pipe or flanges. Direct tension, compression, bearing, and shear stresses shall not exceed the allowable stress limits stated in para. 302.3.1. The summation of general bending stress plus tension or compression stress shall not exceed the stress values listed in Appendix A, Table A-1 or A-1M, and Table A-2 or A-2M, times the shape factor of the cross section. The shape factor is the ratio of the plastic moment to the yield moment (e.g., 1.5 for a rectangular section). For attachment of restraints to piping, see para. 321.3. Local stresses may be evaluated using the criteria of ASME BPVC, Section VIII, Division 2, Part 5. Compression members shall be evaluated for buckling in accordance with the AISC Manual of Steel Construction, Allowable Stress Design. For self-restrained expansion joints, the restraints shall be designed to withstand the full design pressure thrust. Additional considerations may be required where time-dependent stresses prevail.

(d) Pressure design of pipe sections, fittings, and flanges shall meet the requirements of paras. 303 and 304.

(e) When the operating metal temperature of the bellows element is in the creep range,[1] the design shall be given special consideration and, in addition to meeting the requirements of this Appendix, shall be qualified as required by para. 304.7.2.

X302.1.3 Fatigue Analysis

(a) A fatigue analysis[1] that takes into account all design cyclic conditions shall be performed and the calculated design cycle life shall be reported. The method of analysis for convoluted U-shaped bellows shall be in accordance with EJMA standards.

(b) Material design fatigue curves for bellows with seams welded using an autogeneous method are provided in the EJMA standards. The curves are for use only in conjunction with the EJMA stress equations.

(c) Fatigue testing in accordance with Appendix F of the EJMA standards is required to develop fatigue curves for bellows of materials other than those provided for use in conjunction with the EJMA stress equations.

(d) When applying the fatigue curves from the EJMA standards, a fatigue correction factor, f_c = 75%, shall be used.

(e) An alternate fatigue correction factor, f_c, may be used with the permission of the owner.

X302.1.4 Limitations

(a) Expansion joint bellows shall not be constructed from lap welded pipe or lap welded tubing.

[1] Consideration shall be given to the detrimental effects of creep–fatigue interaction when the operating metal temperature of the bellows element will be in the creep range. Creep–fatigue interaction may become significant at temperatures above 425°C (800°F) for austenitic stainless steels.

(b) All pressure containing or pressure thrust restraining materials shall conform to the requirements of Chapter III and Appendix A.

X302.2 Expansion Joint Manufacture

Expansion joints shall be produced in accordance with the manufacturer's specification, which shall include at least the following requirements.

X302.2.1 Fabrication

(a) All welds shall be made by qualified welders or welding operators using welding procedures qualified as required by para. 328.2.

(b) The longitudinal seam weld in the bellows element shall be a full penetration butt weld. Prior to forming, the thickness of the weld shall be not less than 1.00 nor more than 1.10 times the thickness of the bellows material.

(c) A full fillet weld may be used as a primary weld to attach a bellows element to an adjoining piping component.

(d) When bellows are attached directly to an adjoining piping component by welding and the piping component is P-Nos. 4, 5A, 5B, or 5C base metal, the attachment weld shall be heat treated in accordance with para. 331.1, except that the exemptions from heat treatment given in para. 331 shall not be permitted. The holding time shall be based on the thickness of the piping component at the bellows attachment weld location. Examination of the attachment welds shall be performed after heat treatment. This heat treatment may affect bellows pressure capacity, mechanical properties, and corrosion resistance. If the required heat treatment is determined to be detrimental to the bellows' performance, the bellows shall not be attached directly to the piping component. In that case, the piping component side of the weld joint shall be buttered in accordance with ASME BPVC, Section IX, QW-283 with appropriate filler metal, heat treated in accordance with Table 331.1.1, and then welded to the bellows.

X302.2.2 Examination. The following are minimum quality control requirements:

(a) Required examinations shall be in accordance with paras. 341 and 344.

(b) The longitudinal seam weld in the bellows tube shall be 100% examined prior to forming, either by radiography or, for material thickness ≤2.4 mm ($^3\!/_{32}$ in.) welded in a single pass, by liquid penetrant examination of both inside and outside surfaces. For the purposes of this Appendix, either examination is acceptable for design with a factor E_j of 1.00 when used within the stated thickness limits.

