AWS D1.1/D1.1M:2020
An American National Standard

Structural Welding Code— Steel

American Welding Society®

Approved American National Standard
ANSI

AWS D1.1/D1.1M:2020
An American National Standard

Approved by the
American National Standards Institute
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Structural Welding Code—Steel

24th Edition

Supersedes AWS D1.1/D1.1M:2015

Prepared by the
American Welding Society (AWS) D1 Committee on Structural Welding

Under the Direction of the
AWS Technical Activities Committee

Approved by the
AWS Board of Directors

Abstract

This code covers the welding requirements for any type of welded structure made from the commonly used carbon and low-alloy constructional steels. Clauses 1 through 11 constitute a body of rules for the regulation of welding in steel construction. There are eight normative and eleven informative annexes in this code. A Commentary of the code is included with the document.

American Welding Society®

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Foreword

This foreword is not part of AWS D1.1/D1.1M:2020, *Structural Welding Code—Steel*, but is included for informational purposes only.

The first edition of the *Code for Fusion Welding and Gas Cutting in Building Construction* was published by the American Welding Society in 1928 and called Code 1 Part A. It was revised in 1930 and 1937 under the same title. It was revised again in 1941 and given the designation D1.0. D1.0 was revised again in 1946, 1963, 1966, and 1969. The 1963 edition published an amended version in 1965, and the 1966 edition published an amended version in 1967. The code was combined with D2.0, *Specifications for Welding Highway and Railway Bridges*, in 1972, given the designation D1.1, and retitled AWS *Structural Welding Code.* D1.1 was revised again in 1975, 1979, 1980, 1981, 1982, 1983, 1984, 1985, 1986, 1988, 1990, 1992, 1994, 1996, 1998, 2000, 2002, 2004, 2006, 2008 and 2010. A second printing of D1.1:2010 was published in 2011. From 1972 to 1988, the D1.1 code covered the welding of both buildings and bridges.

In 1988, AWS published its first edition of AASHTO/AWS D1.5, *Bridge Welding Code*; coincident with this, the D1.1 code changed references of buildings and bridges to statically loaded and dynamically loaded structures, respectively, in order to make the document applicable to a broader range of structural applications. After the publishing of the 2010 edition, it was decided that the AWS *Structural Welding Code—Steel* would be published on a five year revision cycle instead of a two year revision cycle. This was done in order to sync the publication cycle of AWS Structural Welding Code-Steel with the publication cycles of the AISC Steel Building Specification and the International Building Code. This 2020 edition is the 24th edition of D1.1.

Changes in Code Requirements, underlined text in the clauses, subclauses, tables, figures, or forms indicates a change from the 2015 edition. A vertical line in the margin of a table or figure also indicates a change from the 2015 edition.

The following is a summary of the most significant technical changes contained in D1.1/D1.1M:2020:

Summary of Changes

Clause/Table/Figure/Annex	Modification
Clause 1	
Clause 2	This is a new clause listing normative references. It replaces subclause 1.9 and Annex S from the previous edition.
Clause 3	This is a new clause that provides terms and definitions specific to this standard. It replaces subclause 1.3 and Annex J from the previous edition.
Clause 4	Clause 4 was presented as Clause 2 in the previous edition. Annex A Figures in the previous edition were incorporated into Clause 4.
Clause 5	Clause 5 was presented as Clause 3 in the previous edition. The Clause has also been restructured to follow the normal progression of writing a prequalified WPS. Table 5.2 has been editorially renamed and reorganized to list WPS essential variables. Additional requirements have been added when using shielding gases and a new Table 5.7 was added on shielding gases. New materials have been added to Tables 5.3 and 5.8.
Clause 6	Clause 6 was presented as Clause 4 in the previous edition. Revisions include the requirements for the qualification of WPSs using waveform technology. All the CVN testing requirements have been added to Table 6.7, so they now are all contained in a single place. The WPS retest requirements have been clarified. The PJP Groove weld clause has been reorganized to clarify the qualification of PJP Groove welds using the Joint Details in Figure 5.2. Part D of the Clause has been reorganized to better align the testing procedures and qualification of CVNs with the order that they would be accomplished.

