ASME B31T-2024
(Revision of ASME B31T-2021)

Standard Toughness Requirements for Piping

Supplement to ASME Code for Pressure Piping, B31

AN AMERICAN NATIONAL STANDARD

The American Society of Mechanical Engineers

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The American Society of Mechanical Engineers
150 Clove Road • Little Falls, NJ • 07424 USA

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FOREWORD

In 2000, the ASME B31 Code for Pressure Piping, Materials Technical Committee (MTC) determined that there was a need to develop a standard set of toughness requirements for piping components that can be adopted by reference by various codes, standards, and specifications. At the time, the requirements of the ASME B31 Code books varied, with some having no requirements at all.

This Standard is intended to provide requirements for evaluating the suitability of materials used in piping systems for piping that may be subject to brittle failure due to low-temperature service conditions.

Under direction of ASME Standards and Certification, both SI and U.S. Customary units are provided. The 2010 edition of this Standard was approved by the American National Standards Institute (ANSI) on April 20, 2010.

The 2015 edition of this Standard was approved by ANSI on October 21, 2015.

The 2018 edition of this Standard was approved by ANSI on December 6, 2018.

The 2021 edition of this Standard was approved by ANSI on July 15, 2021.

The 2024 edition of this Standard was approved by ANSI on October 8, 2024.

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Code for Pressure Piping

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Revisions and Errata. The committee processes revisions to this Standard on a continuous basis to incorporate changes that appear necessary or desirable as demonstrated by the experience gained from the application of the Standard. Approved revisions will be published in the next edition of the Standard.

In addition, the committee may post errata on the committee web page. Errata become effective on the date posted. Users can register on the committee web page to receive email notifications of posted errata.

This Standard is always open for comment, and the committee welcomes proposals for revisions. Such proposals should be as specific as possible, citing the paragraph number, the proposed wording, and a detailed description of the reasons for the proposal, including any pertinent background information and supporting documentation.

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(a) The most common applications for cases are

(1) to permit early implementation of a revision based on an urgent need

(2) to provide alternative requirements

(3) to allow users to gain experience with alternative or potential additional requirements prior to incorporation directly into the Standard

(4) to permit the use of a new material or process

(b) Users are cautioned that not all jurisdictions or owners automatically accept cases. Cases are not to be considered as approving, recommending, certifying, or endorsing any proprietary or specific design, or as limiting in any way the freedom of manufacturers, constructors, or owners to choose any method of design or any form of construction that conforms to the Standard.

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(1) a statement of need and background information

(2) the urgency of the case (e.g., the case concerns a project that is underway or imminent)

(3) the Standard and the paragraph, figure, or table number

(4) the editions of the Standard to which the proposed case applies

(d) A case is effective for use when the public review process has been completed and it is approved by the cognizant supervisory board. Approved cases are posted on the committee web page.

Interpretations. Upon request, the committee will issue an interpretation of any requirement of this Standard. An interpretation can be issued only in response to a request submitted through the online Inquiry Submittal Form at https://go.asme.org/InterpretationRequest. Upon submitting the form, the inquirer will receive an automatic email confirming receipt.

ASME does not act as a consultant for specific engineering problems or for the general application or understanding of the Standard requirements. If, based on the information submitted, it is the opinion of the committee that the inquirer should seek assistance, the request will be returned with the recommendation that such assistance be obtained. Inquirers can track the status of their requests at https://go.asme.org/Interpretations.

ASME procedures provide for reconsideration of any interpretation when or if additional information that might affect an interpretation is available. Further, persons aggrieved by an interpretation may appeal to the cognizant ASME committee or subcommittee. ASME does not "approve," "certify," "rate," or "endorse" any item, construction, proprietary device, or activity.

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Committee Meetings. The B31 Standards Committee regularly holds meetings that are open to the public. Persons wishing to attend any meeting should contact the secretary of the committee. Information on future committee meetings can be found on the committee web page at https://go.asme.org/B31committee.

INTRODUCTION

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

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-generating stations, industrial and institutional plants, geothermal and solar power applications, 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 that transports products that are predominately liquid between plants and terminals, and within terminals and pumping, regulating, and metering stations

B31.5 Refrigeration Piping and Heat Transfer Components: piping for refrigerants and secondary coolants

B31.8 Gas Transportation and Distribution Piping Systems: piping that transports products that are predominately gas between sources and terminals, including compressor, regulating, and metering stations and gas-gathering pipelines

B31.9 Building Services Piping: piping typically found in industrial, institutional, commercial, and public buildings and multiunit residences that do not require the range of sizes, pressures, and temperatures covered by ASME B31.1

B31.12 Hydrogen Piping and Pipelines: piping in gaseous and liquid hydrogen service and pipelines for gaseous hydrogen service

The following Codes and Standards provide guidance for a specific task found in one or more ASME B31 Section publications:

B31E Seismic Design and Retrofit of Above-Ground Piping Systems: establishes a method for the seismic design of above-ground metallic piping systems in the scope of the ASME B31 Code for Pressure Piping

B31G Remaining Strength of Corroded Pipelines: provides a simplified procedure to determine the effect of wall loss due to corrosion or corrosion-like defects on the pressure integrity in pipeline systems

B31J Stress Intensification Factors (*i*-Factors), Flexibility Factors (*k*-Factors), and Their Determination for Metallic Piping Components: provides a standardized method to develop the stress intensification factors (*i*-factors), flexibility factors (*k*-factors), and sustained stress factors used in ASME B31 piping analysis

B31P Standard Heat Treatments for Fabrication Processes: provides requirements for heat treatment of piping assemblies that meet the requirements of ASME B31 Code Sections

B31Q Pipeline Personnel Qualification: establishes the requirements for developing and implementing an effective Pipeline Personnel Qualification Program

B31T Standard Toughness Requirements for Piping: provides requirements for evaluating the suitability of materials used in piping systems for piping that may be subject to brittle failure due to low-temperature service conditions

This is ASME B31T, Standard Toughness Requirements for Piping. Hereafter, in this Introduction and in the text of ASME B31T, where the word “Standard” is used without specific identification, it means ASME B31T.

This Standard provides requirements for evaluating the suitability of materials used in piping systems for piping that may be subject to brittle failure due to low-temperature service conditions. While low-temperature service is

usually considered to be below ambient temperature, brittle failure can occur at temperatures above ambient temperature for certain combinations of materials, thicknesses, and stress levels. The definition of "low-temperature service" as used in this Standard, therefore, varies widely across the many applications for which piping systems are used. For a building service air line, low temperature may be 0°C (32°F), whereas for a cryogenic piping system, it could easily be −185°C (−300°F). However, the principles used to evaluate the suitability of a piping system as related to service temperature by evaluating the toughness of the material can be applied across a wide temperature range, and this Standard has been established to provide uniform guidance in this area.

Suitability of piping systems for low-temperature service is a function of several variables, including material properties, design loadings, and fabrication procedures. The three primary factors that generally control the susceptibility for brittle fracture are material toughness, crack size, and tensile stress level. There are a wide variety of services where low-temperature suitability need not even be considered; however, a screening criterion is necessary to determine this.

One objective of this Standard is to provide a simple approach to evaluate whether additional consideration is necessary to evaluate suitability for low-temperature service. This is done by establishing a low-temperature service limit for various materials. Services at or warmer than this limit are not considered low temperature, and additional considerations relative to suitability are not required.

For services colder than this limit, various requirements are provided that, when met, qualify the material for low-temperature services. These requirements include impact testing, qualification of welding and other fabrication procedures, and limiting the design loadings.

The low-temperature service limit established herein is based on a reasonable degree of assurance that at this temperature, the material will have a ductile failure mode. The actual ductile-to-brittle transition temperature for a given material specification will vary based on actual heat chemistry of the material and subsequent processing. For critical applications, the design engineer can select materials with a lower low-temperature service limit or require impact testing. On less-critical applications, material with a higher low-temperature service limit may be acceptable. The final selection is left to the code, standard, or specification referencing this Standard and the design engineer (when permitted by the code, standard, or specification referencing this Standard).

To keep the number of sets of requirements to a minimum, material groupings have been established, and a unique set of requirements have been provided for each group. These groups are assigned "T-numbers" for easy reference. Although most materials used in piping systems are listed, some are not, and these unlisted materials are not addressed in this Standard. Where permitted by the code, standard, or specification referencing this Standard, these requirements may be used for unlisted materials. The code, standard, or specification referencing this Standard may establish the correct T-number group for the material or may invoke the testing and other requirements of this Standard using the worst-case assumption that the design minimum temperature is colder than the temperatures that would allow exemption from any of the requirements of this Standard. The guidelines for establishing the correct T-number group are provided in Nonmandatory Appendix B.

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

The ASME B31 Committee is organized and operates under procedures of ASME that have been accredited by the American National Standards Institute. The Committee is continuing and keeps all Code Sections and Standards current with new developments in methods, materials, construction, and industrial practice.

This Standard may be invoked in whole or in part by various codes, standards, or specifications and is only mandatory when so invoked. The applicable edition of this Standard shall be as specified by the code, standard, or specification referencing this Standard. It is intended that this edition of the ASME B31T Standard not be retroactive. Users of this Standard are cautioned against making use of Standard revisions without assurance that they are acceptable to the proper authorities in the jurisdiction where the material is to be installed.

ASME B31T-2024
SUMMARY OF CHANGES

Following approval by the ASME B31 Standards Committee and ASME, and after public review, ASME B31T-2024 was approved by the American National Standards Institute on October 8, 2024.

ASME B31T-2024 includes the following changes identified by a margin note, **(24)**.

Page	*Location*	*Change*
2	3.6.1	Revised in its entirety
3	3.7.2.2	Revised in its entirety
4	3.7.2.3	Revised in its entirety
7	4.5.3	Revised in its entirety
8	5	Updated
12	Table 3.1-1	CS B governing thickness revised
30	Table 3.2-1	(1) A53 Grade and T-Number Group revised (2) A354 T-Number Group revised
48	Table III-1	(1) A53 Grade and T-Number Group revised (2) A354 T-Number Group revised
56	Figure A-1	In first box under “Fabrication Requirements Evaluation,” “must” revised to “shall”

STANDARD TOUGHNESS REQUIREMENTS FOR PIPING

1 GENERAL

1.1 Scope

This Standard provides requirements for evaluating the suitability of materials used in piping systems for piping that may be subject to brittle failure due to low-temperature service conditions.

1.2 Units of Measure

This Standard states values in both International System (SI, also known as metric) and U.S. Customary (USC) units. Within the text, the USC 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.

When separate equations are provided for SI and USC units, those equations shall be executed using variables in the units associated with the specific equation. The result 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.

2 GLOSSARY

CVN: the abbreviation for Charpy V-notch.

design minimum temperature: the lowest component temperature expected in service.

fully deoxidized steel: steel that has been deoxidized, either by the addition of strong deoxidizing agents or by vacuum treatment, to reduce the oxygen content to such a level that no reaction occurs between the carbon and oxygen during solidification. Also known as killed steel. Steels that are not fully deoxidized include rimmed, semi-killed, and capped steels. Limitations on the use of steels that are not fully deoxidized may be imposed by the code, standard, or specification referencing this Standard.

governing thickness: the thickness used in determining the low-temperature service limit of T-number groups CS A, CS B, CS C, and CS D in Table 3.1-1. Unless defined differently in the code, standard, or specification referencing this Standard, this thickness is the nominal thickness of the component or, for blind flanges and line blanks, $^1/_4$ of the total thickness, where the total thickness is the thickness of the blind flange or line blank, including the thickness of the facing(s), if applicable.

lower critical temperature: the temperature at which the first phase change occurs when heating a metal.

low-temperature service limit: the design minimum temperature at which additional requirements for low-temperature service do not apply.

NDT temperature: the nil ductility transition temperature.

stress ratio: the ratio of the design stress to an allowable stress (see para. 3.6.2).

T-number: a number assigned to a group of similar materials with similar low-temperature requirements. The number consists of the material type and a temperature characteristic, and possibly a suffix.

3 LOW-TEMPERATURE RANGES AND REQUIREMENTS

3.1 Low-Temperature Service Requirements

Low-temperature service requirements are contained in Table 3.1-1. These requirements are established for T-number groups of materials with similar requirements. In addition to T-number group, in some cases, requirements are dependent on thickness and/or other characteristics as listed in Table 3.1-1.

3.2 Material Groupings (Column 1 of Table 3.1-1)

Listed materials are assigned T-number groups in Table 3.2-1. (In addition, a table sorted by material type and T-number group that lists all materials in each T-number group is provided in Mandatory Appendix III.) In determining the applicable T-number group for a material from Table 3.2-1, consideration shall be given to the material specification, grade, and any other variables as established in the notes. The table separates the materials into types (carbon steels, low-alloy steels, etc.), and the group number is representative of the low-temperature service limit for the material; however, the low-temperature service limit may vary based on the design and fabrication requirements. Low-temperature service limits shall be determined from Table 3.1-1. An "(A)" in the T-number group [e.g., CS −20(A)] indicates that materials of that group may not be used

at temperatures colder than the group number [e.g., −29°C (−20°F)].

3.3 Governing Thickness and Notes (Columns 2 and 3 of Table 3.1-1)

For T-number groups in which the low-temperature suitability varies significantly according to the material thickness, a governing thickness is listed in column 2 of Table 3.1-1 at various low-temperature service limit increments. When it is desired to refine the influence of the governing thickness, Mandatory Appendix I provides the continuous curves and tables that can be used at intermediate values or greater governing thicknesses. Since the governing thicknesses in Table I-1 of Mandatory Appendix I are generally derived based on uniform increments of temperature, the table does not contain uniform increments of governing thickness. The continuous curves in Figures I-1 and I-1M in Mandatory Appendix I should be consulted for the precise values.

For material T-number groups in which the low-temperature suitability is dependent on some other factor, those factors are given in the notes listed in column 3 of Table 3.1-1.

3.4 Low-Temperature Service Limit (Column 4 of Table 3.1-1)

Column 4, the first temperature column in Table 3.1-1, is the low-temperature service limit. If the design minimum temperature is equal to or warmer than this value, then low-temperature requirements do not apply. Materials within a T-number group may be used at this temperature or temperatures warmer than this limit without imposing any of the requirements of this Standard. This limit considers material properties and the influence of fabrication processes on the material properties.

3.5 Material Requirements for Low-Temperature Service (Columns 5 and 6 of Table 3.1-1)

Column 5 lists the minimum permitted temperature of the material. When a temperature is listed, this is the design minimum temperature permitted for the T-number group regardless of impact testing or any other requirements except as permitted by column 18, where the applied stress is limited to 30% of the allowable.

Column 6 contains the minimum temperature without impact testing for the material. If the design minimum temperature is equal to or warmer than this value, the material does not require impact testing. If the design minimum temperature is colder than this value, impact testing of the material is required. For carbon steels, this limit may vary with governing thickness or stress ratio. Additional rows are provided in Table 3.1-1 for governing thickness variations. Interpolation between governing thicknesses is permitted. Figures and a table for the curves of the variation of temperature with governing thickness are provided in Mandatory Appendix I, and these may be used as an alternative to the values in Table 3.1-1. Permitted temperatures for stress ratios are provided for by using columns 10 through 18 instead of column 6 as discussed in para. 3.6.

3.6 Design Requirements for Low-Temperature Service (Columns 10 Through 18 of Table 3.1-1)

3.6.1 Minimum Material Temperature Without Impact Testing. Columns 10 through 17 list the minimum material temperature without impact testing based on design stresses and may be used for carbon steels, provided the piping does not operate at temperatures where time-dependent properties govern and (a) through (c) are met. (24)

The curve used to generate columns 10 through 17 in Table 3.1-1 is provided in Mandatory Appendix II and may be used as an alternative to columns 10 through 17.

Column 18 lists the minimum low-temperature service limit achievable by limiting stresses to less than 10% of the tensile strength [i.e., the stress ratio (SR) ≤ 0.3] and may be used, provided (a) through (c) are met. At these stress levels, the design margin is considered adequate to prevent a brittle fracture failure mode. The low-temperature service limit listed in column 18 may be used in lieu of that listed in column 4 when SR ≤ 0.3.

The minimum impact test exemption temperature reduction, as provided in columns 10 through 17 and column 18, may be used only when all of the following apply:

(a) Local stresses caused by shock loading, thermal bowing, and differential expansion between dissimilar metals (e.g., austenitic welded to ferritic), coincident with the low-temperature condition under consideration, are less than 10% of the basic allowable stress at the condition.

(b) The piping is not subjected to maintenance or impact loads at temperatures colder than the low-temperature service limit listed in column 4.

(c) The stress ratio is calculated in accordance with para. 3.6.2.