(c) After forming, a liquid penetrant examination shall be conducted on all accessible surfaces of the weld, inside and outside. Welds attaching the bellows to the piping, etc., shall be 100% liquid penetrant examined.

(d) Acceptance criteria for radiography shall be in accordance with Table 341.3.2. Acceptance criteria for liquid penetrant examination shall be that cracks, undercutting, and incomplete penetration are not permitted.

X302.2.3 Leak Test

(a) Each expansion joint shall receive a hydrostatic, pneumatic, or combination hydrostatic–pneumatic shop pressure test by the manufacturer in accordance with para. 345, except that the test pressure shall be the lesser of that calculated by eq. (24) (para. 345.4.2) or eq. (X1), but not less than 1.5 times the design pressure. S_T/S in eq. (24) shall be based on the bellows material. When the bellows' design temperature is equal to or greater than T_{cr} as defined in Table 302.3.5, General Note (b), S_T/S in eq. (24) shall be replaced by S_{yT}/S_{yt}, where S_{yT} is the yield strength at the test temperature and S_{yt} is the yield strength at the bellows' design temperature. Yield strength values shall be determined in accordance with para. 302.3.2, with the bellows material treated as an unlisted material. The test pressure shall be maintained for not less than 10 min.

$$P_T = 1.5 P_S E_t / E \tag{X1}$$

where

E = modulus of elasticity at design temperature
E_t = modulus of elasticity at test temperature
P_S = limiting design pressure based on column instability (for convoluted U-shaped bellows, see 4.13.1 and 4.13.2 of the EJMA standards)
P_T = minimum test gage pressure

(b) Expansion joints designed to resist the pressure thrust shall not be provided with any additional axial restraint during the leak test. Moment restraint simulating piping rigidity may be applied if necessary.

(c) In addition to examination for leaks and general structural integrity during the pressure test, the expansion joint shall be examined before, during, and after the test to confirm that no unacceptable squirm has occurred. Squirm shall be considered to have occurred if under the internal test pressure an initially symmetrical bellows deforms, resulting in lack of parallelism or uneven spacing of convolutions. Such deformation shall be considered unacceptable when the maximum ratio of bellows pitch under pressure to the pitch before applying pressure exceeds 1.15 for unreinforced bellows or 1.20 for reinforced bellows. Examination for leakage and deformation shall be performed at a pressure not less than two-thirds of the test pressure, after full test pressure has been applied.

(d) Examination for squirm shall be performed at full test pressure. For safety purposes, this may be accomplished by remote viewing (e.g., by optical magnification or video recording) of the changes in convolution spacing with respect to a temporarily mounted dimensional reference. Examination for leakage shall be performed at a pressure not less than two-thirds of test pressure, after application of full test pressure. For a pneumatic test, the precautions of para. 345.5.1 shall be observed.

APPENDIX Z
PREPARATION OF TECHNICAL INQUIRIES

Z300 INTRODUCTION

The ASME B31 Committee, Code for Pressure Piping, will consider written requests for interpretations and revisions of the Code rules, and develop new rules if dictated by technological development. The Committee's activities in this regard are limited strictly to interpretations of the rules or to the consideration of revisions to the present rules on the basis of new data or technology. As a matter of published policy, ASME does not approve, certify, rate, or endorse any item, construction, proprietary device, or activity, and, accordingly, inquiries requesting such consideration will be returned. Moreover, ASME does not act as a consultant on specific engineering problems or on the general application or understanding of the Code rules. If, based on the inquiry information submitted, it is the opinion of the Committee that the inquirer should seek professional assistance, the inquiry will be returned with the recommendation that such assistance be obtained.

An inquiry that does not provide the information needed for the Committee's full understanding will be returned.

The Introduction states that "it is the owner's responsibility to select the Code Section" for a piping installation. An inquiry requesting a Code Section recommendation from the Committee will be returned.