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Summary of Changes (Continued)

Clause/Table/Figure/Annex	Modification
Clause 7	Clause 7 was presented as Clause 5 in the previous edition. Revisions were made to the weld restoration of base metal with mislocated holes.
Clause 8	Clause 8 was presented as Clause 6 in the previous edition. Revisions were made to the qualification requirements for inspection personnel to ensure that all welding inspectors are qualified. The Engineer's responsibilities as it relates to Inspection were also clarified. Digital radiography has been added to Radiographic Testing. The limitations for geometric unsharpness have been added to the Code and the equation has been revised to match the equation in ASME *Boiler and Pressure Vessel Code*, Section V, Article 2. The methodology to determine the attenuation factor has been updated to reflect that UT instruments are now capable of reporting a fractional value for dB.
Clause 9	Clause 9 was presented as Clause 7 in the previous edition. The code was updated to require the manufacturer's permanent identification on headed studs and deformed anchor bars. Revisions were made to provide weld procedure requirements for fillet welding of studs.
Clause 10	Clause 10 was presented as Clause 9 in the previous edition. The calculations for static strength of welded tubular connections were removed in deference to AISC design provisions.
Clause 11	Clause 11 was presented as Clause 8 in the previous edition.
Annex A	Annex A was presented as Annex B in the previous edition.
Annex B	Annex B was presented as Annex H in the previous edition.
Annex D	Annex D was presented as Annex F in the previous edition.
Annex E	Annex E was presented as Annex D in the previous edition.
Annex F	Annex F was presented as Annex E in the previous edition.
Annex H	New Annex that addresses phased array ultrasonic testing (PAUT)
Annex J	Annex J was presented as Annex M in the previous edition.
Annex K	Annex K was presented as Annex P in the previous edition.
Annex L	Annex L was presented as Annex T in the previous edition.
Annex M	Annex M was presented as Annex U in the previous edition.
Annex N	Annex N was presented as Annex K in the previous edition.
Annex O	Annex O was presented as Annex Q in the previous edition.
Annex P	Annex P was presented as Annex L in the previous edition.
Annex Q	Annex Q was presented as Annex O in the previous edition.
Annex R	Annex R has been modified to contain preliminary design of circular tube connections previously contained in the Tubular Structures clause as well as ovalizing parameter alpha.
Annex T	Annex T was presented as Annex N in the previous edition.
C-Annex H	Commentary was added for Annex H

Commentary. The Commentary is nonmandatory and is intended only to provide insightful information into provision rationale.

Normative Annexes. These annexes address specific subjects in the code and their requirements are mandatory requirements that supplement the code provisions.

Informative Annexes. These annexes are not code requirements but are provided to clarify code provisions by showing examples, providing information, or suggesting alternative good practices.

Index. As in previous codes, the entries in the Index are referred to by subclause number rather than by page number. This should enable the user of the Index to locate a particular item of interest in minimum time.

(Continued)

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Errata. It is the Structural Welding Committee's Policy that all errata should be made available to users of the code. Therefore, any significant errata will be published in the Society News Section of the *Welding Journal* and posted on the AWS web site at: http://www.aws.org/standards/page/errata.

Suggestions. Your comments for improving AWS D1.1/D1.1M:2015, *Structural Welding Code—Steel* are welcome. Submit comments to the Secretary of the D1Q Subcommittee, American Welding Society, 8669 NW 36 St, # 130, Miami, FL 33166.

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Structural Welding Code—Steel

1. General Requirements

1.1 Scope

This code contains the requirements for fabricating and erecting welded steel structures. When this code is stipulated in contract documents, conformance with all provisions of the code shall be required, except for those provisions that the Engineer (see 1.5.1) or contract documents specifically modifies or exempts.

The following is a summary of the code clauses:

1. General Requirements. This clause contains basic information on the scope and limitations of the code, key definitions, and the major responsibilities of the parties involved with steel fabrication.

2. Normative References. This clause contains a list of reference documents that assist the user in implementation of this code or are required for implementation.

3. Terms and Definitions. This clause contains terms and definitions as they relate to this code.

4. Design of Welded Connections. This clause contains requirements for the design of welded connections composed of tubular, or nontubular, product form members.

5. Prequalification of WPSs. This clause contains the requirements for exempting a Welding Procedure Specification (WPS) from the WPS qualification requirements of this code.

6. Qualification. This clause contains the requirements for WPS qualification and the performance qualification tests required to be passed by all welding personnel (welders, welding operators, and tack welders) to perform welding in accordance with this code.

7. Fabrication. This clause contains general fabrication and erection requirements applicable to welded steel structures governed by this code, including the requirements for base metals, welding consumables, welding technique, welded details, material preparation and assembly, workmanship, weld repair, and other requirements.

8. Inspection. This clause contains criteria for the qualifications and responsibilities of inspectors, acceptance criteria for production welds, and standard procedures for performing visual inspection and nondestructive testing (NDT).

9. Stud Welding. This clause contains the requirements for the welding of studs to structural steel.

10. Tubular Structures. This clause contains exclusive tubular requirements. Additionally, the requirements of all other clauses apply to tubulars, unless specifically noted otherwise.