3.6.2 Stress Ratio. The stress ratio is defined as the maximum of the following:

(a) nominal pressure stress (based on minimum pipe wall thickness less allowances) divided by the allowable stress at the design minimum temperature.

(b) for piping components with pressure ratings, the pressure for the condition under consideration divided by the pressure rating at the design minimum temperature.

(c) combined longitudinal stress due to pressure, dead weight, and displacement strain (stress intensification factors are not included in this calculation) divided by the allowable stress at the design minimum temperature.

In calculating longitudinal stress, the forces and moments in the piping system shall be calculated using nominal dimensions, and the stresses shall be calculated using section properties based on the nominal dimensions less corrosion, erosion, and mechanical allowances.

In determining the stress ratio, the loadings coincident with the metal temperature under consideration may be used in lieu of maximum design values. Where there are several low-temperature design conditions, each shall be evaluated to determine the stress ratio.

3.7 Fabrication Requirements for Low-Temperature Service (Columns 7, 8, and 9 of Table 3.1-1)

3.7.1 Temperature Limits. Column 7 lists the minimum weld-permitted temperature. When a temperature is listed, this is the design minimum temperature permitted for welded construction for this T-number group, governing thickness, and notes regardless of impact testing or any other requirements. Use of the material is prohibited at temperatures colder than this temperature unless permitted by column 9.

Column 8 of Table 3.1-1 lists the design minimum temperature permitted for each T-number group without additional fabrication requirements. Alternatively, when stresses are limited to 30% of allowable, the temperatures in column 9 may be used instead of the values in column 8.

When materials are used at temperatures colder than those listed in column 8 or column 9, as applicable, the welding, bending, and forming procedures shall be qualified to verify that they do not result in significant loss of material toughness. In addition, weld filler metal shall meet the impact test requirements of para. 3.7.4.

3.7.2 Welding Procedure Specifications

3.7.2.1 General. Welding procedures that are required by para. 3.7.1 to be qualified with impact testing shall be qualified for toughness, and the supplementary essential variables of ASME Boiler and Pressure Vessel Code (BPVC), Section IX shall apply. Temper bead welding procedures shall be prepared and qualified in accordance with Section IX using impact testing as the basis for acceptance.

Impact tests of the weld metal and heat-affected zone (HAZ) shall be performed in accordance with paras. 3.7.2.2 and 3.7.2.3 except that impact tests of the HAZ are not required for

(a) the qualification for welds in P-Nos. 1 and 3 materials that are postweld heat treated and are made by any process other than electroslag, electrogas, or thermit

(b) the qualification for weld deposit cladding or hardfacing on any base material

(c) that portion of the HAZ associated with gas tungsten arc welding (GTAW) root deposits with a maximum of two layers or 5 mm ($^{3}/_{16}$ in.) thickness, whichever is less

3.7.2.2 Test Specimens. The weld procedure qualification impact test specimens shall be Charpy V-notch (CVN) specimens prepared and tested in accordance with (a) or (b) and the requirements in ASME BPVC, Section IX. (24)

(a) Except as provided in (b), a test shall consist of five specimens, all of which shall be tested at or below the design minimum temperature. The highest and lowest values of these specimens shall be disregarded, and the values of the three remaining specimens shall equal or exceed the acceptance criteria required by para. 4.5.3.

(b) Alternatively, only three specimens may be prepared and tested, and the values of these three specimens shall equal or exceed the acceptance criteria required by para. 4.5.3.

3.7.2.2.1 Test Specimen Locations

(a) Impact test specimens representing the weld deposit shall be taken from the welding procedure qualification test assemblies across the weld, with the notch in the weld metal. The notch axis shall be normal to the material surface, with one face of the specimen ≤1.5 mm (≤$^{1}/_{16}$ in.) from the material surface.

(b) Impact test specimens representing the HAZ shall be taken from the welding procedure qualification test assemblies across the weld and long enough to locate the notch in the HAZ after etching. The notch axis shall be approximately normal to material surface and shall include as much as possible of the HAZ in the fracture.

3.7.2.2.2 Supplemental Test Specimen Locations.

Supplemental test specimen locations in (a) through (e) apply only when specified by the designer.

(a) If the qualification test material is in the form of a plate or a forging, the axis of the weld shall be oriented in the direction parallel to the principal direction of rolling or forging.

(b) The specimens shall be removed from a location as near as practical to a depth midway between the surface and center thickness. The coupons for HAZ impact specimens shall be taken transverse to the axis of the weld and etched to define the HAZ. The notch of the CVN specimen shall be cut approximately normal to the material surface in such a manner as to include as much HAZ as possible in the resulting fracture. Where the material thickness permits, the axis of a specimen may be inclined to allow the root of the notch to align parallel to the fusion line. When a grain-refining heat treatment is not performed on welds made by the electroslag or electrogas welding process, the notch for the impact specimens shall be located in the grain-coarsened region.

(c) For the comparison of HAZ values with base material values, CVN specimens shall be removed from the unaffected base material at approximately the same distance from the base material surface as the HAZ specimens. The axis of the unaffected base material specimens shall be parallel to the axis of the HAZ specimens, and the axis of the notch shall be normal to the surface of the base material.

(d) The CVN specimens representing the HAZ material and those representing the unaffected base material shall be tested at the design minimum temperature of the base material. Where two different materials that have different toughness requirements are to be joined by welding, the test shall be conducted on the HAZ from each material and corresponding unaffected base material, unless otherwise specified by the code, standard, or specification referencing this Standard.

(e) When the postweld heat treatment temperature exceeds the maximum temperature specified by the code, standard, or specification referencing this Standard and the test assembly is cooled at an accelerated rate, the longitudinal axis of all specimens shall be removed from the test assembly at a distance not less than t, measured from the outer perimeter of the test assembly to the longitudinal axis of the specimen, where t is the thickness of the test weld.

(24) **3.7.2.3 Test Requirements.** The impact test requirements for the weld metal used for welding procedure qualification shall be the same as specified in section 4 for the base material to be welded or repaired. Retests in accordance with the provisions of para. 4.5.4 are permitted during welding procedure qualification testing.

3.7.3 Forming and Bending Processes. Any process may be used to hot form, cold form, or bend material, including weld metal, provided the impact properties of the material, when required, are not reduced below the minimum specified values, or they are effectively restored by heat treatment following the forming operation. Hot forming is defined as forming with the material temperature warmer than 56°C (100°F) below the lower critical temperature of the material.

When required, the hot- or cold-forming process shall be qualified for impact properties as described below.

A procedure qualification test shall be conducted using specimens taken from material of the same specification, grade or class, and heat treatment, and with similar impact properties as required for the material to be used in production. These specimens shall be subjected to the equivalent forming or bending process and heat treatment as the material to be used in production. Applicable tests shall be conducted to determine that the required impact properties of section 4 are met after straining.

3.7.3.1 Materials Not Requiring Procedure Qualification Tests. Procedure qualification tests are not required for the following materials:

(a) hot-formed material, such as forgings, in which the hot forming is completed prior to removal of the impact test specimens

(b) hot-formed material represented by test coupons that have been subjected to heat treatment representing the hot-forming procedure and the heat treatments to be applied to the parts

(c) material that has a final strain less than 0.5%

(d) material for which the final strain is less than that of a previously qualified procedure for that material

(e) material from which the impact testing in accordance with section 4 is performed on each heat and lot, as applicable, after forming

3.7.3.2 Performance of Procedure Qualification Test. The procedure qualification test shall be performed in the manner stipulated in (a) through (f).

(a) The tests shall be performed on three different heats of material both before straining and after straining and heat treatment to establish the effects of the forming and subsequent heat treatment operations.

(b) Specimens shall be taken in accordance with the requirements of section 4 and shall be taken from the tension side of the strained material.

(c) The percent strain shall be established by the following formulas:

For cylinders:

$$\% \text{ strain} = 50t/R_f[1 - (R_f/R_o)]$$

For spherical or dished surfaces:

$$\% \text{ strain} = 75t/R_f[1 - (R_f/R_o)]$$

For pipe:

$$\% \text{ strain} = 100r/R$$

where

R = nominal bending radius to the centerline of the pipe, mm (in.)
r = nominal radius of the pipe, mm (in.)
R_f = final radius to the centerline of the shell, mm (in.)
R_o = original radius (equal to infinity for a flat part), mm (in.)
t = nominal thickness, mm (in.)

(d) The procedure qualification shall simulate the maximum percent surface strain, employing a bending process similar to that used in the fabrication of the material or by direct tension on the specimen.

(e) Sufficient CVN test specimens shall be taken from each of the three heats of material to establish a transition curve showing both the upper and lower shelves. On each of the three heats, tests consisting of three impact specimens shall be conducted at a minimum of five different temperatures distributed throughout the transition region. The upper and lower shelves may be established

by the use of one test specimen for each shelf. Depending on the product form, it may be necessary to plot the transition curves using both lateral expansion and energy level data.

(f) Using the results of the impact test data from each of three heats, taken both before and after straining, determine either of the following:

(1) the maximum change in nil ductility transition (NDT) temperature along with (-a) or (-b)

(-a) the maximum change of lateral expansion and energy at the temperature under consideration

(-b) the maximum change of temperature at the lateral expansion and energy levels under consideration

(2) when lateral expansion is the acceptance criterion, either the maximum change in temperature or the maximum change in lateral expansion

3.7.3.3 Acceptance Criteria. To be acceptable, the formed material used in production shall have impact properties before forming sufficient to compensate for the maximum loss of impact properties due to the qualified forming processes used. A new procedure qualification test is required when any of the changes in (a), (b), or (c) are made.

(a) The actual postweld heat treatment time at temperature is warmer than previously qualified unless the material is P-No. 1 and the thickness is less than 50 mm (2 in.). If the material is not postweld heat treated, the procedure shall be qualified without postweld heat treatment.

(b) The maximum calculated strain of the material exceeds the previously qualified strain by more than 0.5%.

(c) Preheat over 120°C (250°F) is used in the forming or bending operation but is not followed by a subsequent postweld heat treatment.

3.7.4 Weld Filler Metal

3.7.4.1 General. Weld filler metal for applications in which the design minimum temperature is colder than the temperature listed in column 8 or column 9 of Table 3.1-1, as applicable, shall be impact tested. The impact tests shall be conducted for

(a) each lot of covered, flux cored, metal cored, or fabricated electrodes

(b) each heat of bare electrodes, rod, or wire for use with the oxy fuel welding (OFW), gas metal arc welding (GMAW), GTAW, plasma arc welding (PAW), and electrogas welding (EGW) processes (ASME BPVC, Section IX, QW/QB-492)

(c) each heat of consumable inserts

(d) each combination of heat of bare electrodes and lot of submerged arc flux

(e) each combination of lot of fabricated electrodes and lot of submerged arc flux

(f) each combination of heat of bare electrodes or lot of fabricated electrodes and dry blend of supplementary powdered filler metal and lot of submerged arc flux

(g) each combination of heat of bare electrodes and lot of electroslag flux

Where the specification for welding consumables specifies impact testing at a temperature equal to or colder than the design minimum temperature, testing of each heat/lot combination is not required, provided the filler metal will be used in the same heat treatment condition as is specified in the filler metal specification. Tests performed on the welding material in the qualification of weld procedures may satisfy the testing requirements for the lot, heat, or combination of heat and batch of welding material used.

3.7.4.2 Test Coupons. The welding test coupon shall be made using the welding process, filler metal specification and classification, minimum tensile strength, preheat and interpass temperatures, and postweld heat treatment to be used in the production welding using each process to be used in the production welding. The test coupon shall be of sufficient size and thickness that the required test specimens can be removed.

The weld metal to be tested for all processes except electroslag welding shall be deposited in such a manner as to eliminate substantially the influence of the base material on the results of the tests. Weld metal to be used with the electroslag process shall be deposited in such a manner as to conform to an applicable WPS for production welding; see ASME BPVC, Section IX, QW-201.1.

The welding of the test coupon shall be performed within the range of preheat and interpass temperatures that will be used in production welding. Coupons shall be tested in the as-welded condition or they shall be tested in the applicable postweld heat-treated condition when the production welds are to be postweld heat treated. The postweld heat treatment holding time shall be at least 80% of the maximum time to be applied to the weld metal in production application. The total time for postweld heat treatment of the test specimen may be applied in one heating cycle. The cooling rate from the postweld heat treatment temperature shall be of the same order as that applicable to the weld metal in the production welds. In addition, weld coupons for weld metal to be used with the electroslag process that are tested in the as-welded condition, or following a postweld heat treatment within the holding temperature ranges of the code, standard, or specification referencing this Standard for the material being tested, shall have a thickness within the range of 0.5 times to 1.1 times the thickness of the welds to be made in production. Electroslag weld coupons to be tested following a postweld heat treatment, which will include heating the coupon to a temperature warmer than the holding temperature ranges of the code, standard, or specification referencing this Standard for the material being tested, shall have a thickness within the range of

0.9 times to 1.1 times the thickness of the welds to be made in production.

3.7.4.3 Test Specimens. Regardless of the welding process or welding material being tested, the impact test specimens shall be located and prepared in accordance with the requirements of ASME BPVC, Section II, Part C, SFA-5.1.

3.7.4.4 Test Requirements. Impact testing of the weld metal shall meet the requirements applicable to the base metal. Where different requirements exist for the two base metals, the weld metal may conform to either of the two requirements unless the requirement of para. 4.5.3 applies.

4 IMPACT TESTING METHODS AND ACCEPTANCE CRITERIA

4.1 General

When impact testing is required by section 3 or the code, standard, or specification referencing this Standard, it shall be done in accordance with this section unless otherwise required by the code, standard, or specification referencing this Standard.

4.2 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, and in conformance with the impact testing requirements of the following specifications:

Product Form	Specification
Pipe	ASTM A333 or API 5L
Tube	ASTM A334
Fittings	ASTM A420
Forgings	ASTM A350
Castings	ASTM A352
Bolting	ASTM A320
Plate	ASTM A20

The specific requirements of this section or the code, standard, or specification referencing this Standard shall also be met.

If a conflict exists between the requirements, the order of precedence shall be as follows:

(a) the code, standard, or specification referencing this Standard

(b) this Standard

(c) the product form specification

(d) ASTM A370

4.3 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 CVN 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. If subsize specimens are used, the test temperature shall be adjusted in accordance with para. 4.4.2. Toughness tests are not required when the maximum obtainable Charpy specimen has a width along the notch less than 2.5 mm (0.098 in.).

4.4 Test Temperatures

For all Charpy impact tests, the test temperature criteria in para. 4.4.1 or para. 4.4.2 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.

4.4.1 For Materials With Thickness Equal to or Greater Than 10 mm (0.394 in.). Where the largest attainable CVN 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 warmer than the design minimum temperature. Where the largest possible test specimen has a width along the notch less than 8 mm (0.315 in.), the test shall be conducted at a temperature colder than the design minimum temperature in accordance with para. 4.4.2.

4.4.2 For Materials With Thickness Less Than 10 mm (0.394 in.). Where the largest attainable CVN 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 warmer 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 colder than the design minimum temperature by an amount equal to the difference (referring to Table 4.4.2-1) between the temperature reduction corresponding to the actual material thickness and the temperature reduction corresponding to the Charpy specimen width actually tested. These temperature reduction criteria do not apply when Table 4.5.1-1 specifies lateral expansion for minimum required values.

Test Temperature = (Design Minimum Temperature) + (Temperature Reduction Based on Actual Material Thickness) − (Temperature Reduction Based on Charpy Impact Specimen Width)

For example, if the design minimum temperature is −20°C, the actual material thickness is 6 mm, and the specimen is 4 mm, the test temperature is (−20) + 8.3 − 16.7 = −28.4°C.

4.5 Acceptance Criteria

4.5.1 Minimum Energy Requirements. Except for bolting materials and high-alloy steels (P-Nos. 6, 7, and 8), the applicable minimum energy requirement for carbon and low-alloy steels and other materials with specified minimum tensile strengths less than 656 MPa (95 ksi) shall be those shown in Table 4.5.1-1. If subsize specimens are used, the minimum energy acceptance criteria may be reduced by the ratio of the test specimen width to the standard size width [10 mm (0.394 in.)].

4.5.2 Lateral Expansion Requirements. Carbon and low-alloy steels and other materials 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, and 8) 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). For bolting materials with specified minimum tensile strength greater than 656 MPa (95 ksi) and size less than or equal to M50 (2 in.), the impact requirements of ASTM A320 may be applied.

(24) **4.5.3 Weld Impact Test Requirements**

4.5.3.1 Acceptance Criteria. The absorbed energy or lateral expansion results, as applicable, from the weld metal and HAZ locations shall meet the provisions of para. 4.5.1 or para. 4.5.2, as required.