Z301 PREVIOUS INTERPRETATIONS

Previously issued interpretations are available at http://go.asme.org/interpretations. The user is encouraged to use this feature to review previously published interpretations for additional understanding of the Code prior to submitting an inquiry. While this approach is timelier than submitting new inquiries, it should be used with caution because published interpretations are usually not updated based on subsequent Code revisions.

Z302 REQUIREMENTS

Inquiries shall be limited strictly to interpretations of the rules or to the consideration of revisions to the present rules on the basis of new data or technology. Inquiries shall meet the following requirements:

(a) Scope. Involve a single rule or closely related rules in the scope of the Code. An inquiry letter concerning unrelated subjects will be returned.

(b) Background. State the purpose of the inquiry, which may be either to obtain an interpretation of Code rules, or to propose consideration of a revision to the present rules. Provide concisely the information needed for the Committee's understanding of the inquiry, being sure to include reference to the applicable Code Section, Edition, Addenda, paragraphs, figures, and tables. If sketches are provided, they shall be limited to the scope of the inquiry.

(c) Inquiry Structure

(1) Proposed Question(s). The inquiry shall be stated in a condensed and precise question format, omitting superfluous background information, and, where appropriate, composed in such a way that "yes" or "no" (perhaps with provisos) would be an acceptable reply. The inquiry statement should be technically and editorially correct.

(2) Proposed Reply(ies). Provide a proposed reply stating what it is believed that the Code requires.

If in the inquirer's opinion, a revision to the Code is needed, recommended wording shall be provided in addition to information justifying the change.

Z303 SUBMITTAL

Inquiries should be submitted through the online Interpretation Submittal Form. The form is accessible at http://go.asme.org/InterpretationRequest.

Inquiries submitted by e-mail or by hard copy in typewritten or legible handwritten form will be considered. The e-mail and hard-copy submittals shall include the name and mailing address of the inquirer, and be sent to the following addresses, as applicable:

Secretary
ASME B31 Committee
Two Park Avenue
New York, NY 10016-5990
E-mail: MohamedR@asme.org

INDEX[1]

(20)

[1] General Notes follow at end of this Index.

NOTES FOR INDEX

GENERAL NOTES:
(a) Reference is not made to a paragraph that merely states that a previous paragraph applies.
(b) To locate references with letter prefix, refer to the table below.

Prefix	Location	Prefix	Location	Prefix	Location
A*	Chapter VII	FU	App. F	U	Chapter X
B	App. B	G	App. G	UM	Chapter X
C	App. C	K	Chapter IX, App. K	V	App. V
D	App. D	M	Chapter VIII	X	App. X
F	App. F	MA	Chapter VIII		
FA	App. F	N	App. N		

* For Tables A-1, A-1M, A-1A, A-1B, A-2, and A-2M, see Appendix A.

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ASME CODE FOR PRESSURE PIPING, B31

B31.1-2020	Power Piping
B31.3-2020	Process Piping
B31.3-2010	Tuberías de Proceso
B31.4-2019	Pipeline Transportation Systems for Liquids and Slurries
B31.5-2019	Refrigeration Piping and Heat Transfer Components
B31.8-2020	Gas Transmission and Distribution Piping Systems
B31.8S-2020	Managing System Integrity of Gas Pipelines
B31.8S-2010	Gestión de Integridad de Sistemas de Gasoductos
B31.9-2020	Building Services Piping
B31.12-2019	Hydrogen Piping and Pipelines
B31E-2008	Standard for the Seismic Design and Retrofit of Above-Ground Piping Systems
B31G-2012	Manual for Determining the Remaining Strength of Corroded Pipelines: Supplement to ASME B31 Code for Pressure Piping
B31G-2012	Manual para la determinación de la resistencia remanente de tuberiás corroídas
B31J-2017	Stress Intensification Factors (*i*-Factors), Flexibility Factors (*k*-Factors), and Their Determination for Metallic Piping Components
B31J-2008 (R2013)	Método de prueba estándar para determinar factores de intensificación de esfuerzo (Factores *i*) para components de tuberiás metálicas
B31P-2017	Standard Heat Treatments for Fabrication Processes
B31Q-2021	Pipeline Personnel Qualification
B31Q-2010	Calificación del personal de líneas de tuberiás
B31T-2018	Standard Toughness Requirements for Piping

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