11. Strengthening and Repair of Existing Structures. This clause contains basic information pertinent to the welded modification or repair of existing steel structures.

1.2 Standard Units of Measurement

This standard makes use of both U.S. Customary Units and the International System of Units (SI). The latter are shown within brackets ([ ]) or in appropriate columns in tables and figures. The measurements may not be exact equivalents; therefore, each system must be used independently.

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1.3 Safety Precautions

Safety and health issues and concerns are beyond the scope of this standard and therefore are not fully addressed herein. It is the responsibility of the user to establish appropriate safety and health practices. Safety and health information is available from the following sources:

American Welding Society:

(1) ANSI Z49.1, *Safety in Welding, Cutting, and Allied Processes*

(2) AWS Safety and Health Fact Sheets

(3) Other safety and health information on the AWS website

Material or Equipment Manufacturers:

(1) Safety Data Sheets supplied by materials manufacturers

(2) Operating Manuals supplied by equipment manufacturers

Applicable Regulatory Agencies

Work performed in accordance with this standard may involve the use of materials that have been deemed hazardous, and may involve operations or equipment that may cause injury or death. This standard does not purport to address all safety and health risks that may be encountered. The user of this standard should establish an appropriate safety program to address such risks as well as to meet applicable regulatory requirements. ANSI Z49.1 should be considered when developing the safety program.

1.4 Limitations

The code was specifically developed for welded steel structures that utilize carbon or low alloy steels that are 1/8 in [3 mm] or thicker with a minimum specified yield strength of 100 ksi [690 MPa] or less. The code may be suitable to govern structural fabrications outside the scope of the intended purpose. However, the Engineer should evaluate such suitability, and based upon such evaluations, incorporate into contract documents any necessary changes to code requirements to address the specific requirements of the application that is outside the scope of the code. The Structural Welding Committee encourages the Engineer to consider the applicability of other AWS D1 codes for applications involving aluminum (AWS D1.2), sheet steel equal to or less than 3/16 in [5 mm] thick (AWS D1.3), reinforcing steel (AWS D1.4), stainless steel (AWS D1.6), strengthening and repair of existing structures (AWS D1.7), seismic supplement (AWS D1.8), and titanium (AWS D1.9). The AASHTO/AWS D1.5 *Bridge Welding Code* was specifically developed for welding highway bridge components and is recommended for those applications.

1.5 Responsibilities

1.5.1 Engineer's Responsibilities. The Engineer shall be responsible for the development of the contract documents that govern products or structural assemblies produced under this code. The Engineer may add to, delete from, or otherwise modify, the requirements of this code to meet the particular requirements of a specific structure. All requirements that modify this code shall be incorporated into contract documents. The Engineer shall determine the suitability of all joint details to be used in a welded assembly.

The Engineer shall specify in contract documents, as necessary, and as applicable, the following:

(1) Code requirements that are applicable only when specified by the Engineer.

(2) All additional NDT that is not specifically addressed in the code.

(3) Extent of verification inspection, when required.

(4) Weld acceptance criteria other than that specified in Clause 8.

(5) CVN toughness criteria for weld metal, base metal, and/or HAZ when required.

(6) For nontubular applications, whether the structure is statically or cyclically loaded.

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(7) Which welded joints are loaded in tension.

(8) All additional requirements that are not specifically addressed in the code.

(9) For OEM applications, the responsibilities of the parties involved.

1.5.2 Contractor's Responsibilities. The Contractor shall be responsible for WPSs, qualification of welding personnel, the Contractor's inspection, and performing work in conformance with the requirements of this code and contract documents.

1.5.3 Inspector's Responsibilities

1.5.3.1 Contractor Inspection. Contractor inspection shall be supplied by the Contractor and shall be performed as necessary to ensure that materials and workmanship meet the requirements of the contract documents.

1.5.3.2 Verification Inspection. The Engineer shall determine if Verification Inspection shall be performed. Responsibilities for Verification Inspection shall be established between the Engineer and the Verification Inspector.

1.6 Approval

All references to the need for approval shall be interpreted to mean approval by the Authority Having Jurisdiction or the Engineer.

1.7 Mandatory and Nonmandatory Provisions

1.7.1 Code Terms "Shall," "Should," and "May." "Shall," "should," and "may" have the following significance:

1.7.1.1 Shall. Code provisions that use "shall" are mandatory unless specifically modified in contract documents by the Engineer.

1.7.1.2 Should. The word "should" is used to recommend practices that are considered beneficial, but are not requirements.

1.7.1.3 May. The word "may" in a provision allows the use of optional procedures or practices that can be used as an alternative or supplement to code requirements. Those optional procedures that require the Engineer's approval shall either be specified in the contract documents, or require the Engineer's approval. The Contractor may use any option without the Engineer's approval when the code does not specify that the Engineer's approval shall be required.