Where two base metals having different impact acceptance criteria are joined by welding, the impact acceptance criteria for the weld metal and HAZ locations shall be those of the base material having a specified minimum tensile strength most closely matching the specified minimum tensile strength of the weld metal.

4.5.3.2 Supplemental Acceptance Criteria. When the designer specifies the supplemental test specimen locations in para. 3.7.2.2.2, the following acceptance criteria apply:

(a) The CVN impact tests of the unaffected base material shall meet the requirements of this Standard. If the average lateral expansion values of the three HAZ specimens are equal to or greater than the average value for the unaffected base material CVN specimens, the qualification test shall be considered acceptable, and the values and testing temperature shall be recorded on the welding Procedure Qualification Record (PQR).

(b) If the average CVN lateral expansion for the HAZ of (a) is less than that for the unaffected base material, and the qualification test meets the other criteria of acceptance, the CVN test results may be recorded on the PQR. Data shall then be obtained as specified in (c) to provide an additive temperature for the adjustment to compensate for the HAZ toughness decrease as described in (d). Alternatively, the welding procedure qualification may be rewelded and retested.

(c) The data for development of the temperature adjustment (T_{ADJ}) shall be developed by performing additional CVN tests on either the welding procedure qualification HAZ or the unaffected base material, or both, at temperatures that provide toughness values that meet or exceed those required for the thickness of material to be welded in production. The average toughness data for the HAZ and the unaffected base material shall be plotted on a property–temperature chart. The temperatures at which these two sets of data exhibit a common acceptable value of toughness for the production thickness involved shall be determined. The determined temperature for the unaffected base material shall be subtracted from the similarly determined temperature for the HAZ. This difference shall be used in (d) as T_{ADJ}. If the temperature difference is zero or a negative number, no adjustment is required for the base material to be welded in production, and the minimum temperature established by this Standard will still apply as stated in (a). The CVN testing results shall be recorded on the PQR, and any offsetting T_{ADJ} or increased toughness requirements shall be noted on the PQR and the Welding Procedure Specification (WPS).

(d) At least one of the following methods shall be used to compensate for the HAZ toughness decrease due to the welding procedure. More than one compensation method may be used on a par basis.

(1) The low-temperature service limit for all of the material to be welded in a production WPS supported by this PQR shall be increased by the adjustment temperature T_{ADJ}.

(2) The specified testing temperature for the production material may be reduced by T_{ADJ}.

(3) The materials to be welded may be welded using the WPS, provided they exhibit CVN values that are no less than the minimum required lateral expansion value for the material plus the difference in average lateral expansion values between the unaffected base metal and the HAZ.

4.5.4 Retests

4.5.4.1 For Absorbed Energy Criterion. 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.

4.5.4.2 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 (0.010 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 shall 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 re–heat treated and retested. After re–heat treatment, a set of three specimens shall be made. For acceptance, the lateral expansion of each of the specimens shall equal or exceed the specified minimum value of 0.38 mm (0.015 in.).

4.5.4.3 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.

(24) 5 REFERENCES

The following is a list of publications referenced in this Standard. 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 Standard is specified is the specific edition referenced by this Standard, unless otherwise specified in the engineering design. Materials manufactured to other editions of the referenced API or ASTM specifications may be used if the designer verifies the material meets the requirements of the referenced edition of the specification.

API 5L-2018[e1]. Line Pipe. American Petroleum Institute.

ASME Boiler and Pressure Vessel Code (BPVC), Section II, Part C: Specification for Welding Rods, Electrodes, and Filler Metals. The American Society of Mechanical Engineers.

ASME Boiler and Pressure Vessel Code (BPVC), Section IX: Qualification Standard for Welding, Brazing, and Fusing Procedures; Welders; Brazers; and Welding, Brazing, and Fusing Operators. The American Society of Mechanical Engineers.

ASME SFA-5.1/SFA-5.1M. Specification for Carbon Steel Electrodes for Shielded Metal Arc Welding. The American Society of Mechanical Engineers.

ASTM A20/A20M-2020. Standard Specification for General Requirements for Steel Plates for Pressure Vessels. ASTM International.

ASTM A36/A36M-2019. Standard Specification for Carbon Structural Steel. ASTM International.

ASTM A47/A47M-1999(R2022)[e1]. Standard Specification for Ferritic Malleable Iron Castings. ASTM International.

ASTM A48/A48M-2022. Standard Specification for Gray Iron Castings. ASTM International.

ASTM A53/A53M-2022. Standard Specification for Pipe, Steel, Black and Hot-Dipped, Zinc-Coated, Welded and Seamless. ASTM International.

ASTM A105/A105M-2023. Standard Specification for Carbon Steel Forgings for Piping Applications. ASTM International.

ASTM A106/A106M-2019a. Standard Specification for Seamless Carbon Steel Pipe for High-Temperature Service. ASTM International.

ASTM A126-2004(R2023). Standard Specification for Gray Iron Castings for Valves, Flanges, and Pipe Fittings. ASTM International.

ASTM A134/A134M-2019. Standard Specification for Pipe, Steel, Electric-Fusion (Arc)-Welded (Sizes NPS 16 and Over). ASTM International.

ASTM A135/A135M-2021. Standard Specification for Electric-Resistance-Welded Steel Pipe. ASTM International.

ASTM A139/A139M-2022. Standard Specification for Electric-Fusion (Arc)-Welded Steel Pipe (NPS 4 and Over). ASTM International.

ASTM A178/A178M-2019. Standard Specification for Electric-Resistance-Welded Carbon Steel and Carbon-Manganese Steel Boiler and Superheater Tubes. ASTM International.

ASTM A179/A179M-2019. Standard Specification for Seamless Cold-Drawn Low-Carbon Steel Heat-Exchanger and Condenser Tubes. ASTM International.

ASTM A181/A181M-2023. Standard Specification for Carbon Steel Forgings, for General-Purpose Piping. ASTM International.

ASTM A182/A182M-2023. Standard Specification for Forged or Rolled Alloy and Stainless Steel Pipe Flanges, Forged Fittings, and Valves and Parts for High-Temperature Service. ASTM International.

ASTM A192/A192M-2017. Standard Specification for Seamless Carbon Steel Boiler Tubes for High-Pressure Service. ASTM International.

ASTM A193/A193M-2023. Standard Specification for Alloy-Steel and Stainless Steel Bolting for High Temperature or High Pressure Service and Other Special Purpose Applications. ASTM International.

ASTM A194/A194M-2023. Standard Specification for Carbon Steel, Alloy Steel, and Stainless Steel Nuts for Bolts for High Pressure or High Temperature Service, or Both. ASTM International.

ASTM A197/A197M-2000(R2023)[e1]. Standard Specification for Cupola Malleable Iron. ASTM International.

ASTM A203/A203M-2023. Standard Specification for Pressure Vessel Plates, Alloy Steel, Nickel. ASTM International.

ASTM A204/A204M-2017(R2022). Standard Specification for Pressure Vessel Plates, Alloy Steel, Molybdenum. ASTM International.

ASTM A210/A210M-2019. Standard Specification for Seamless Medium-Carbon Steel Boiler and Superheater Tubes. ASTM International.
ASTM A214/A214M-2019. Standard Specification for Electric-Resistance-Welded Carbon Steel Heat-Exchanger and Condenser Tubes. ASTM International.
ASTM A216/A216M-2021. Standard Specification for Steel Castings, Carbon, Suitable for Fusion Welding, for High-Temperature Service. ASTM International.
ASTM A217/A217M-2022. Standard Specification for Steel Castings, Martensitic Stainless and Alloy, for Pressure-Containing Parts, Suitable for High-Temperature Service. ASTM International.
ASTM A234/A234M-2023a. Standard Specification for Piping Fittings of Wrought Carbon Steel and Alloy Steel for Moderate and High Temperature Service. ASTM International.
ASTM A240/A240M-2023a. Standard Specification for Chromium and Chromium-Nickel Stainless Steel Plate, Sheet, and Strip for Pressure Vessels and for General Applications. ASTM International.
ASTM A268/A268M-2022. Standard Specification for Seamless and Welded Ferritic and Martensitic Stainless Steel Tubing for General Service. ASTM International.
ASTM A269/A269M-2022. Standard Specification for Seamless and Welded Austenitic Stainless Steel Tubing for General Service. ASTM International.
ASTM A278/A278M-2001(R2020). Standard Specification for Gray Iron Castings for Pressure-Containing Parts for Temperatures Up to 650°F (350°C). ASTM International.
ASTM A283/A283M-2018. Standard Specification for Low and Intermediate Tensile Strength Carbon Steel Plates. ASTM International.
ASTM A285/A285M-2017. Standard Specification for Pressure Vessel Plates, Carbon Steel, Low- and Intermediate-Tensile Strength. ASTM International.
ASTM A299/A299M-2017(R2022). Standard Specification for Pressure Vessel Plates, Carbon Steel, Manganese-Silicon. ASTM International.
ASTM A302/A302M-2017(R2022). Standard Specification for Pressure Vessel Plates, Alloy Steel, Manganese-Molybdenum and Manganese-Molybdenum-Nickel. ASTM International.
ASTM A307-2021. Standard Specification for Carbon Steel Bolts, Studs, and Threaded Rod 60 000 psi Tensile Strength. ASTM International.
ASTM A312/A312M-2022a. Standard Specification for Seamless, Welded, and Heavily Cold Worked Austenitic Stainless Steel Pipes. ASTM International.
ASTM A320/A320M-2022a. Standard Specification for Alloy-Steel and Stainless Steel Bolting for Low-Temperature Service. ASTM International.
ASTM A333/A333M-2018. Standard Specification for Seamless and Welded Steel Pipe for Low-Temperature Service and Other Applications With Required Notch Toughness. ASTM International.
ASTM A334/A334M-2004a(R2021). Standard Specification for Seamless and Welded Carbon and Alloy-Steel Tubes for Low-Temperature Service. ASTM International.
ASTM A335/A335M-2023. Standard Specification for Seamless Ferritic Alloy-Steel Pipe for High-Temperature Service. ASTM International.
ASTM A350/A350M-2023. Standard Specification for Carbon and Low-Alloy Steel Forgings, Requiring Notch Toughness Testing for Piping Components. ASTM International.
ASTM A351/A351M-2018^{e1}. Standard Specification for Castings, Austenitic, for Pressure-Containing Parts. ASTM International.
ASTM A352/A352M-2021. Standard Specification for Steel Castings, Ferritic and Martensitic, for Pressure-Containing Parts, Suitable for Low-Temperature Service. ASTM International.
ASTM A353/A353M-2017(R2022). Standard Specification for Pressure Vessel Plates, Alloy Steel, Double-Normalized and Tempered 9% Nickel. ASTM International.
ASTM A354-2017^{e2}. Standard Specification for Quenched and Tempered Alloy Steel Bolts, Studs, and Other Externally Threaded Fasteners. ASTM International.
ASTM A358/A358M-2019. Standard Specification for Electric-Fusion-Welded Austenitic Chromium-Nickel Stainless Steel Pipe for High-Temperature Service and General Applications. ASTM International.
ASTM A369/A369M-2023. Standard Specification for Carbon and Ferritic Alloy Steel Forged and Bored Pipe for High-Temperature Service. ASTM International.
ASTM A370-2023. Standard Test Methods and Definitions for Mechanical Testing of Steel Products. ASTM International.
ASTM A376/A376M-2022. Standard Specification for Seamless Austenitic Steel Pipe for High-Temperature Service. ASTM International.
ASTM A381/A381M-2023. Standard Specification for Metal-Arc-Welded Carbon or High-Strength Low-Alloy Steel Pipe for Use With High-Pressure Transmission Systems. ASTM International.
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ASTM A420/A420M-2022. Standard Specification for Piping Fittings of Wrought Carbon Steel and Alloy Steel for Low-Temperature Service. ASTM International.
ASTM A426/A426M-2018. Standard Specification for Centrifugally Cast Ferritic Alloy Steel Pipe for High-Temperature Service. ASTM International.
ASTM A437/A437M-2015(R2021). Standard Specification for Stainless and Alloy-Steel Turbine-Type Bolting Specially Heat Treated for High-Temperature Service. ASTM International.
ASTM A451/A451M-2020. Standard Specification for Centrifugally Cast Austenitic Steel Pipe for High-Temperature Service. ASTM International.
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ASTM A479/A479M-2023a. Standard Specification for Stainless Steel Bars and Shapes for Use in Boilers and Other Pressure Vessels. ASTM International.
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ASTM A515/A515M-2017(R2022). Standard Specification for Pressure Vessel Plates, Carbon Steel, for Intermediate- and Higher-Temperature Service. ASTM International.
ASTM A516/A516M-2017. Standard Specification for Pressure Vessel Plates, Carbon Steel, for Moderate and Lower-Temperature Service. ASTM International.
ASTM A524/A524M-2021. Standard Specification for Seamless Carbon Steel Pipe for Atmospheric and Lower Temperatures. ASTM International.
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ASTM A537/A537M-2020. Standard Specification for Pressure Vessel Plates, Heat-Treated, Carbon-Manganese-Silicon Steel. ASTM International.
ASTM A553/A553M-2022. Standard Specification for Pressure Vessel Plates, Alloy Steel, Quenched and Tempered 7, 8, and 9% Nickel. ASTM International.
ASTM A563/A563M-2023. Standard Specification for Carbon and Alloy Steel Nuts (Inch and Metric). ASTM International.
ASTM A571/A571M-2001(R2023)^{e1}. Standard Specification for Austenitic Ductile Iron Castings for Pressure-Containing Parts Suitable for Low-Temperature Service. ASTM International.
ASTM A587-2022. Standard Specification for Electric-Resistance-Welded Low-Carbon Steel Pipe for the Chemical Industry. ASTM International.
ASTM A645/A645M-2010(R2022). Standard Specification for Pressure Vessel Plates, 5% and 5½% Nickel Alloy Steels, Specially Heat Treated. ASTM International.
ASTM A671/A671M-2020. Standard Specification for Electric-Fusion-Welded Steel Pipe for Atmospheric and Lower Temperatures. ASTM International.
ASTM A672/A672M-2019. Standard Specification for Electric-Fusion-Welded Steel Pipe for High-Pressure Service at Moderate Temperatures. ASTM International.
ASTM A675/A675M-2014(R2019). Standard Specification for Steel Bars, Carbon, Hot-Wrought, Special Quality, Mechanical Properties. ASTM International.
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Table 3.1-1
Low-Temperature Service Requirements by Material Group

SI Units [Note (1)]

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
				Material		Weld			Minimum Material Temperature, °C, Without Impacts for Stress Ratios								
T-Number Group	Governing Thickness, mm	Notes	Low-Temp., °C, Service Limit	Minimum Material Permitted Temp., °C	Minimum Temp., °C, Without Impacts	Minimum Weld Permitted Temp., °C	Temp., °C, Without Impacts SR > 0.3	Temp., °C, Without Impacts SR ≤ 0.3	1	0.9	0.8	0.7	0.6	0.5	0.4	>0.3	Low-Temp., °C, Service Limit SR ≤ 0.3
Carbon Steels																	
CS −55	...	Max. possible Charpy t < 2.5 mm [Note (2)]	−29	−48	−48	...	−29	−104	−48	−48	−48	−48	−48	−48	−48	−48	−104
CS −55	...	Max. possible Charpy t ≥ 2.5 mm [Note (3)]	−29	...	−48	...	−29	−104	−48	−48	−48	−48	−48	−48	−48	−48	−104
CS −50	...	Max. possible Charpy t < 2.5 mm [Note (2)]	−29	−48	−48	...	−29	−104	−48	−48	−48	−48	−48	−48	−48	−48	−104
CS −50	...	Max. possible Charpy t ≥ 2.5 mm [Note (3)]	−29	...	−46	...	−29	−104	−46	−48	−48	−48	−48	−48	−48	−48	−104
CS −20	...	Max. possible Charpy t < 2.5 mm [Note (2)]	−29	−48	−48	...	−29	−104	−48	−48	−48	−48	−48	−48	−48	−48	−104
CS −20	...	Max. possible Charpy t ≥ 2.5 mm [Note (3)]	−29	...	−29	...	−29	−104	−29	−34	−40	−46	−48	−48	−48	−48	−104
CS −20(A)	...	...	−29	−29	−29	...	−29	−29	N/A	...	...	...	...	...	...	...	...
CS 0	...	...	−18	−18	−18	...	−29	−29	−18	−23	−29	−34	−40	−48	−48	−48	−104
CS +20(A)	...	...	−7	−7	−7	...	−7	−7	N/A	...	...	...	...	...	...	...	...
CS A	≤10.0	Max. possible Charpy t < 2.5 mm [Note (2)]	−7	−48	−48	...	−7	−104	−48	−48	−48	−48	−48	−48	−48	−48	−104

Table 3.1-1
Low-Temperature Service Requirements by Material Group (Cont'd)