1.8 Welding Symbols

Welding symbols shall be those shown in AWS A2.4, *Standard Symbols for Welding, Brazing, and Nondestructive Examination*. Special conditions shall be fully explained by added notes or details.

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2. Normative References

The documents listed below are referenced within this publication and are mandatory to the extent specified herein. For undated references, the latest edition of the referenced standard shall apply. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply.

American Welding Society (AWS) Standards:

AWS A2.4, *Standard Symbols for Welding, Brazing, and Nondestructive Examination*

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

AWS A4.3, *Standard Methods for Determination of the Diffusible Hydrogen Content of Martensitic, Bainitic, and Ferritic Steel Weld Metal Produced by Arc Welding*

AWS A5.01M/A5.01:2013 (ISO 14344:2010 MOD), *Procurement Guidelines for Consumables—Welding and Allied Processes—Flux and Gas Shielded Electrical Welding Processes*

AWS A5.1/A5.1M:2012, *Specification for Carbon Steel Electrodes for Shielded Metal Arc Welding*

AWS A5.5/A5.5M:2014, *Specification for Low-Alloy Steel Electrodes for Shielded Metal Arc Welding*

AWS A5.12M/A5.12:2009 (ISO 6848:2004 MOD), *Specification for Tungsten and Oxide Dispersed Tungsten Electrodes for Arc Welding and Cutting*

AWS A5.17/A5.17M-97 (R2007), *Specification for Carbon Steel Electrodes and Fluxes for Submerged Arc Welding*

AWS A5.18/A5.18M:2005, *Specification for Carbon Steel Electrodes and Rods for Gas Shielded Arc Welding*

AWS A5.20/A5.20M:2005, *Specification for Carbon Steel Electrodes for Flux Cored Arc Welding*

AWS A5.23/A5.23M:2011, *Specification for Low-Alloy Steel Electrodes and Fluxes for Submerged Arc Welding*

AWS A5.25/A5.25M-97 (R2009), *Specification for Carbon and Low-Alloy Steel Electrodes and Fluxes for Electroslag Welding*

AWS A5.26/A5.26M-97 (R2009), *Specification for Carbon and Low-Alloy Steel Electrodes for Electrogas Welding*

AWS A5.28/A5.28M:2005, *Specification for Low-Alloy Steel Filler Metals for Gas Shielded Arc Welding*

AWS A5.29/A5.29M:2010, *Specification for Low-Alloy Steel Electrodes for Flux Cored Arc Welding*

AWS A5.30/A5.30M:2007, *Specification for Consumable Inserts*

AWS A5.32M/A5.32:2011 (ISO 14175:2008 MOD), *Welding Consumables—Gases and Gas Mixtures for Fusion Welding and Allied Processes*

AWS A5.36/A5.36M:2012, *Specification for Carbon and Low-Alloy Steel Flux Cored Electrodes for Flux Cored Arc Welding and Metal Cored Electrodes for Gas Metal Arc Welding*

AWS B5.1, *Specification for the Qualification of Welding Inspectors*

AWS B4.0, *Standard Methods for Mechanical Testing of Welds*

AWS C4.1-77 (R2010), *Criteria for Describing Oxygen-Cut Surfaces and Oxygen Cutting Surface Roughness Gauge*

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AWS D1.0, *Code for Welding in Building Construction*

AWS D1.8/D1.8M, *Structural Welding Code—Seismic Supplement*

AWS D2.0, *Specification for Welded Highway and Railway Bridges*

AWS QC1, *Standard for AWS Certification of Welding Inspectors*

ANSI Z49.1, *Safety in Welding, Cutting, and Allied Processes*

American Institute of Steel Construction (AISC) Standards:

ANSI/AISC 360, *Specification for Structural Buildings*

American Petroleum Institute (API) Standards:

API 2W, *Specification for Steel Plates for Offshore Structures, Produced by Thermo-Mechanical Control Processing*

API 2Y, *Specification for Steel Plates, Quenched and- Tempered, for Offshore Structures*

American Society of Mechanical Engineers (ASME) Standards:

ASME *Boiler and Pressure Vessel Code*, Section V, Article 2

ASME B46.1, *Surface Texture (Surface Roughness, Waviness, and Lay)*

American Society for Nondestructive Testing (ASNT) Standards:

ASNT CP–189, *ASNT Standard for Qualification and Certification of Nondestructive Personnel*

ASNT *Recommended Practice No.* SNT-TC-1A, *Personnel Qualification and Certification in Nondestructive Testing*

American Society for Testing and Materials (ASTM) Standards:

All ASTM base metals listed in Table 5.3 and Table 6.9 are found in ASTM 01.04, *Steel—Structural, Reinforcing, Pressure Vessel Railway*, ASTM 01.03, *Steel-Plate, Sheet, Strip, Wire; Stainless Steel Bar*, or ASTM 01.01, *Steel-Piping, Tubing, Fittings*

ASTM A6, *Standard Specification for General Requirements for Rolled Structural Steel Bars, Plates, Shapes, and Sheet Piling*

ASTM A109, *Standard Specification for Steel, Strip, Carbon, (0.25 Maximum Percent), Cold–Rolled*

ASTM A370, *Mechanical Testing of Steel Products*

ASTM A435, *Specification for Straight Beam Ultrasonic Examination of Steel Plates*

ASTM A673, *Specification for Sampling Procedure for Impact Testing of Structural Steel*

ASTM E23, *Standard Methods for Notched Bar Impact Testing of Metallic Materials, for Type A Charpy (Simple Beam) Impact Specimen*

ASTM E92, *Test Method for Vickers Hardness of Metallic Materials*

ASTM E94, *Standard Guide for Radiographic Examination Using Industrial Radiographic Film*

ASTM E140, *Hardness Conversion Tables for Metals*

ASTM E165, *Test Method for Liquid Penetrant Examination*

ASTM E709, *Guide for Magnetic Particle Inspection*

ASTM E747, *Controlling Quality of Radiographic Testing Using Wire Parameters*

ASTM E1032, *Radiographic Examination of Weldments Using Industrial X-Ray Film*

ASTM E1254, *Standard Guide for Storage of Radiographs and Unexposed Industrial Radiographic Films*

ASTM E2033, *Standard Practice for Radiographic Examination using Computed Radiology (Photostimulable Luminescence Method)*

ASTM E2445, *Standard Practice for Performance Evaluation and Long-Term Stability of Computed Radiology Systems*

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ASTM E2698, *Standard Practice for Radiological Examination Using Digital Detector Arrays*

ASTM E2699, *Standard Practice for Digital Imaging and Communication in Nondestructive Evaluation (DICONDE) for Digital Radiographic (DR) Test Methods.*

ASTM E2737, *Standard Practice for Digital Detector Array Performance Evaluation and Long-Term Stability*

Canadian Standards Association (CSA) Standards:

CSA W178.2, *Certification of Welding Inspectors*

International Institute of Welding (IIW) Ultrasonic Reference Block

The Society for Protective Coatings (SSPC) Standards:

SSPC-SP2, *Hand Tool Cleaning*

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3. Terms and Definitions

AWS A3.0M/A3.0, *Standard Welding Terms and Definitions, Including Terms for Adhesive Bonding, Brazing, Soldering, Thermal Cutting, and Thermal Spraying*, provides the basis for terms and definitions used herein. However, the following terms and definitions are included below to accomodate usage specific to this document.

The terms and definitions in this glossary are divided into three categories: (1) general welding terms compiled by the AWS Committee on Definitions and Symbols; (2) terms, defined by the AWS Structural Welding Committee, which apply only to UT, designated by (UT) following the term; and (3) other terms, preceded by asterisks, which are defined as they relate to this code.

For the purposes of this document, the following terms and definitions apply:

A

***alloy flux.** A flux upon which the alloy content of the weld metal is largely dependent.

***all-weld-metal test specimen.** A test specimen with the reduced section composed wholly of weld metal.

***amplitude length rejection level (UT).** The maximum length of discontinuity allowed by various indication ratings associated with weld size, as indicated in Tables 8.2 and 8.3.

***angle of bevel.** See **bevel angle**.

arc gouging. Thermal gouging that uses an arc cutting process variation to form a bevel or groove.

as-welded. The condition of weld metal, welded joints, and weldments after welding, but prior to any subsequent thermal, mechanical, or chemical treatments.

***attenuation (UT).** The loss in acoustic energy which occurs between any two points of travel. This loss may be due to absorption, reflection, etc. (In this code, using the shear wave pulse-echo method of testing, the attenuation factor is 2 dB per inch of sound path distance after the first inch.)

automatic welding. Welding with equipment that requires only occasional or no observation of the welding, and no manual adjustment of the equipment controls. Variations of this term are **automatic brazing, automatic soldering, automatic thermal cutting**, and **automatic thermal spraying**.

***auxiliary attachments.** Members or appurtenances attached to main stress-carrying members by welding. Such members may or may not carry loads.

average instantaneous power (AIP), *waveform-controlled welding*. The average of products of amperages and voltages determined at sampling frequencies sufficient to quantify waveform changes during a welding interval.

axis of a weld. See **weld axis.**

B

backgouging. The removal of weld metal and base metal from the weld root side of a welded joint to facilitate complete fusion and CJP upon subsequent welding from that side.

backing. A material or device placed against the back side of the joint, or at both sides of a weld in ESW and EGW, to support and retain molten weld metal. The material may be partially fused or remain unfused during welding and may be either metal or nonmetal.

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backing pass. A weld pass made for a backing weld.

backing ring. Backing in the form of a ring, generally used in the welding of pipe.

backing weld. Backing in the form of a weld.

***backup weld (tubular structures).** The initial closing pass in a CJP groove weld, made from one side only, which serves as a backing for subsequent welding, but is not considered as a part of the theoretical weld (Figures 10.9 through 10.11, Details C and D).

back weld. A weld made at the back of a single groove weld.

base metal. The metal or alloy that is welded, brazed, soldered, or cut.

bevel angle. The angle between the bevel of a joint member and a plane perpendicular to the surface of the member.

box tubing. Tubular product of square or rectangular cross section. See **tubular**.

***brace intersection angle, θ (tubular structures).** The acute angle formed between brace centerlines.

***Building Code.** The building law or specification or other construction regulations in conjunction with which this code is applied.

NOTE: In the absence of any locally applicable building law or specifications or other construction regulations, it is recommended that the construction be required to comply with the Specification for Structural Steel Buildings (AISC).

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

butt weld. A nonstandard term for a weld in a butt joint. See **butt joint**.

C

***cap pass.** One or more weld passes that form the weld face (exposed surface of completed weld). Adjacent cap passes may partially cover, but not completely cover, a cap pass.

***caulking.** Plastic deformation of weld and base metal surfaces by mechanical means to seal or obscure discontinuities.

complete fusion. Fusion over the entire fusion faces and between all adjoining weld beads.

complete joint penetration (CJP). A joint root condition in a groove weld in which weld metal extends through the joint thickness.

***Computed radiography (CR).**

***CJP groove weld (statically and cyclically loaded structures).** A groove weld which has been made from both sides or from one side on a backing having CJP and fusion of weld and base metal throughout the depth of the joint.

***CJP groove weld (tubular structures).** A groove weld having CJP and fusion of weld and base metal throughout the depth of the joint or as detailed in Figures 10.4 10.7 through 10.11, and 10.19. A CJP tubular groove weld made from one side only, without backing, is allowed where the size or configuration, or both, prevent access to the root side of the weld.

complete penetration. A nonstandard term for **CJP**. See **complete joint penetration**.

construction aid weld. A weld made to attach a piece or pieces to a weldment for temporary use in handling, shipping, or working on the structure.

consumable guide ESW. See **ESW, consumable guide**.

continuous weld. A weld that extends continuously from one end of a joint to the other. Where the joint is essentially circular, it extends completely around the joint.

***contract documents.** Any codes, specifications, drawings, or additional requirements that are contractually specified by the Owner.

***Contractor.** Any company, or that individual representing a company, responsible for the fabrication, erection manufacturing or welding, in conformance with the provisions of this code.

***Contractor's Inspector.** The duly designated person who acts for, and in behalf of, the Contractor on all inspection and quality matters within the scope of the code and of the contract documents.

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corner joint. A joint between two members located approximately at right angles to each other in the form of an L.

***cover pass.** See **cap pass**.

CO_2 welding. A nonstandard term for **GMAW** with carbon dioxide shielding gas.

crater. A depression in the weld face at the termination of a weld bead.

*** Charpy V-notch (CVN).**

D

*** digital detector array (DDA).**

***decibel (dB) (UT).** The logarithmic expression of a ratio of two amplitudes or intensities of acoustic energy.

***decibel rating (UT).** See preferred term **indication rating**.

defect. A discontinuity or discontinuities that by nature or accumulated effect (for example total crack length) render a part or product unable to meet minimum applicable acceptance standards or specifications. This term designates rejectability.

defective weld. A weld containing one or more defects.

***defect level (UT).** See **indication level**.

***defect rating (UT).** See **indication rating**.

depth of fusion. The distance that fusion extends into the base metal or previous bead from the surface melted during welding.

***dihedral angle.** See **local dihedral angle. discontinuity.** An interruption of the typical structure of a material, such as a lack of homogeneity in its mechanical or metallurgical, or physical characteristics. A discontinuity is not necessarily a defect.

downhand. A nonstandard term for **flat welding position**.

***direct radiography (DR).**

***drawings.** Refers to plans design and detail drawings, and erection plans.

E

***edge angle (tubular structures).** The acute angle between a bevel edge made in preparation for welding and a tangent to the member surface, measured locally in a plane perpendicular to the intersection line. All bevels open to outside of brace.