SI Units [Note (1)]

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
				Material		Weld			Minimum Material Temperature, °C, Without Impacts for Stress Ratios								
T-Number Group	Governing Thickness, mm	Notes	Low-Temp., °C, Service Limit	Minimum Material Permitted Temp., °C	Minimum Temp., °C, Without Impacts	Minimum Weld Permitted Temp., °C	Temp., °C, Without Impacts SR > 0.3	Temp., °C, Without Impacts SR ≤ 0.3	1	0.9	0.8	0.7	0.6	0.5	0.4	>0.3	Low-Temp., °C, Service Limit SR ≤ 0.3
Carbon Steels (Cont'd)																	
CS A	≤10.0	Max. possible Charpy $t \geq 2.5$ mm [Note (3)]	−7	...	−7	...	−7	−104	−7	−12	−18	−23	−29	−40	−48	−48	−104
CS A	≤11.1	...	−4	...	−4	...	−4	−104	−4	−9	−15	−21	−26	−37	−48	−48	−104
CS A	≤12.7	...	−1	...	−1	...	−1	−104	−1	−7	−12	−18	−23	−34	−48	−48	−104
CS A	≤15.2	...	4	...	4	...	4	−104	4	−1	−7	−12	−18	−29	−48	−48	−104
CS A	≤17.7	...	10	...	10	...	10	−104	10	4	−1	−7	−12	−23	−43	−48	−104
CS A	≤21.6	...	16	...	16	...	16	−104	16	10	4	−1	−7	−18	−37	−48	−104
CS A	≤26.2	...	21	...	21	...	21	−104	21	16	10	4	−1	−12	−32	−48	−104
CS A	≤31.1	...	27	...	27	...	27	−104	27	21	16	10	4	−7	−26	−48	−104
CS A	≤39.7	...	32	...	32	...	32	−104	32	27	21	16	10	−1	−21	−48	−104
CS A	≤51.6	...	38	...	38	...	38	−104	38	32	27	21	16	4	−15	−48	−104
CS A	≤76.2	...	43	...	43	...	43	−104	43	38	32	27	21	10	−9	−48	−104
CS A	≤93.7	...	46	...	46	...	46	−104	46	41	35	29	24	13	−7	−48	−104
CS A	>93.7	...	49	...	49	...	49	−104	49	43	38	32	27	16	−4	−48	−104
CS B	≤10.0	Max. possible Charpy $t < 2.5$ mm [Note (2)]	−29	−48	−48	...	−29	−104	−48	−48	−48	−48	−48	−48	−48	−48	−104
CS B	≤10.0	Max. possible Charpy $t \geq 2.5$ mm [Note (3)]	−29	...	−29	...	−29	−104	−29	−34	−40	−46	−48	−48	−48	−48	−104
CS B	≤12.7	...	−29	...	−29	...	−29	−104	−29	−35	−40	−46	−48	−48	−48	−48	−104
CS B	≤14.3	...	−22	...	−22	...	−22	−104	−22	−27	−33	−38	−44	−48	−48	−48	−104
CS B	≤17.5	...	−13	...	−13	...	−13	−104	−13	−19	−24	−30	−35	−47	−48	−48	−104

Table 3.1-1
Low-Temperature Service Requirements by Material Group (Cont'd)

SI Units [Note (1)]

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
				Material		Weld			Minimum Material Temperature, °C, Without Impacts for Stress Ratios								
T-Number Group	Governing Thickness, mm	Notes	Low-Temp., °C, Service Limit	Minimum Material Permitted Temp., °C	Minimum Temp., °C, Without Impacts	Minimum Weld Permitted Temp., °C	Temp., °C, Without Impacts SR > 0.3	Temp., °C, Without Impacts SR ≤ 0.3	1	0.9	0.8	0.7	0.6	0.5	0.4	>0.3	Low-Temp., °C, Service Limit SR ≤ 0.3
Carbon Steels (Cont'd)																	
CS B	≤20.6	...	−7	...	−7	...	−7	−104	−7	−12	−18	−23	−29	−40	−48	−48	−104
CS B	≤24.9	...	−1	...	−1	...	−1	−104	−1	−7	−12	−18	−23	−34	−48	−48	−104
CS B	≤30.2	...	4	...	4	...	4	−104	4	−1	−7	−12	−18	−29	−48	−48	−104
CS B	≤37.3	...	10	...	10	...	10	−104	10	4	−1	−7	−12	−23	−43	−48	−104
CS B	≤47.0	...	16	...	16	...	16	−104	16	10	4	−1	−7	−18	−37	−48	−104
CS B	≤61.9	...	21	...	21	...	21	−104	21	16	10	4	−1	−12	−32	−48	−104
CS B	≤82.6	...	27	...	27	...	27	−104	27	21	16	10	4	−7	−26	−48	−104
CS B	≤101.6	...	32	...	32	...	32	−104	32	27	21	16	10	−1	−21	−48	−104
CS B	>101.6	...	49	...	49	...	49	−104	49	43	38	32	27	16	−4	−48	−104
CS C	≤10.0	Max. possible Charpy t < 2.5 mm [Note (2)]	−48	−48	−48	...	−48	−104	−48	−48	−48	−48	−48	−48	−48	−48	−104
CS C	≤10.0	Max. possible Charpy t ≥ 2.5 mm [Note (3)]	−29	...	−48	...	−29	−104	−48	−48	−48	−48	−48	−48	−48	−48	−104
CS C	≤10.4	...	−29	...	−46	...	−29	−104	−46	−48	−48	−48	−48	−48	−48	−48	−104
CS C	≤11.2	...	−29	...	−40	...	−29	−104	−40	−46	−48	−48	−48	−48	−48	−48	−104
CS C	≤13.5	...	−29	...	−34	...	−29	−104	−34	−40	−46	−48	−48	−48	−48	−48	−104
CS C	≤16.5	...	−29	...	−29	...	−29	−104	−29	−34	−40	−46	−48	−48	−48	−48	−104
CS C	≤21.6	...	−23	...	−23	...	−23	−104	−23	−29	−34	−40	−46	−48	−48	−48	−104
CS C	≤27.4	...	−18	...	−18	...	−18	−104	−18	−23	−29	−34	−40	−48	−48	−48	−104
CS C	≤35.1	...	−12	...	−12	...	−12	−104	−12	−18	−23	−29	−34	−46	−48	−48	−104
CS C	≤44.5	...	−7	...	−7	...	−7	−104	−7	−12	−18	−23	−29	−40	−48	−48	−104
CS C	≤57.2	...	−1	...	−1	...	−1	−104	−1	−7	−12	−18	−23	−34	−48	−48	−104
CS C	≤74.7	...	4	...	4	...	4	−104	4	−1	−7	−12	−18	−29	−48	−48	−104

Table 3.1-1
Low-Temperature Service Requirements by Material Group (Cont'd)

SI Units [Note (1)]

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
				Material		Weld			Minimum Material Temperature, °C, Without Impacts for Stress Ratios								
T-Number Group	Governing Thickness, mm	Notes	Low-Temp., °C, Service Limit	Minimum Material Permitted Temp., °C	Minimum Temp., °C, Without Impacts	Minimum Weld Permitted Temp., °C	Temp., °C, Without Impacts SR > 0.3	Temp., °C, Without Impacts SR ≤ 0.3	1	0.9	0.8	0.7	0.6	0.5	0.4	>0.3	Low-Temp., °C, Service Limit SR ≤ 0.3
Carbon Steels (Cont'd)																	
CS C	≤95.3	...	10	...	10	...	10	−104	10	4	−1	−7	−12	−23	−43	−48	−104
CS C	≤101.6	...	11	...	11	...	11	−104	11	6	0	−6	−11	−22	−42	−48	−104
CS C	>101.6	...	49	...	49	...	49	−104	49	43	38	32	27	16	−4	−48	−104
CS D	≤12.7	Max. possible Charpy t < 2.5 mm [Note (2)]	−48	−48	−48	...	−48	−104	−48	−48	−48	−48	−48	−48	−48	−48	−104
CS D	≤12.7	Max. possible Charpy $t \geq 2.5$ mm [Note (3)]	−29	...	−48	...	−29	−104	−48	−48	−48	−48	−48	−48	−48	−48	−104
CS D	≤14.7	...	−29	...	−46	...	−29	−104	−46	−48	−48	−48	−48	−48	−48	−48	−104
CS D	≤19.8	...	−29	...	−40	...	−29	−104	−40	−46	−48	−48	−48	−48	−48	−48	−104
CS D	≤25.4	...	−29	...	−34	...	−29	−104	−34	−40	−46	−48	−48	−48	−48	−48	−104
CS D	≤33.0	...	−29	...	−29	...	−29	−104	−29	−34	−40	−46	−48	−48	−48	−48	−104
CS D	≤42.9	...	−23	...	−23	...	−23	−104	−23	−29	−34	−40	−46	−48	−48	−48	−104
CS D	≤57.2	...	−18	...	−18	...	−18	−104	−18	−23	−29	−34	−40	−48	−48	−48	−104
CS D	≤74.6	...	−12	...	−12	...	−12	−104	−12	−18	−23	−29	−34	−46	−48	−48	−104
CS D	≤95.3	...	−7	...	−7	...	−7	−104	−7	−12	−18	−23	−29	−40	−48	−48	−104
CS D	≤101.6	...	−5	...	−5	...	−5	−104	−5	−11	−16	−22	−27	−38	−48	−48	−104
CS D	>101.6	...	49	...	49	...	49	−104	49	43	38	32	27	16	−4	−48	−104

Table 3.1-1
Low-Temperature Service Requirements by Material Group (Cont'd)

SI Units [Note (1)]

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
				Material		Weld			Minimum Material Temperature, °C, Without Impacts for Stress Ratios								
T-Number Group	Governing Thickness, mm	Notes	Low-Temp., °C, Service Limit	Minimum Material Permitted Temp., °C	Minimum Temp., °C, Without Impacts	Minimum Weld Permitted Temp., °C	Temp., °C, Without Impacts SR > 0.3	Temp., °C, Without Impacts SR ≤ 0.3	1	0.9	0.8	0.7	0.6	0.5	0.4	>0.3	Low-Temp., °C, Service Limit SR ≤ 0.3
Low-Alloy Steels																	
LA −320	...	Max. possible Charpy t < 2.5 mm [Note (2)]	−48	−196	−196	−48	−48	−104	N/A	...	...	...	...	...	...	...	N/A
LA −320	...	Max. possible Charpy t ≥ 2.5 mm [Note (3)]	−29	...	−196	...	−29	−104	N/A	...	...	...	...	...	...	...	N/A
LA −275	...	Max. possible Charpy t < 2.5 mm [Note (2)]	−48	−171	−171	−48	−48	−104	N/A	...	...	...	...	...	...	...	N/A
LA −275	...	Max. possible Charpy t ≥ 2.5 mm [Note (3)]	−29	...	−171	...	−29	−104	N/A	...	...	...	...	...	...	...	N/A
LA −150	...	Max. possible Charpy t < 2.5 mm [Note (2)]	−48	−101	−101	−48	−48	−104	N/A	...	...	...	...	...	...	...	−104
LA −150	...	Max. possible Charpy t ≥ 2.5 mm [Note (3)]	−29	...	−101	...	−29	−104	N/A	...	...	...	...	...	...	...	−104
LA −100	...	Max. possible Charpy t < 2.5 mm [Note (2)]	−48	−73	−73	−48	−48	−104	N/A	...	...	...	...	...	...	...	−104
LA −100	...	Max. possible Charpy t ≥ 2.5 mm [Note (3)]	−29	...	−73	...	−29	−104	N/A	...	...	...	...	...	...	...	−104

Table 3.1-1
Low-Temperature Service Requirements by Material Group (Cont'd)

SI Units [Note (1)]

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
				Material		Weld			Minimum Material Temperature, °C, Without Impacts for Stress Ratios								
T-Number Group	Governing Thickness, mm	Notes	Low-Temp., °C, Service Limit	Minimum Material Permitted Temp., °C	Minimum Temp., °C, Without Impacts	Minimum Weld Permitted Temp., °C	Temp., °C, Without Impacts SR > 0.3	Temp., °C, Without Impacts SR ≤ 0.3	1	0.9	0.8	0.7	0.6	0.5	0.4	>0.3	Low-Temp., °C, Service Limit SR ≤ 0.3
Low-Alloy Steels (Cont'd)																	
LA −75	...	Max. possible Charpy t < 2.5 mm [Note (2)]	−48	−59	−59	...	−48	−104	N/A	...	...	...	...	...	...	...	−104
LA −75	...	Max. possible Charpy t ≥ 2.5 mm [Note (3)]	−29	...	−59	...	−29	−104	N/A	...	...	...	...	...	...	...	−104
LA −55	...	Max. possible Charpy t < 2.5 mm [Note (2)]	−48	−48	−48	...	−48	−104	N/A	...	...	...	...	...	...	...	−104
LA −55	...	Max. possible Charpy t ≥ 2.5 mm [Note (3)]	−29	...	−48	...	−29	−104	N/A	...	...	...	...	...	...	...	−104
LA −40	...	Max. possible Charpy t < 2.5 mm [Note (2)]	−48	−48	−48	...	−48	−104	N/A	...	...	...	...	...	...	...	−104
LA −40	...	Max. possible Charpy t ≥ 2.5 mm [Note (3)]	−29	...	−40	...	−29	−104	N/A	...	...	...	...	...	...	...	−104
LA −20	...	Max. possible Charpy t < 2.5 mm [Note (2)]	−48	−48	−48	...	−48	−104	N/A	...	...	...	...	...	...	...	−104
LA −20	...	Max. possible Charpy t ≥ 2.5 mm [Note (3)]	−29	...	−29	...	−29	−104	N/A	...	...	...	...	...	...	...	−104

Table 3.1-1
Low-Temperature Service Requirements by Material Group (Cont'd)

SI Units [Note (1)]

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
				Material		Weld			Minimum Material Temperature, °C, Without Impacts for Stress Ratios								
T-Number Group	Governing Thickness, mm	Notes	Low-Temp., °C, Service Limit	Minimum Material Permitted Temp., °C	Minimum Temp., °C, Without Impacts	Minimum Weld Permitted Temp., °C	Temp., °C, Without Impacts SR > 0.3	Temp., °C, Without Impacts SR ≤ 0.3	1	0.9	0.8	0.7	0.6	0.5	0.4	>0.3	Low-Temp., °C, Service Limit SR ≤ 0.3
Low-Alloy Steels (Cont'd)																	
LA 0	...	Max. possible Charpy t < 2.5 mm [Note (2)]	−48	−48	−48	...	−48	−104	N/A	...	...	...	...	...	...	...	−104
LA 0	...	Max. possible Charpy t ≥ 2.5 mm [Note (3)]	−18	...	−18	...	−29	−104	N/A	...	...	...	...	...	...	...	−104
LA +20	...	Max. possible Charpy t < 2.5 mm [Note (2)]	−48	−48	−48	...	−48	−104	N/A	...	...	...	...	...	...	...	−104
LA +20	...	Max. possible Charpy t ≥ 2.5 mm [Note (3)]	−7	...	−7	...	−29	−104	N/A	...	...	...	...	...	...	...	−104
Stainless Steels																	
SS −425	...	Max. possible Charpy t < 2.5 mm [Note (2)]	−254	...	−254	...	−254	−254	N/A	...	...	...	...	...	...	...	...
SS −425	...	Carbon ≤0.1% and solution heat treated	−101	...	−254	...	−101	−104	N/A	...	...	...	...	...	...	...	−104
SS −425	...	Carbon >0.1% or not solution heat treated	−29	...	−29	...	−29	−104	N/A	...	...	...	...	...	...	...	−104

Table 3.1-1
Low-Temperature Service Requirements by Material Group (Cont'd)

SI Units [Note (1)]

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
				Material		Weld			Minimum Material Temperature, °C, Without Impacts for Stress Ratios								
T-Number Group	Governing Thickness, mm	Notes	Low-Temp., °C, Service Limit	Minimum Material Permitted Temp., °C	Minimum Temp., °C, Without Impacts	Minimum Weld Permitted Temp., °C	Temp., °C, Without Impacts SR > 0.3	Temp., °C, Without Impacts SR ≤ 0.3	1	0.9	0.8	0.7	0.6	0.5	0.4	>0.3	Low-Temp., °C, Service Limit SR ≤ 0.3
Stainless Steels (Cont'd)																	
SS −325	...	Max. possible Charpy t < 2.5 mm [Note (2)]	−198	...	−198	...	−254	−254	N/A	...	...	...	...	...	...	...	...
SS −325	...	Carbon ≤0.1% and solution heat treated	−101	...	−198	...	−101	−104	N/A	...	...	...	...	...	...	...	−104
SS −325	...	Carbon >0.1% or not solution heat treated	−29	...	−29	...	−29	−104	N/A	...	...	...	...	...	...	...	−104
SS −60	...	...	−29	...	−51	...	−29	−29	N/A	...	...	...	...	...	...	...	−104
SS −20	...	...	−29	...	−29	...	−29	−29	N/A	...	...	...	...	...	...	...	−104
Nickel Alloys																	
NI −325	...	...	−198	...	−198	...	−198	−198	N/A	...	...	...	...	...	...	...	...
Cast Irons																	
CI −20	...	...	−29	...	...	N/P	N/P	N/P	N/A	...	...	...	...	...	...	...	...
CI −20(A)	...	...	−29	−29	N/A	N/P	N/P	N/P	N/A	...	...	...	...	...	...	...	...
Copper Alloys																	
CU −452	...	...	−269	...	−269	...	−269	−269	N/A	...	...	...	...	...	...	...	...
CU −325	...	...	−198	...	−198	...	−198	−198	N/A	...	...	...	...	...	...	...	...