***effective length of weld.** The length throughout which the correctly proportioned cross section of the weld exists. In a curved weld, it shall be measured along the weld axis.

electrogas welding (EGW). An arc welding process that uses an arc between a continuous filler metal electrode and the weld pool, employing approximately vertical welding progression with backing to confine the molten weld metal. The process is used with or without an externally supplied shielding gas and without the application of pressure.

electroslag welding (ESW). A welding process that produces coalescence of metals with molten slag that melts the filler metal and the surfaces of the workpieces. The weld pool is shielded by this slag, which moves along the full cross section of the joint as welding progresses. The process is initiated by an arc that heats the slag. The arc is then extinguished by the conductive slag, which is kept molten by its resistance to electric current passing between the electrode and the workpieces.

ESW, consumable guide. An electroslag welding process variation in which filler metal is supplied by an electrode and its guiding member.

***end return.** The continuation of a fillet weld around a corner of a member as an extension of the principal weld.

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***Engineer.** A duly designated individual who acts for and in behalf of the Owner on all matters within the scope of the code.

F

***fatigue.** Fatigue, as used herein, is defined as the damage that may result in fracture after a sufficient number of stress fluctuations. Stress range is defined as the peak-to-trough magnitude of these fluctuations. In the case of stress reversal, stress range shall be computed as the numerical sum (algebraic difference) of maximum repeated tensile and compressive stresses, or the sum of shearing stresses of opposite direction at a given point, resulting from changing conditions of load.

faying surface. The mating surface of a member that is in contact with or in close proximity to another member to which it is to be joined.

filler metal. The metal or alloy to be added in making a welded, brazed, or soldered joint.

fillet weld leg. The distance from the joint root to the toe of the fillet weld.

fin. A defect in a bar or other rolled section caused by the steel spreading into the clearance between the rolls. This produces a thick overfill which, if rolled again, usually becomes a lap.

flare-bevel-groove weld. A weld in the groove formed between a joint member with a curved surface and another with a planar surface.

***flash.** The material which is expelled or squeezed out of a weld joint and which forms around the weld.

flat welding position. The welding position used to weld from the upper side of the joint at a point where the weld axis is approximately horizontal, and the weld face lies in an approximately horizontal plane.

flux cored arc welding <u>(FCAW).</u> An arc welding process that uses an arc between a continuous filler metal electrode and the weld pool. The process is used with shielding gas from a flux contained within the tubular electrode, with or without additional shielding from an externally supplied gas, and without the application of pressure.

***flux cored are welding—gas shielded <u>(FCAW-G).</u>** A flux cored arc welding process variation in which additional shielding is obtained from an externally supplied gas or gas mixture.

***flux cored arc welding—self shielded <u>(FCAW-S).</u>** A flux cored arc welding process where shielding is exclusively provided by a flux contained within the tubular electrode.

fusion. The melting together of filler metal and base metal (substrate), or of base metal only, to produce a weld.

<u>**fusion line**. The boundary between weld metal and base metal in a fusion weld.</u>

***fusion-type discontinuity.** Signifies slag inclusion, incomplete fusion, incomplete joint penetration, and similar discontinuities associated with fusion.

fusion zone. The area of base metal melted as determined on the cross section of a weld.

G

gas metal arc welding <u>(GMAW).</u> An arc welding process that uses an arc between a continuous filler metal electrode and the weld pool. The process is used with shielding from an externally supplied gas and without the application of pressure.

gas metal arc welding-short circuit arc <u>(GMAW-S).</u> A gas metal arc welding process variation in which the consumable electrode is deposited during repeated short circuits.

gas pocket. A nonstandard term for **porosity**.

Geometric unsharpness U_g). The fuzziness or lack of definition in a radiographic image resulting from the <u>combination</u> of source size, object-to-film distance, and source-to-object distance.

gouging. See **thermal gouging**.

groove angle. The total included angle of the groove between workpieces.

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***groove angle, θ (tubular structures).** The angle between opposing faces of the groove to be filled with weld metals, determined after the joint is fit-up.

groove face. The surface of a joint member included in the groove.

groove weld. A weld made in the groove between the workpieces.

H

heat-affected zone (HAZ). The portion of the base metal whose mechanical properties or microstructure have been altered by the heat of welding, brazing, soldering, or thermal cutting.

horizontal fixed position (pipe welding). The position of a pipe joint in which the axis of the pipe is approximately horizontal, and the pipe is not rotated during welding (see Figures 6.1, 6.2, and 10.12).

horizontal welding position, *fillet weld*. The welding position in which the weld is on the upper side of an approximately horizontal surface and against an approximately vertical surface (see Figures 6.1, 6.2, 6.3, and 6.4).