Table 3.1-1
Low-Temperature Service Requirements by Material Group (Cont'd)

SI Units [Note (1)]

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
				Material		Weld			Minimum Material Temperature, °C, Without Impacts for Stress Ratios								
T-Number Group	Governing Thickness, mm	Notes	Low-Temp., °C, Service Limit	Minimum Material Permitted Temp., °C	Minimum Temp., °C, Without Impacts	Minimum Weld Permitted Temp., °C	Temp., °C, Without Impacts SR > 0.3	Temp., °C, Without Impacts SR ≤ 0.3	1	0.9	0.8	0.7	0.6	0.5	0.4	>0.3	Low-Temp., °C, Service Limit SR ≤ 0.3
Aluminum Alloys																	
AL −452	...	...	−269	...	−269	...	−269	−269	N/A	...	...	...	...	...	...	...	...
Titanium and Titanium Alloys																	
TI −75	...	...	−59	...	−59	...	−59	−59	N/A	...	...	...	...	...	...	...	...
Zirconium and Zirconium Alloys																	
ZI −75	...	...	−59	...	−59	...	−59	−59	N/A	...	...	...	...	...	...	...	...

U.S. Customary Units [Note (4)]

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
				Material		Weld			Minimum Material Temperature, °F, Without Impacts for Stress Ratios								
T-Number Group	Governing Thickness, in.	Notes	Low-Temp., °F, Service Limit	Minimum Material Permitted Temp., °F	Minimum Temp., °F, Without Impacts	Minimum Weld Permitted Temp., °F	Temp., °F, Without Impacts SR > 0.3	Temp., °F, Without Impacts SR ≤ 0.3	1	0.9	0.8	0.7	0.6	0.5	0.4	>0.3	Low-Temp., °F, Service Limit SR ≤ 0.3
Carbon Steels																	
CS −55	...	Max. possible Charpy t < 2.5 mm [Note (2)]	−20	−55	−55	...	−20	−155	−55	−55	−55	−55	−55	−55	−55	−55	−155
CS −55	...	Max. possible Charpy t ≥ 2.5 mm [Note (3)]	−20	...	−55	...	−20	−155	−55	−55	−55	−55	−55	−55	−55	−55	−155
CS −50	...	Max. possible Charpy t < 2.5 mm [Note (2)]	−20	−55	−55	...	−20	−155	−55	−55	−55	−55	−55	−55	−55	−55	−155
CS −50	...	Max. possible Charpy t ≥ 2.5 mm [Note (3)]	−20	...	−50	...	−20	−155	−50	−55	−55	−55	−55	−55	−55	−55	−155

Table 3.1-1
Low-Temperature Service Requirements by Material Group (Cont'd)

U.S. Customary Units [Note (4)]

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
				Material		Weld			Minimum Material Temperature, °F, Without Impacts for Stress Ratios								
T-Number Group	Governing Thickness, in.	Notes	Low-Temp., °F, Service Limit	Minimum Material Permitted Temp., °F	Minimum Temp., °F, Without Impacts	Minimum Weld Permitted Temp., °F	Temp., °F, Without Impacts SR > 0.3	Temp., °F, Without Impacts SR ≤ 0.3	1	0.9	0.8	0.7	0.6	0.5	0.4	>0.3	Low-Temp., °F, Service Limit SR ≤ 0.3
Carbon Steels (Cont'd)																	
CS −20	...	Max. possible Charpy t < 2.5 mm [Note (2)]	−20	−55	−55	...	−20	−155	−55	−55	−55	−55	−55	−55	−55	−55	−155
CS −20	...	Max. possible Charpy t ≥ 2.5 mm [Note (3)]	−20	...	−20	...	−20	−155	−20	−30	−40	−50	−55	−55	−55	−55	−155
CS −20(A)	...	...	−20	−20	−20	...	−20	−20	N/A	...	...	...	...	...	...	...	...
CS 0	...	...	0	0	0	...	−20	−20	0	−10	−20	−30	−40	−55	−55	−55	−155
CS +20(A)	...	...	20	20	20	...	20	20	N/A	...	...	...	...	...	...	...	...
CS A	≤0.394	Max. possible Charpy t < 2.5 mm [Note (2)]	20	−55	−55	...	20	−155	−55	−55	−55	−55	−55	−55	−55	−55	−155
CS A	≤0.394	Max. possible Charpy t ≥ 2.5 mm [Note (3)]	20	...	20	...	20	−155	20	10	0	−10	−20	−40	−55	−55	−155
CS A	≤0.4375	...	25	...	25	...	25	−155	25	15	5	−5	−15	−35	−55	−55	−155
CS A	≤0.5	...	30	...	30	...	30	−155	30	20	10	0	−10	−30	−55	−55	−155
CS A	≤0.6	...	40	...	40	...	40	−155	40	30	20	10	0	−20	−55	−55	−155
CS A	≤0.7	...	50	...	50	...	50	−155	50	40	30	20	10	−10	−45	−55	−155
CS A	≤0.85	...	60	...	60	...	60	−155	60	50	40	30	20	0	−35	−55	−155
CS A	≤1.03	...	70	...	70	...	70	−155	70	60	50	40	30	10	−25	−55	−155
CS A	≤1.25	...	80	...	80	...	80	−155	80	70	60	50	40	20	−15	−55	−155
CS A	≤1.5625	...	90	...	90	...	90	−155	90	80	70	60	50	30	−5	−55	−155
CS A	≤2.0325	...	100	...	100	...	100	−155	100	90	80	70	60	40	5	−55	−155

Table 3.1-1
Low-Temperature Service Requirements by Material Group (Cont'd)

U.S. Customary Units [Note (4)]

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
				Material		Weld			Minimum Material Temperature, °F, Without Impacts for Stress Ratios								
T-Number Group	Governing Thickness, in.	Notes	Low-Temp., °F, Service Limit	Minimum Material Permitted Temp., °F	Minimum Temp., °F, Without Impacts	Minimum Weld Permitted Temp., °F	Temp., °F, Without Impacts SR > 0.3	Temp., °F, Without Impacts SR ≤ 0.3	1	0.9	0.8	0.7	0.6	0.5	0.4	>0.3	Low-Temp., °F, Service Limit SR ≤ 0.3
Carbon Steels (Cont'd)																	
CS A	≤3	...	110	...	110	...	110	−155	110	100	90	80	70	50	15	−55	−155
CS A	≤3.6875	...	115	...	115	...	115	−155	115	105	95	85	75	55	20	−55	−155
CS A	>3.6875	...	120	...	120	...	120	−155	120	110	100	90	80	60	25	−55	−155
CS B	≤0.394	Max. possible Charpy t < 2.5 mm [Note (2)]	−20	−55	−55	...	−20	−155	−55	−55	−55	−55	−55	−55	−55	−55	−155
CS B	≤0.394	Max. possible Charpy t ≥ 2.5 mm [Note (3)]	−20	...	−20	...	−20	−155	−20	−30	−40	−50	−55	−55	−55	−55	−155
CS B	≤0.50	...	−20	...	−20	...	−20	−155	−20	−30	−40	−50	−55	−55	−55	−55	−155
CS B	≤0.57	...	−7	...	−7	...	−7	−155	−7	−17	−27	−37	−47	−55	−55	−55	−155
CS B	≤0.69	...	9	...	9	...	9	−155	9	−1	−11	−21	−31	−51	−55	−55	−155
CS B	≤0.82	...	20	...	20	...	20	−155	20	10	0	−10	−20	−40	−55	−55	−155
CS B	≤0.98	...	30	...	30	...	30	−155	30	20	10	0	−10	−30	−55	−55	−155
CS B	≤1.19	...	40	...	40	...	40	−155	40	30	20	10	0	−20	−55	−55	−155
CS B	≤1.47	...	50	...	50	...	50	−155	50	40	30	20	10	−10	−45	−55	−155
CS B	≤1.85	...	60	...	60	...	60	−155	60	50	40	30	20	0	−35	−55	−155
CS B	≤2.4385	...	70	...	70	...	70	−155	70	60	50	40	30	10	−25	−55	−155
CS B	≤3.25	...	80	...	80	...	80	−155	80	70	60	50	40	20	−15	−55	−155
CS B	≤4.00	...	90	...	90	...	90	−155	90	80	70	60	50	30	−5	−55	−155
CS B	>4.00	...	120	...	120	...	120	−155	120	110	100	90	80	60	25	−55	−155

Table 3.1-1
Low-Temperature Service Requirements by Material Group (Cont'd)

U.S. Customary Units [Note (4)]

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
				Material		Weld			Minimum Material Temperature, °F, Without Impacts for Stress Ratios								
T-Number Group	Governing Thickness, in.	Notes	Low-Temp., °F, Service Limit	Minimum Material Permitted Temp., °F	Minimum Temp., °F, Without Impacts	Minimum Weld Permitted Temp., °F	Temp., °F, Without Impacts SR > 0.3	Temp., °F, Without Impacts SR ≤ 0.3	1	0.9	0.8	0.7	0.6	0.5	0.4	>0.3	Low-Temp., °F, Service Limit SR ≤ 0.3
Carbon Steels (Cont'd)																	
CS C	≤0.394	Max. possible Charpy t < 2.5 mm [Note (2)]	−55	−55	−55	...	−55	−155	−55	−55	−55	−55	−55	−55	−55	−55	−155
CS C	≤0.394	Max. possible Charpy $t \geq$ 2.5 mm [Note (3)]	−20	...	−55	...	−20	−155	−55	−55	−55	−55	−55	−55	−55	−55	−155
CS C	≤0.41	...	−20	...	−50	...	−20	−155	−50	−55	−55	−55	−55	−55	−55	−55	−155
CS C	≤0.44	...	−20	...	−40	...	−20	−155	−40	−50	−55	−55	−55	−55	−55	−55	−155
CS C	≤0.53	...	−20	...	−30	...	−20	−155	−30	−40	−50	−55	−55	−55	−55	−55	−155
CS C	≤0.65	...	−20	...	−20	...	−20	−155	−20	−30	−40	−50	−55	−55	−55	−55	−155
CS C	≤0.85	...	−10	...	−10	...	−10	−155	−10	−20	−30	−40	−50	−55	−55	−55	−155
CS C	≤1.08	...	0	...	0	...	0	−155	0	−10	−20	−30	−40	−55	−55	−55	−155
CS C	≤1.38	...	10	...	10	...	10	−155	10	0	−10	−20	−30	−50	−55	−55	−155
CS C	≤1.75	...	20	...	20	...	20	−155	20	10	0	−10	−20	−40	−55	−55	−155
CS C	≤2.25	...	30	...	30	...	30	−155	30	20	10	0	−10	−30	−55	−55	−155
CS C	≤2.94	...	40	...	40	...	40	−155	40	30	20	10	0	−20	−55	−55	−155
CS C	≤3.75	...	50	...	50	...	50	−155	50	40	30	20	10	−10	−45	−55	−155
CS C	≤4.00	...	52	...	52	...	52	−155	52	42	32	22	12	−8	−43	−55	−155
CS C	>4.00	...	120	...	120	...	120	−155	120	110	100	90	80	60	25	−55	−155
CS D	≤0.5	Max possible Charpy t < 2.5 mm [Note (2)]	−55	−55	−55	...	−55	−155	−55	−55	−55	−55	−55	−55	−55	−55	−155

Table 3.1-1
Low-Temperature Service Requirements by Material Group (Cont'd)

U.S. Customary Units [Note (4)]

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
				Material		Weld			Minimum Material Temperature, °F, Without Impacts for Stress Ratios								
T-Number Group	Governing Thickness, in.	Notes	Low-Temp., °F, Service Limit	Minimum Material Permitted Temp., °F	Minimum Temp., °F, Without Impacts	Minimum Weld Permitted Temp., °F	Temp., °F, Without Impacts SR > 0.3	Temp., °F, Without Impacts SR ≤ 0.3	1	0.9	0.8	0.7	0.6	0.5	0.4	>0.3	Low-Temp., °F, Service Limit SR ≤ 0.3
Carbon Steels (Cont'd)																	
CS D	≤0.5	Max possible Charpy $t \geq 2.5$ mm [Note (3)]	−20	...	−55	...	−20	−155	−55	−55	−55	−55	−55	−55	−55	−55	−155
CS D	≤0.58	...	−20	...	−50	...	−20	−155	−50	−55	−55	−55	−55	−55	−55	−55	−155
CS D	≤0.78	...	−20	...	−40	...	−20	−155	−40	−50	−55	−55	−55	−55	−55	−55	−155
CS D	≤1.0	...	−20	...	−30	...	−20	−155	−30	−40	−50	−55	−55	−55	−55	−55	−155
CS D	≤1.3	...	−20	...	−20	...	−20	−155	−20	−30	−40	−50	−55	−55	−55	−55	−155
CS D	≤1.6875	...	−10	...	−10	...	−10	−155	−10	−20	−30	−40	−50	−55	−55	−55	−155
CS D	≤2.25	...	0	...	0	...	0	−155	0	−10	−20	−30	−40	−55	−55	−55	−155
CS D	≤2.9375	...	10	...	10	...	10	−155	10	0	−10	−20	−30	−50	−55	−55	−155
CS D	≤3.75	...	20	...	20	...	20	−155	20	10	0	−10	−20	−40	−55	−55	−155
CS D	≤4.00	...	23	...	23	...	23	−155	23	13	3	−7	−17	−37	−55	−55	−155
CS D	>4.00	...	120	...	120	...	120	−155	120	110	100	90	80	60	25	−55	−155
Low-Alloy Steels																	
LA −320	...	Max. possible Charpy $t < 2.5$ mm [Note (2)]	−55	−320	−320	−55	−55	−155	N/A	...	...	...	...	...	...	...	N/A
LA −320	...	Max. possible Charpy $t \geq 2.5$ mm [Note (3)]	−20	...	−320	...	−20	−155	N/A	...	...	...	...	...	...	...	N/A
LA −275	...	Max. possible Charpy $t < 2.5$ mm [Note (2)]	−55	−275	−275	−55	−55	−155	N/A	...	...	...	...	...	...	...	N/A

Table 3.1-1
Low-Temperature Service Requirements by Material Group (Cont'd)

U.S. Customary Units [Note (4)]

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
				Material		Weld			Minimum Material Temperature, °F, Without Impacts for Stress Ratios								
T-Number Group	Governing Thickness, in.	Notes	Low-Temp., °F, Service Limit	Minimum Material Permitted Temp., °F	Minimum Temp., °F, Without Impacts	Minimum Weld Permitted Temp., °F	Temp., °F, Without Impacts SR > 0.3	Temp., °F, Without Impacts SR ≤ 0.3	1	0.9	0.8	0.7	0.6	0.5	0.4	>0.3	Low-Temp., °F, Service Limit SR ≤ 0.3
Low-Alloy Steels (Cont'd)																	
LA −275	...	Max. possible Charpy $t \geq 2.5$ mm [Note (3)]	−20	...	−275	...	−20	−155	N/A	...	...	...	...	...	...	...	N/A
LA −150	...	Max. possible Charpy $t < 2.5$ mm [Note (2)]	−55	−150	−150	−55	−55	−155	N/A	...	...	...	...	...	...	...	−155
LA −150	...	Max. possible Charpy $t \geq 2.5$ mm [Note (3)]	−20	...	−150	...	−20	−155	N/A	...	...	...	...	...	...	...	−155
LA −100	...	Max. possible Charpy $t < 2.5$ mm [Note (2)]	−55	−100	−100	−55	−55	−155	N/A	...	...	...	...	...	...	...	−155
LA −100	...	Max. possible Charpy $t \geq 2.5$ mm [Note (3)]	−20	...	−100	...	−20	−155	N/A	...	...	...	...	...	...	...	−155
LA −75	...	Max. possible Charpy $t < 2.5$ mm [Note (2)]	−55	−75	−75	...	−55	−155	N/A	...	...	...	...	...	...	...	−155
LA −75	...	Max. possible Charpy $t \geq 2.5$ mm [Note (3)]	−20	...	−75	...	−20	−155	N/A	...	...	...	...	...	...	...	−155
LA −55	...	Max. possible Charpy $t < 2.5$ mm [Note (2)]	−55	−55	−55	...	−55	−155	N/A	...	...	...	...	...	...	...	−155

Table 3.1-1
Low-Temperature Service Requirements by Material Group (Cont'd)

U.S. Customary Units [Note (4)]

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
				Material		Weld			Minimum Material Temperature, °F, Without Impacts for Stress Ratios								
T-Number Group	Governing Thickness, in.	Notes	Low-Temp., °F, Service Limit	Minimum Material Permitted Temp., °F	Minimum Temp., °F, Without Impacts	Minimum Weld Permitted Temp., °F	Temp., °F, Without Impacts SR > 0.3	Temp., °F, Without Impacts SR ≤ 0.3	1	0.9	0.8	0.7	0.6	0.5	0.4	>0.3	Low-Temp., °F, Service Limit SR ≤ 0.3
Low-Alloy Steels (Cont'd)																	
LA −55	...	Max. possible Charpy $t \geq 2.5$ mm [Note (3)]	−20	...	−55	...	−20	−155	N/A	...	...	...	...	...	...	...	−155
LA −40	...	Max. possible Charpy $t < 2.5$ mm [Note (2)]	−55	−55	−55	...	−55	−155	N/A	...	...	...	...	...	...	...	−155
LA −40	...	Max. possible Charpy $t \geq 2.5$ mm [Note (3)]	−20	...	−40	...	−20	−155	N/A	...	...	...	...	...	...	...	−155
LA −20	...	Max. possible Charpy $t < 2.5$ mm [Note (2)]	−55	−55	−55	...	−55	−155	N/A	...	...	...	...	...	...	...	−155
LA −20	...	Max. possible Charpy $t \geq 2.5$ mm [Note (3)]	−20	...	−20	...	−20	−155	N/A	...	...	...	...	...	...	...	−155
LA 0	...	Max. possible Charpy $t < 2.5$ mm [Note (2)]	−55	−55	−55	...	−55	−155	N/A	...	...	...	...	...	...	...	−155
LA 0	...	Max. possible Charpy $t \geq 2.5$ mm [Note (3)]	0	...	0	...	−20	−155	N/A	...	...	...	...	...	...	...	−155
LA +20	...	Max. possible Charpy $t < 2.5$ mm [Note (2)]	−55	−55	−55	...	−55	−155	N/A	...	...	...	...	...	...	...	−155

Table 3.1-1
Low-Temperature Service Requirements by Material Group (Cont'd)

U.S. Customary Units [Note (4)]

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
				Material		Weld			Minimum Material Temperature, °F, Without Impacts for Stress Ratios								
T-Number Group	Governing Thickness, in.	Notes	Low-Temp., °F, Service Limit	Minimum Material Permitted Temp., °F	Minimum Temp., °F, Without Impacts	Minimum Weld Permitted Temp., °F	Temp., °F, Without Impacts SR > 0.3	Temp., °F, Without Impacts SR ≤ 0.3	1	0.9	0.8	0.7	0.6	0.5	0.4	>0.3	Low-Temp., °F, Service Limit SR ≤ 0.3
Low-Alloy Steels (Cont'd)																	
LA +20	...	Max. possible Charpy $t \geq 2.5$ mm [Note (3)]	20	...	20	...	−20	−155	N/A	...	...	...	...	...	...	...	−155
Stainless Steels																	
SS −425	...	Max. possible Charpy $t < 2.5$ mm [Note (2)]	−425	...	−425	...	−425	−425	N/A	...	...	...	...	...	...	...	...
SS −425	...	Carbon ≤0.1% and solution heat treated	−150	...	−425	...	−150	−155	N/A	...	...	...	...	...	...	...	−155
SS −425	...	Carbon >0.1% or not solution heat treated	−20	...	−20	...	−20	−155	N/A	...	...	...	...	...	...	...	−155
SS −325	...	Max. possible Charpy $t < 2.5$ mm [Note (2)]	−325	...	−325	...	−425	−425	N/A	...	...	...	...	...	...	...	...
SS −325	...	Carbon ≤0.1% and solution heat treated	−150	...	−325	...	−150	−155	N/A	...	...	...	...	...	...	...	−155

Table 3.1-1
Low-Temperature Service Requirements by Material Group (Cont'd)

U.S. Customary Units [Note (4)]

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
				Material		Weld			Minimum Material Temperature, °F, Without Impacts for Stress Ratios								
T-Number Group	Governing Thickness, in.	Notes	Low-Temp., °F, Service Limit	Minimum Material Permitted Temp., °F	Minimum Temp., °F, Without Impacts	Minimum Weld Permitted Temp., °F	Temp., °F, Without Impacts SR > 0.3	Temp., °F, Without Impacts SR ≤ 0.3	1	0.9	0.8	0.7	0.6	0.5	0.4	>0.3	Low-Temp., °F, Service Limit SR ≤ 0.3
Stainless Steels (Cont'd)																	
SS −325	...	Carbon >0.1% or not solution heat treated	−20	...	−20	...	−20	−155	N/A	...	...	...	...	...	...	...	−155
SS −60	...	...	−20	...	−60	...	−20	−20	N/A	...	...	...	...	...	...	...	−155
SS −20	...	...	−20	...	−20	...	−20	−20	N/A	...	...	...	...	...	...	...	−155
Nickel Alloys																	
NI −325	...	...	−325	...	−325	...	−325	−325	N/A	...	...	...	...	...	...	...	...
Cast Irons																	
CI −20	...	...	−20	...	...	N/P	N/P	N/P	N/A	...	...	...	...	...	...	...	...
CI −20(A)	...	...	−20	−20	N/A	N/P	N/P	N/P	N/A	...	...	...	...	...	...	...	...
Copper Alloys																	
CU −452	...	...	−452	...	−452	...	−452	−452	N/A	...	...	...	...	...	...	...	...
CU −325	...	...	−325	...	−325	...	−325	−325	N/A	...	...	...	...	...	...	...	...
Aluminum Alloys																	
AL −452	...	...	−452	...	−452	...	−452	−452	N/A	...	...	...	...	...	...	...	...
Titanium and Titanium Alloys																	
TI −75	...	...	−75	...	−75	...	−75	−75	N/A	...	...	...	...	...	...	...	...
Zirconium and Zirconium Alloys																	
ZI −75	...	...	−75	...	−75	...	−75	−75	N/A	...	...	...	...	...	...	...	...

Table 3.1-1
Low-Temperature Service Requirements by Material Group (Cont'd)

GENERAL NOTES:
(a) N/A = not applicable.
(b) N/P = not permitted.
(c) SR = stress ratio per para. 3.6.2.

NOTES:
(1) All temperatures are in degrees Celsius.
(2) This line is applicable if the maximum Charpy specimen obtainable from the product is less than 2.5 mm (0.098 in.).
(3) This line is applicable if the maximum Charpy specimen obtainable from the product is equal to or greater than 2.5 mm (0.098 in.).
(4) All temperatures are in degrees Fahrenheit.

(24)

Table 3.2-1
Material Groupings by Material Specification

Specification	Type/Grade/Class/Condition/Temper/UNS	T-Number Group	Material Type	Product Form	Notes
A36	...	CS A	Carbon steels	PL	...
A47	Grade 32510	CI −20(A)	Cast irons	C	...
A48	Grade 20, 25, 30, 35, 40, 45, 50, 55, 60	CI −20	Cast irons	C	...
A53	Grade A (Type F), B (Type F)	CS −20(A)	Carbon steels	P	...
A53	Grade A (except Type F), B (except Type F)	CS B	Carbon steels	P	...
A105	...	CS −20	Carbon steels	FI & FO	...
A106	Grade A, B, C	CS B	Carbon steels	P	...
A126	Class A, B, C	CI −20	Cast irons	C	...
A134	A283 Grade C, D	CS A	Carbon steels	P	...
A134	A285 Grade A, B	CS B	Carbon steels	P	...
A134	A285 Grade C	CS A	Carbon steels	P	...
A134	A36	CS A	Carbon steels	P	...
A134	A1011 Designation SS Grade 30, 33, 36 Type 1 and 2, 40, 45 Type 1 and 2, 50	CS A	Carbon steels	P	...
A135	Grade A, B	CS B	Carbon steels	P	...
A139	Grade A, B, C, D, E	CS A	Carbon steels	P	...
A178	Grade A, C	CS −20	Carbon steels	T	...
A179	...	CS −20	Carbon steels	T	...
A181	Class 60, 70	CS A	Carbon steels	FI & FO	...
A182	Grade F1, F2, F5, F5a, F9, F11, F12, F21, F22, F91	LA −20	Low-alloy steels	FI & FO	...
A182	Grade F10	SS −325	Stainless steels	FI & FO	(3)
A182	Grade F10	SS −20	Stainless steels	FI & FO	(4)
A182	Grade F304, F304L, F316, F316L	SS −425	Stainless steels	FI & FO	...
A182	Grade F304H, F316H, F317L, F321, F321H, F347, F347H, F348, F348H	SS −325	Stainless steels	FI & FO	...
A182	Grade F310	SS −325	Stainless steels	FI & FO	(3), (5)
A182	Grade F310	SS −20	Stainless steels	FI & FO	(4), (5)
A182	Grade F6a	SS −20	Stainless steels	FI & FO	(5)
A182	Grade F60 (S32205)	SS −20	Stainless steels	FI & FO	(5)
A182	Grade S32760	SS −60	Stainless steels	FI & FO	...
A192	...	CS −20	Carbon steels	T	...
A193	Grade B5 ≤4 in., B16 ≤4 in.	LA −20	Low-alloy steels	B	...
A193	Grade B6	SS −20	Stainless steels	B	...
A193	Grade B7 (≤2½ in.)	LA −55	Low-alloy steels	B	...
A193	Grade B7 (>2½ in., ≤4 in.)	LA −40	Low-alloy steels	B	...
A193	Grade B7M (≤4 in.)	LA −55	Low-alloy steels	B	...
A193	Grade B8 Class 1, B8C Class 1	SS −425	Stainless steels	B	...
A193	Grade B8 Class 2, B8C Class 2, B8M, B8T	SS −325	Stainless steels	B	(6)
A194	Grade 1	CS −20	Carbon steels	N	...
A194	Grade 3	LA −20	Low-alloy steels	N	...
A194	Grade 6	SS −20	Stainless steels	N	...

Table 3.2-1
Material Groupings by Material Specification (Cont'd)

Specification	Type/Grade/Class/Condition/Temper/UNS	T-Number Group	Material Type	Product Form	Notes
A194	Grade 2, 2H, 2HM	CS −55	Carbon steels	N	...
A194	Grade 7, 7M	LA −150	Low-alloy steels	N	...
A194	Grade 8, 8CA, 8FA, 8MA, 8TA	SS −325	Stainless steels	N	...
A194	Grade 8A	SS −425	Stainless steels	N	...
A197	...	CI −20(A)	Cast irons	C	...
A203	Grade A, B, D, E	LA −20	Low-alloy steels	PL	...
A204	Grade A, B, C	LA −20	Low-alloy steels	PL	...
A210	Grade A-1	CS −20	Carbon steels	T	...
A214	...	CS −20	Carbon steels	T	...
A216	Grade WCA, WCB, WCC	CS −20	Carbon steels	C	...
A217	Grade C5, C12, WC1, WC4, WC5, WC6, WC9	LA −20	Low-alloy steels	C	...
A217	Grade CA−15	SS −20	Stainless steels	C	(5)
A234	Grade WP1, WP5, WP9, WP11, WP12, WP22, WP91	LA −20	Low-alloy steels	FI	...
A234	Grade WPB, WPC	CS B	Carbon steels	FI	...
A240	Type 305	SS −325	Stainless steels	PL	(1), (3)
A240	Type 305	SS −20	Stainless steels	PL	(2) or (4)
A240	Type 302, 317, 317L, 321, 321H, 347, 348	SS −325	Stainless steels	PL	(1)
A240	Type 302, 317, 317L, 321H, 348	SS −20	Stainless steels	PL	(2)
A240	Type 304, 304L, 316, 316L	SS −425	Stainless steels	PL	(1)
A240	Type 304, 304L, 316, 316L, 321, 347	SS −20	Stainless steels	PL	(2)
A240	Type 309S, 310S	SS −325	Stainless steels	PL	(1), (5)
A240	Type 309S, 310S	SS −20	Stainless steels	PL	(2), (5)
A240	Type 405, 410, 410S, 420, 429, X8M	SS −20	Stainless steels	PL	(5)
A240	UNS S32205	SS −20	Stainless steels	PL	(5)
A240	UNS S32760	SS −60	Stainless steels	PL	...
A268	Grade TP405, TP409, TP410, TP430, TP430Ti, TP433, TP436	SS −20	Stainless steels	T	(5)
A269	Grade TP304, TP304L, TP316, TP316L	SS −425	Stainless steels	P	(1)
A269	Grade TP304, TP304L, TP316, TP316L	SS −20	Stainless steels	P	(2)
A278	Class 20, 25, 30, 35, 40, 45, 50, 60	CI −20	Cast irons	C	...
A283	Grade C, D	CS A	Carbon steels	PL	...
A285	Grade A, B	CS B	Carbon steels	PL	...
A285	Grade C	CS A	Carbon steels	PL	...
A299	...	CS A	Carbon steels	PL	...
A302	Grade A, B, C, D	LA −20	Low-alloy steels	PL	...
A307	Grade B	CS −20	Carbon steels	B	...
A312	Grade TP304, TP304L, TP316, TP316L	SS −425	Stainless steels	P	(1)
A312	Grade TP304, TP304L, TP316, TP316L	SS −20	Stainless steels	P	(2)
A312	Grade TP304H, TP316H, TP321H, TP347H, TP348H	SS −325	Stainless steels	P	...
A312	Grade TP309, TP310	SS −325	Stainless steels	P	(1), (3), (5)

Table 3.2-1
Material Groupings by Material Specification (Cont'd)

Specification	Type/Grade/Class/Condition/Temper/UNS	T-Number Group	Material Type	Product Form	Notes
A312	Grade TP309, TP310	SS −20	Stainless steels	P	(2) or (4), (5)
A312	Grade TP317, TP317L, TP321, TP347, TP348	SS −325	Stainless steels	P	(1)
A312	Grade TP317, TP317L, TP321, TP347, TP348	SS −20	Stainless steels	P	(2)
A320	Grade B8 Class 1, B8C Class 1	SS −425	Stainless steels	B	...
A320	Grade B8 Class 2, B8C Class 2, B8F, B8M, B8T	SS −325	Stainless steels	N	...
A320	Grade L7, L43	LA −150	Low-alloy steels	B	(7)
A320	Grade L7A, L7B, L7C	LA −150	Low-alloy steels	B	(7)
A320	Grade L7M	LA −100	Low-alloy steels	B	(7)
A333	Grade 8	LA −320	Low-alloy steels	P	(7)
A333	Grade 1, 6	CS −50	Carbon steels	P	(7)
A333	Grade 3, 4	LA −150	Low-alloy steels	P	(7)
A333	Grade 7, 9	LA −100	Low-alloy steels	P	(7)
A334	Grade 3	LA −150	Low-alloy steels	T	(7)
A334	Grade 8	LA −320	Low-alloy steels	T	(7)
A334	Grade 1, 6	CS −50	Carbon steels	T	(7)
A334	Grade 7, 9	LA −100	Low-alloy steels	T	(7)
A335	Grade P1, P2, P5, P5b, P5c, P9, P11, P12, P15, P21, P22, P91	LA −20	Low-alloy steels	P	...
A350	Grade LF1	CS −20	Carbon steels	FI & FO	(7)
A350	Grade LF2 Class 1	CS −50	Carbon steels	FI & FO	(7)
A350	Grade LF2 Class 2	CS 0	Carbon steels	FI & FO	(7)
A350	Grade LF3	LA −150	Low-alloy steels	FI & FO	(7)
A351	Grade CE20N, CH20, CK20, HK30, HK40	SS −20	Stainless steels	C	(5)
A351	Grade CF8C, CF10MC, CH8, CH10, CN7M	SS −325	Stainless steels	C	...
A351	Grade HT30	SS −325	Stainless steels	C	(1)
A351	Grade CF3, CF3A, CF3M, CF8, CF8A, CF8M	SS −425	Stainless steels	C	...
A352	Grade LC1	LA −75	Low-alloy steels	C	(7)
A352	Grade LC2	LA −100	Low-alloy steels	C	(7)
A352	Grade LC3	LA −150	Low-alloy steels	C	(7)
A352	Grade LCB	CS −50	Carbon steels	C	(7)
A353	...	LA −320	Low-alloy steels	PL	(7)
A354	Grade BC	LA 0	Low-alloy steels	B	...
A354	Grade BD	LA −20	Low-alloy steels	B	...
A358	Grade 304, 304L, 316, 316L	SS −425	Stainless steels	P	(1)
A358	Grade 304, 304L, 316, 316L	SS −20	Stainless steels	P	(2)
A358	Grade 309S, 310S	SS −325	Stainless steels	P	(1), (5)
A358	Grade 309S, 310S	SS −20	Stainless steels	P	(2), (5)
A358	Grade 321, 347, 348, S34565	SS −325	Stainless steels	P	(1)
A358	Grade 321, 347, 348, S34565	SS −20	Stainless steels	P	(2)

Table 3.2-1
Material Groupings by Material Specification (Cont'd)

Specification	Type/Grade/Class/Condition/Temper/UNS	T-Number Group	Material Type	Product Form	Notes
A369	Grade FP1, FP2, FP3b, FP5, FP9, FP11, FP12, FP21, FP22	LA -20	Low-alloy steels	P	...
A369	Grade FPA	CS B	Carbon steels	P	...
A369	Grade FPB	CS -20	Carbon steels	P	...
A376	Grade 16-8-2H	SS -325	Stainless steels	P	(1), (5)
A376	Grade 16-8-2H	SS -20	Stainless steels	P	(2), (5)
A376	Grade TP304, TP316	SS -425	Stainless steels	P	(1)
A376	Grade TP304, TP316, TP321, TP347, TP348	SS -20	Stainless steels	P	(2)
A376	Grade TP304H, TP316H, TP321, TP321H, TP347, TP347H, TP348	SS -325	Stainless steels	P	(1)
A376	Grade TP304H, TP316H, TP321H, TP347H	SS -20	Stainless steels	P	(2)
A381	Class Y35, Y42, Y46, Y48, Y50, Y52, Y56, Y60	CS A	Carbon steels	P	...
A387	Grade 2, 5, 9, 11, 12, 21, 22, 91	LA -20	Low-alloy steels	PL	...
A395	...	CI -20(A)	Cast irons	C	...
A403	Grade WP304, WP304L, WP316, WP316L	SS -425	Stainless steels	FI	...
A403	Grade WP304H, WP316H, WP317, WP317L, WP321, WP321H, WP347H, WP347, WP348	SS -325	Stainless steels	FI	...
A403	Grade WP309, WP310	SS -325	Stainless steels	FI	(3), (5)
A403	Grade WP309, WP310	SS -20	Stainless steels	FI	(4), (5)
A409	Grade TP304, TP316	SS -425	Stainless steels	P	(1)
A409	Grade TP304, TP316	SS -20	Stainless steels	P	(2)
A409	Grade TP309, TP310	SS -20	Stainless steels	P	(2) or (4), (5)
A409	Grade TP309, TP310	SS -325	Stainless steels	P	(1), (3), (5)
A409	Grade TP317, TP321, TP347, TP348	SS -325	Stainless steels	P	(1)
A409	Grade TP317, TP321, TP347, TP348	SS -20	Stainless steels	P	(2)
A414	Grade A	CS B	Carbon steels	PL	...
A414	Grade B, C, D, E, F, G	CS A	Carbon steels	PL	...
A420	Grade WPL3	LA -150	Low-alloy steels	FI	(7)
A420	Grade WPL6	CS -50	Carbon steels	FI	(7)
A420	Grade WPL8	LA -320	Low-alloy steels	FI	(7)
A426	Grade CP1, CP2, CP5, CP5b, CP9, CP11, CP12, CP15, CP21, CP22	LA -20	Low-alloy steels	P	...
A426	Grade CPCA-15	SS -20	Stainless steels	P	(5)
A437	Grade B4B, B4C	SS -20	Stainless steels	B	...
A451	Grade CPE20N, CPH8, CPH10, CPH20, CPK20	SS -20	Stainless steels	P	(5)
A451	Grade CPF8, CPF8C, CPF8M, CPF10MC	SS -20	Stainless steels	P	...
A453	Grade 651 Class A, 651 Class B	SS -20	Stainless steels	B	...
A453	Grade 660 Class A, 660 Class B	SS -325	Stainless steels	B	...
A479	Type 304H, 316, 316H	SS -325	Stainless steels	PL	(8)
A479	Type 304, 304L, 316L	SS -425	Stainless steels	PL	(8)

Table 3.2-1
Material Groupings by Material Specification (Cont'd)

Specification	Type/Grade/Class/Condition/Temper/UNS	T-Number Group	Material Type	Product Form	Notes
A487	Grade CA6NM	SS −20	Stainless steels	C	(5)
A515	Grade 60	CS B	Carbon steels	PL	...
A515	Grade 65, 70	CS A	Carbon steels	PL	...
A516	Grade 55, 60 not normalized	CS C	Carbon steels	PL	(9)
A516	Grade 55, 60, 65, 70 normalized	CS D	Carbon steels	PL	(9)
A516	Grade 65, 70 not normalized	CS B	Carbon steels	PL	(9)
A524	Grade I, II	CS −20	Carbon steels	P	...
A536	Grade 60–40–18, 65–45–12	CI −20	Cast irons	C	...
A537	Class 1	CS D	Carbon steels	PL	...
A553	Type 2	LA −275	Low-alloy steels	PL	(7)
A553	Type 1	LA −320	Low-alloy steels	PL	(7)
A563	Grade A	CS −20(A)	Carbon steels	N	...
A571	Type D–2M Class 1	CI −20	Cast irons	C	(10)
A587	...	CS −20	Carbon steels	P	...
A645	...	LA −275	Low-alloy steels	PL	(7)
A671	Grade CA55 (A285 Gr C), CB70 (A515 Gr 70), CK75 (A299), CMS75 (A299)	CS A	Carbon steels	P	...
A671	Grade CB60 (A515 Gr 60)	CS B	Carbon steels	P	...
A671	Grade CC60 (A516 Gr 60) not normalized	CS C	Carbon steels	P	(9)
A671	Grade CC65 (A516 Gr 65), CC70 (A516 Gr 70) not normalized	CS B	Carbon steels	P	(9)
A671	Grade CC60 (A516 Gr 60), CC65 (A516 Gr 65), CC70 (A516 Gr 70) normalized	CS D	Carbon steels	P	(9)
A671	Grade CD70 (A537 Cl 1)	CS D	Carbon steels	P	...
A671	Grade CF70, CF71	LA −20	Low-alloy steels	P	...
A672	Grade A45 (A285 Gr A), A50 (A285 Gr B), B60 (A515 Gr 60)	CS B	Carbon steels	P	...
A672	Grade A55 (A285 Gr C), B65 (A515 Gr 65), B70 (A515 Gr 70), N75 (A299)	CS A	Carbon steels	P	...
A672	Grade C55 (A516 Gr 55), C60 (A516 Gr 60) not normalized	CS C	Carbon steels	P	(9)
A672	Grade C65 (A516 Gr 65), C70 (A516 Gr 70) not normalized	CS B	Carbon steels	P	(9)
A672	Grade C55 (A516 Gr 55), C60 (A516 Gr 60), C65 (A516 Gr 65), C70 (A516 Gr 70) normalized	CS D	Carbon steels	P	(9)
A672	Grade D70 (A537 Cl 1)	CS D	Carbon steels	P	...
A672	Grade L65, L70, L75	LA −20	Low-alloy steels	P	...
A675	Grade 45, 50, 55, 60, 65, 70, 80	CS −20	Carbon steels	B	(11)
A691	Grade ½CR, 1CR, 1¼CR, 2¼CR, 3CR, 5CR, 9CR, CM-65, CM-70, CM-75, P91	LA −20	Low-alloy steels	P	...
A691	Grade CMS-75 (A299)	CS A	Carbon steels	P	...
A691	Grade CMSH-70 (A537 Cl 1)	CS D	Carbon steels	P	...

Table 3.2-1
Material Groupings by Material Specification (Cont'd)

Specification	Type/Grade/Class/Condition/Temper/UNS	T-Number Group	Material Type	Product Form	Notes
A789	UNS S31803, S32304, S32750, S32760	SS −60	Stainless steels	T	...
A789	UNS S32205	SS −20	Stainless steels	P	(5)
A789	UNS S32900	SS −20	Stainless steels	T	...
A790	UNS S31803, S32304, S32750, S32760	SS −60	Stainless steels	P	...
A790	UNS S32205	SS −20	Stainless steels	P	(5)
A790	UNS S32900	SS −20	Stainless steels	P	...
A815	UNS S32205	SS −20	Stainless steels	FI & FO	(5)
A815	UNS S32760	SS −60	Stainless steels	FI & FO	...
A995	Grade 2A, 6A	SS −60	Stainless steels	C	...
A1011	Designation SS Grade 30, 33, 36 Type 1 and 2, 40, 45 Type 1 and 2, 50	CS A	Carbon steels	PL	...
API 5L	Grade A, A25 (Smls & ERW), B	CS B	Carbon steels	P	...
API 5L	Grade A25 (Butt weld)	CS −20(A)	Carbon steels	P	...
API 5L	Grade X42, X46, X52, X56, X60, X65, X70, X80	CS A	Carbon steels	P	...
API 5L	Grade X42, X46, X52, X56, X60, X65, X70, X80	CS B	Carbon steels	P	(12)
B21	UNS C46400, C48200, C48500	CU −325	Copper alloys	B	(11)
B42	UNS C10200, C12000, C12200	CU −452	Copper alloys	P	...
B43	UNS C23000	CU −452	Copper alloys	P	...
B61	UNS C92200	CU −325	Copper alloys	C	...
B62	UNS C83600	CU −325	Copper alloys	C	...
B68	UNS C12200	CU −452	Copper alloys	T	...
B75	UNS C10200, C12000, C12200	CU −452	Copper alloys	T	...
B88	UNS C12200	CU −452	Copper alloys	T	...
B96	UNS C65500	CU −452	Copper alloys	PL	...
B98	UNS C65100, C65500, C66100	CU −325	Copper alloys	B	(11)
B148	UNS C95200, C95300, C95500	CU −452	Copper alloys	C	...
B148	UNS C95400, C95600	CU −325	Copper alloys	C	...
B150	UNS C61400, C63000, C64200	CU −325	Copper alloys	B	(11)
B152	UNS C10200, C10400, C10500, C10700, C12200, C12300	CU −452	Copper alloys	PL	...
B169	UNS C61400	CU −452	Copper alloys	PL	...
B171	UNS C70600, C71500	CU −452	Copper alloys	PL	...
B187	UNS C10200, C11000, C12000, C12200	CU −325	Copper alloys	B	(11)
B280	UNS C12200	CU −452	Copper alloys	T	...
B283	UNS C11000, C46400, C65500	CU −452	Copper alloys	FO	...
B283	UNS C37700, C48500, C67500	CU −325	Copper alloys	FO	...
B466	UNS C70600, C71000	CU −452	Copper alloys	P & T	...
B467	UNS C70600, C71500	CU −452	Copper alloys	P	...
B493	Grade R60702, R60705	ZI −75	Zirconium	FO	...
B523	Grade R60702, R60705	ZI −75	Zirconium	T	...
B550	Grade R60702, R60705	ZI −75	Zirconium	PL	...

Table 3.2-1
Material Groupings by Material Specification (Cont'd)

Specification	Type/Grade/Class/Condition/Temper/UNS	T-Number Group	Material Type	Product Form	Notes
B551	Grade R60702, R60705	ZI −75	Zirconium	PL	...
B584	UNS C86200, C86300, C86400, C86500, C86700, C90300, C90500, C92200, C92300, C97300, C97600, C97800	CU −325	Copper alloys	C	...
B658	Grade R60702, R60705	ZI −75	Zirconium	P	...
Various	Various	NI −325	Nickel alloys	...	...
Various	Various	AL −452	Aluminum	...	...
Various	Various	TI −75	Titanium	...	...

GENERAL NOTES:
(a) Specifications are ASTM unless otherwise indicated.
(b) Product form abbreviations are
B = bolts
C = castings
FI = fittings
FO = forgings
N = nuts
P = pipe
PL = plates, sheets, and bars
T = tube

NOTES:
(1) Solution heat treated after forming.
(2) Not solution heat treated after forming.
(3) Carbon content ≤0.10%.
(4) Carbon content >0.10%.
(5) This material may have low impact properties at room temperature after being exposed to high service temperatures.
(6) Strain-hardened varieties of this carbide solution–treated bolting material can also be used at the low temperatures indicated.
(7) Material specification requires impact testing.
(8) Strain-hardened varieties of this material can also be used at the low temperatures indicated.
(9) This materials group depends on whether they are normalized.
(10) Minimum temperature −195°C (−320°F) with impact testing.
(11) Bar specification used for making bolting material.
(12) T-number group CS B may be used only when normalized or quenched and tempered.

Table 4.4.2-1
Charpy Impact Test (Absorbed Energy) Temperature Reduction for Material or Specimens <10 mm (0.394 in.)

Actual Material Thickness or Charpy Impact Specimen Width [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 4.5.1-1 specifies lateral expansion for minimum required values.

NOTE: (1) Straight-line interpolation for intermediate values is permitted.

Table 4.5.1-1
Minimum Required Charpy V-Notch Impact Values

Specified Minimum Tensile Strength	Number of Specimens (See Para. 4.5.4 for Retests)	Energy (Standard Size Specimens)			
		Fully Deoxidized Steels		Other Than Fully Deoxidized Steels	
		J	ft-lbf	J	ft-lbf
Carbon, Low-Alloy Steels, and Other Materials (Other Than Steels in P-Numbers 6, 7, and 8)					
448 MPa (65 ksi) and less	Average for three specimens	18	13	14	10
	Minimum for one specimen	14	10	10	7
Over 448 MPa (65 ksi) to 517 MPa (75 ksi)	Average for three specimens	20	15	18	13
	Minimum for one specimen	16	12	14	10
Over 517 MPa (75 ksi) to 656 MPa (95 ksi)	Average for three specimens	27	20	...	...
	Minimum for one specimen	20	15	...	...
		Lateral Expansion			
Over 656 MPa (95 ksi)	Minimum for three specimens	0.38 mm (0.015 in.)			
Steels in P-Numbers 6, 7, and 8					
All	Minimum for three specimens	0.38 mm (0.015 in.)			

MANDATORY APPENDIX I
IMPACT TEST EXEMPTION CURVES

Refer to paras. 3.3 and 3.5 for applicability of the impact test exemption curves in Figures I-1 and I-1M and Table I-1 of this Appendix.

Figure I-1
Impact Test Exemption Curves for T-Number Groups CS A, CS B, CS C, and CS D (U.S. Customary Units)

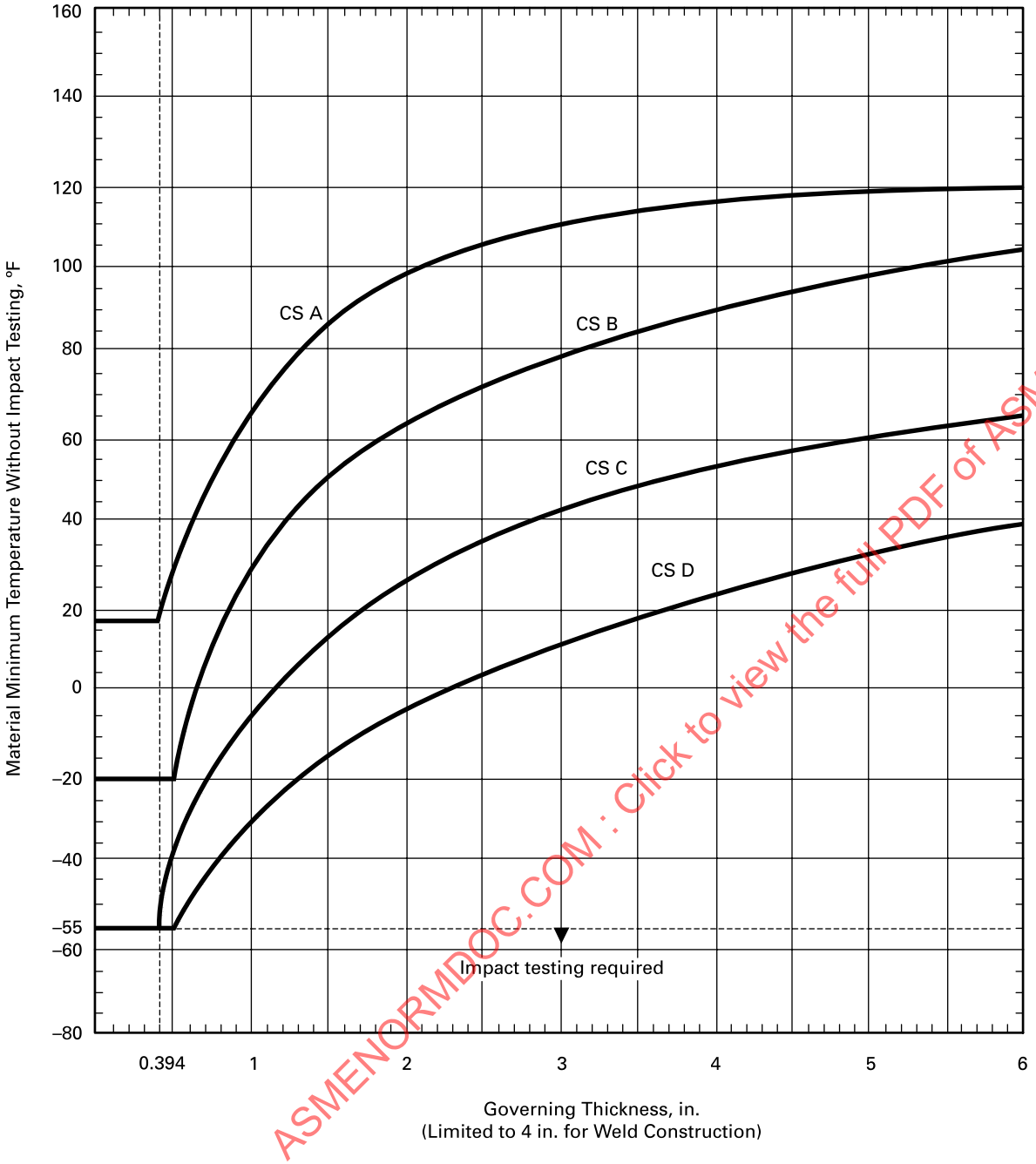

Figure I-1M
Impact Test Exemption Curves for T-Number Groups CS A, CS B, CS C, and CS D (SI Units)

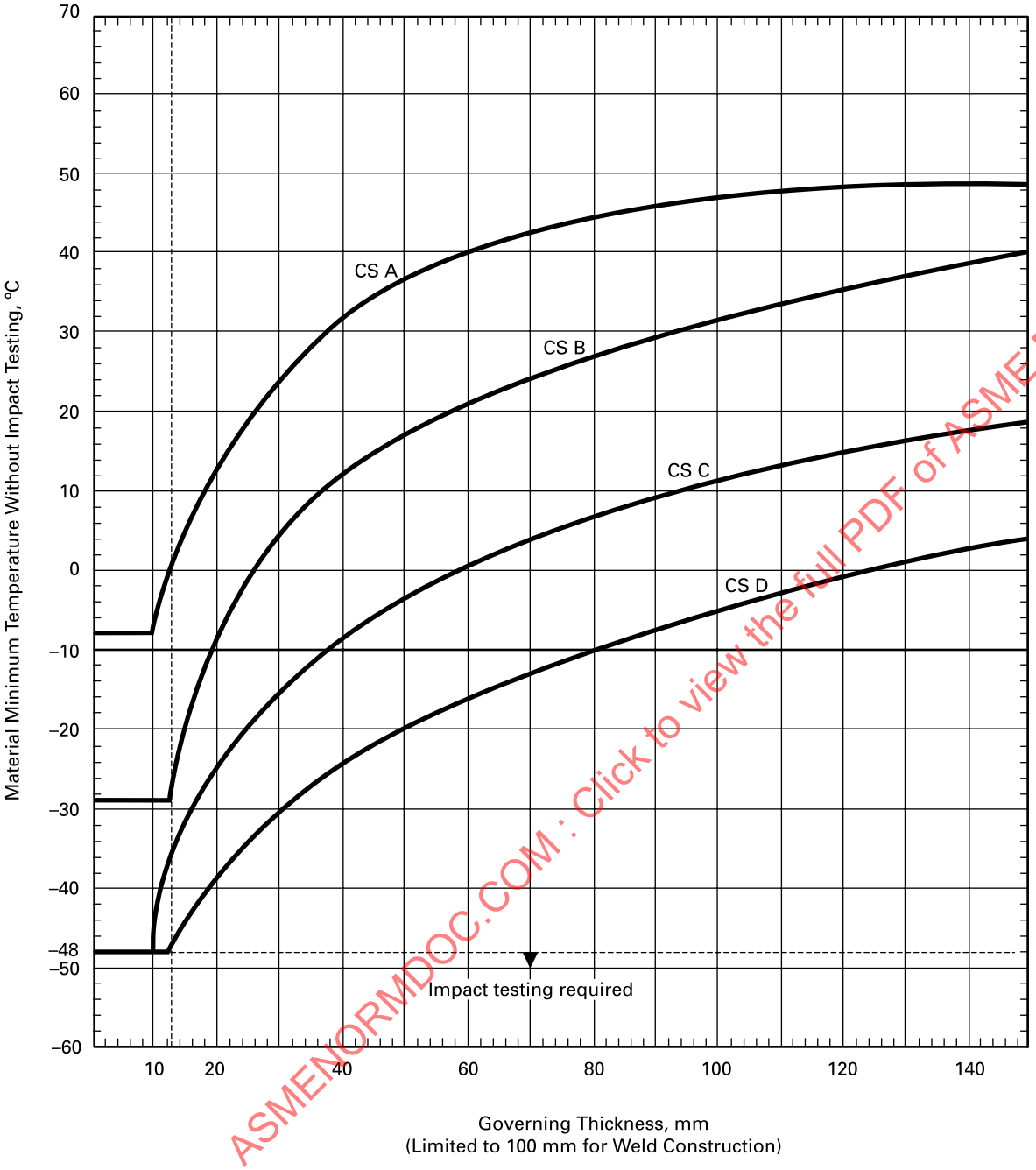

Table I-1
Tabular Values for Figures I-1 and I-1M

U.S. Customary Units					SI Units				
	Material Minimum Temperature Without Impact Testing, °F					Material Minimum Temperature Without Impact Testing, °C			
Governing Thickness, in.	Curve CS A	Curve CS B	Curve CS C	Curve CS D	Governing Thickness, mm	Curve CS A	Curve CS B	Curve CS C	Curve CS D
0.25	18	−20	−55	−55	6.4	−8	−29	−48	−48
0.3125	18	−20	−55	−55	7.9	−8	−29	−48	−48
0.375	18	−20	−55	−55	9.5	−8	−29	−48	−48
0.4375	25	−20	−40	−55	11.1	−4	−29	−40	−48
0.5	32	−20	−34	−55	12.7	0	−29	−37	−48
0.5625	37	−7	−26	−51	14.3	3	−22	−32	−46
0.625	43	2	−22	−48	15.9	6	−17	−30	−44
0.6875	48	9	−18	−45	17.5	9	−13	−28	−43
0.75	53	15	−15	−42	19.1	12	−9	−26	−41
0.8125	57	20	−12	−38	20.6	14	−7	−24	−39
0.875	61	25	−9	−36	22.2	16	−4	−23	−38
0.9375	65	29	−6	−33	23.8	18	−2	−21	−36
1	68	33	−3	−30	25.4	20	1	−19	−34
1.0625	72	36	−1	−28	27.0	22	2	−18	−33
1.125	75	39	2	−26	28.6	24	4	−17	−32
1.1875	77	42	4	−23	30.2	25	6	−16	−31
1.25	80	44	6	−21	31.8	27	7	−14	−29
1.3125	82	46	8	−19	33.3	28	8	−13	−28
1.375	84	48	10	−18	34.9	29	9	−12	−28
1.4375	86	49	12	−16	36.5	30	9	−11	−27
1.5	88	51	14	−14	38.1	31	11	−10	−26
1.5625	90	53	16	−13	39.7	32	12	−9	−25
1.625	92	55	17	−11	41.3	33	13	−8	−24
1.6875	93	57	19	−10	42.9	34	14	−7	−23
1.75	94	58	20	−8	44.5	34	14	−7	−22
1.8125	96	59	22	−7	46.0	36	15	−6	−22
1.875	97	61	23	−6	47.6	36	16	−5	−21
1.9375	98	62	24	−5	49.2	37	17	−4	−21
2	99	63	26	−4	50.8	37	17	−3	−20
2.0625	100	64	27	−3	52.4	38	18	−3	−19
2.125	101	65	28	−2	54.0	38	18	−2	−19
2.1875	102	66	29	−1	55.6	39	19	−2	−18
2.25	102	67	30	0	57.2	39	19	−1	−18
2.3125	103	68	31	1	58.7	39	20	−1	−17
2.375	104	69	32	2	60.3	40	21	0	−17
2.4375	105	70	33	3	61.9	41	21	1	−16
2.5	105	71	34	4	63.5	41	22	1	−16
2.5625	106	71	35	5	65.1	41	22	2	−15

Table I-1
Tabular Values for Figures I-1 and I-1M (Cont'd)

U.S. Customary Units					SI Units				
	Material Minimum Temperature Without Impact Testing, °F					Material Minimum Temperature Without Impact Testing, °C			
Governing Thickness, in.	Curve CS A	Curve CS B	Curve CS C	Curve CS D	Governing Thickness, mm	Curve CS A	Curve CS B	Curve CS C	Curve CS D
2.625	107	73	36	6	66.7	42	23	2	−14
2.6875	107	73	37	7	68.3	42	23	3	−14
2.75	108	74	38	8	69.9	42	23	3	−13
2.8125	108	75	39	8	71.4	42	24	4	−13
2.875	109	76	40	9	73.0	43	24	4	−13
2.9375	109	77	40	10	74.6	43	25	4	−12
3	110	77	41	11	76.2	43	25	5	−12
3.0625	111	78	42	12	77.8	44	26	6	−11
3.125	111	79	43	12	79.4	44	26	6	−11
3.1875	112	80	44	13	81.0	44	27	7	−11
3.25	112	80	44	14	82.6	44	27	7	−10
3.3125	113	81	45	15	84.1	45	27	7	−9
3.375	113	82	46	15	85.7	45	28	8	−9
3.4375	114	83	46	16	87.3	46	28	8	−9
3.5	114	83	47	17	88.9	46	28	8	−8
3.5625	114	84	48	17	90.5	46	29	9	−8
3.625	115	85	49	18	92.1	46	29	9	−8
3.6875	115	85	49	19	93.7	46	29	9	−7
3.75	116	86	50	20	95.3	47	30	10	−7
3.8125	116	87	51	21	96.8	47	31	11	−6
3.875	116	88	51	21	98.4	47	31	11	−6
3.9375	117	88	52	22	100.0	47	32	11	−6
4	117	89	52	23	101.6	47	32	11	−5
4.0625	117	90	53	23	103.2	47	32	12	−5
4.125	118	90	54	24	104.8	48	32	12	−4
4.1875	118	91	54	25	106.4	48	33	12	−4
4.25	118	91	55	25	108.0	48	33	13	−4
4.3125	118	92	55	26	109.5	48	33	13	−3
4.375	119	93	56	27	111.1	48	34	13	−3
4.4375	119	93	56	27	112.7	48	34	13	−3
4.5	119	94	57	28	114.3	48	34	14	−2
4.5625	119	94	57	29	115.9	48	34	14	−2
4.625	119	95	58	29	117.5	48	35	14	−2
4.6875	119	95	58	30	119.1	48	35	14	−1
4.75	119	96	59	30	120.7	48	36	15	−1
4.8125	119	96	59	31	122.2	48	36	15	−1
4.875	119	97	60	31	123.8	48	36	16	−1

Table I-1
Tabular Values for Figures I-1 and I-1M (Cont'd)

U.S. Customary Units					SI Units				
	Material Minimum Temperature Without Impact Testing, °F					Material Minimum Temperature Without Impact Testing, °C			
Governing Thickness, in.	Curve CS A	Curve CS B	Curve CS C	Curve CS D	Governing Thickness, mm	Curve CS A	Curve CS B	Curve CS C	Curve CS D
4.9375	119	97	60	32	125.4	48	36	16	0
5	119	97	60	32	127.0	48	36	16	0
5.0625	119	98	61	33	128.6	48	37	16	1
5.125	119	98	61	33	130.2	48	37	16	1
5.1875	119	98	62	34	131.8	48	37	17	1
5.25	119	99	62	34	133.4	48	37	17	1
5.3125	119	99	62	35	134.9	48	37	17	2
5.375	119	100	63	35	136.5	48	38	17	2
5.4375	119	100	63	36	138.1	48	38	17	2
5.5	119	100	63	36	139.7	48	38	17	2
5.5625	119	101	64	36	141.3	48	38	18	2
5.625	119	101	64	37	142.9	48	38	18	3
5.6875	119	102	64	37	144.5	48	39	18	3
5.75	120	102	65	38	146.1	49	39	18	3
5.8125	120	103	65	38	147.6	49	39	18	3
5.875	120	103	66	38	149.2	49	39	19	3
5.9375	120	104	66	39	150.8	49	40	19	4
6	120	104	66	39	152.4	49	40	19	4

MANDATORY APPENDIX II
STRESS RATIO CURVES

See Figures II-1 and II-1M.

Figure II-1
Stress Ratio Curve (U.S. Customary Units)

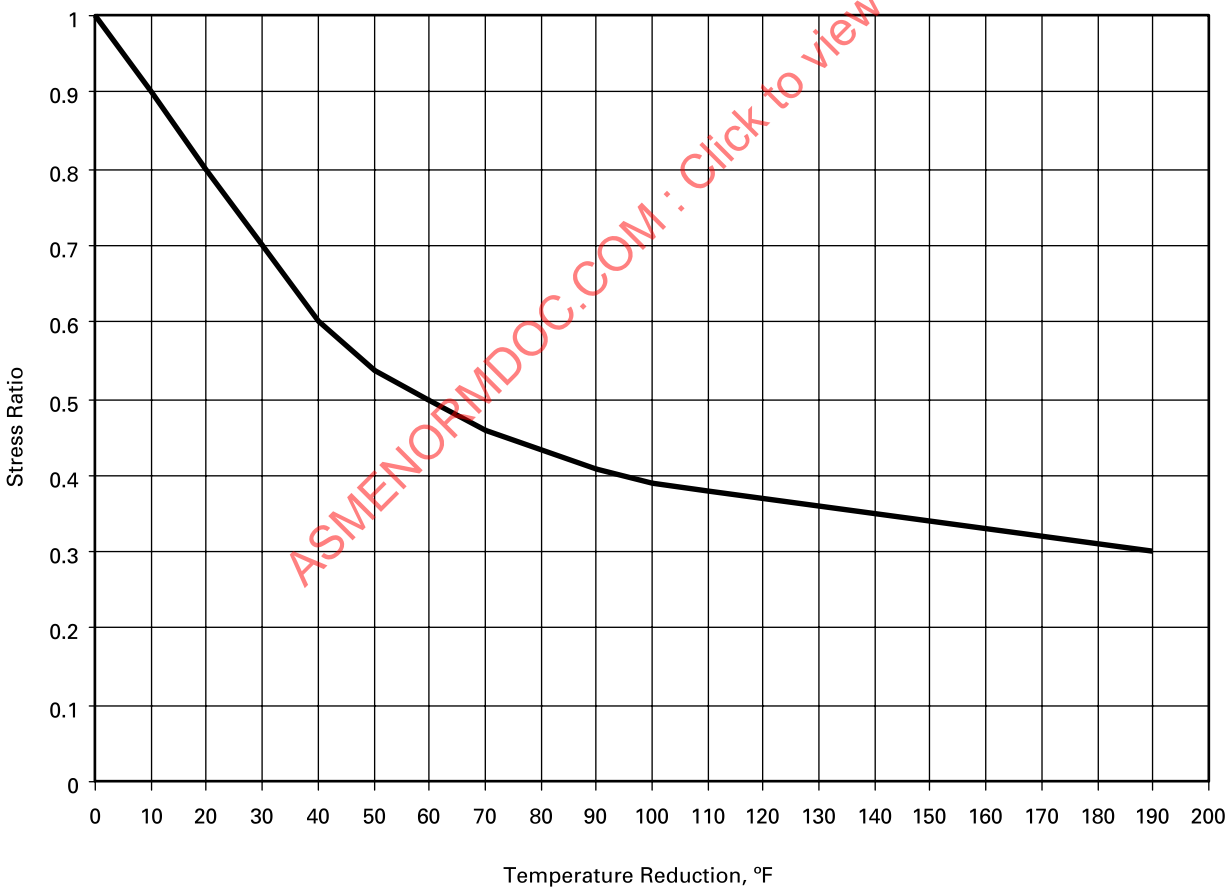

Figure II-1M
Stress Ratio Curve (SI Units)