***horizontal reference line (UT).** A horizontal line near the center of the UT instrument scope to which all echoes are adjusted for dB reading.

horizontal rotated position (pipe welding). The position of a pipe joint in which the axis of the pipe is approximately horizontal, and welding is performed in the flat position by rotating the pipe (see Figures 6.1, 6.2, and 10.12).

***hot-spot strain (tubular structures).** The cyclic total range of strain which would be measured at the point of highest stress concentration in a welded connection.

NOTE: When measuring hot-spot strain, the strain gage should be sufficiently small to avoid averaging high and low strains in the regions of steep gradients.

I

***image quality indicator (IQI).** A device whose image in a radiograph is used to determine RT quality level. It is not intended for use in judging the size nor for establishing acceptance limits of discontinuities.

***indication (UT).** The signal displayed on the oscilloscope signifying the presence of a sound wave reflector in the part being tested.

***indication level (UT).** The calibrated gain or attenuation control reading obtained for a reference line height indication from a discontinuity.

***indication rating (UT).** The decibel reading in relation to the zero reference level after having been corrected for sound attenuation.

intermittent weld. A weld in which the continuity is broken by recurring unwelded spaces.

interpass temperature. In a multipass weld, the temperature of the weld area between weld passes.

J

joint. The junction of members or the edges of members that are to be joined or have been joined.

joint penetration. The distance the weld metal extends from the weld face into a joint, exclusive of weld reinforcement.

joint root. That portion of a joint to be welded where the members approach closest to each other. In cross section, the joint root may be either a point, a line, or an area.

L

lap joint. A joint between two overlapping members in parallel planes.

***layer.** A stratum of weld metal or surfacing material. The layer may consist of one or more weld beads laid side by side.

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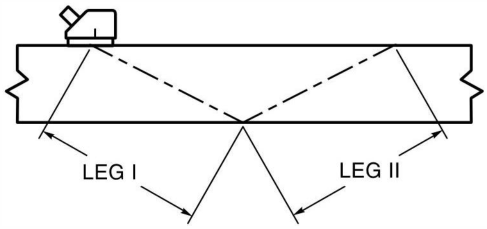
***leg (UT).** The path the shear wave travels in a straight line before being reflected by the surface of material being tested. See sketch for leg identification. Note: Leg I plus leg II equals one V-path.



leg of a fillet weld. See **fillet weld leg.**

***local dihedral angle, θ (tubular structures).** The angle, measured in a plane perpendicular to the line of the weld, between tangents to the outside surfaces of the tubes being joined at the weld. The exterior dihedral angle, where one looks at a localized section of the connection, such that the intersecting surfaces may be treated as planes.

M

manual welding. Welding with the torch, gun or electrode holder held and manipulated by hand. Accessory equipment, such as part motion devices and manually controlled filler material feeders may be used. See **automatic welding, mechanized welding**, and **semiautomatic welding**.

mechanized process (XXXX-ME). An operation with equipment requiring manual adjustment by an operator in response to visual observation, with the torch, gun, wire guide assembly, or electrode holder held by a mechanical device. See **mechanized welding**.

mechanized welding (W-ME). See **mechanized process.**

***Magnetic particle testing (MT).**

N

***nondestructive testing (NDT).** The process of determining acceptability of a material or a component in accordance with established criteria without impairing its future usefulness.

***node (UT).** See **leg**.

***nominal tensile strength of the weld metal.** The tensile strength of the weld metal indicated by the classification number of the filler metal (e.g., nominal tensile strength of E60XX is 60 ksi [420 MPa]).

O

***Original Equipment Manufacturer (OEM).** A single Contractor that assumes some or all of the responsibilities assigned by this code to the Engineer.

overhead welding position. The welding position in which welding is performed from the underside of the joint (see Figures 6.1, 6.2, 6.3, and 6.4).

overlap, *fusion welding*. The protrusion of weld metal beyond the weld toe or weld root.

***Owner.** The individual or company that exercises legal ownership of the product or structural assembly produced to this code.

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

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

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P

***parallel electrode. See SAW.**

partial joint penetration (PJP). Joint penetration that is intentionally less than complete.

pass. See **weld pass**.

peening. The mechanical working of metals using impact blows.

***pipe.** Hollow circular cross section produced or manufactured in accordance with a pipe product specification. See **tubular**.

***piping porosity (ESW and EGW).** Elongated porosity whose major dimension lies in a direction approximately parallel to the weld axis.

***piping porosity (general).** Elongated porosity whose major dimension lies in a direction approximately normal to the weld surface. Frequently referred to as *pin holes* when the porosity extends to the weld surface.

plug weld. A weld made in a circular hole in one member of a joint fusing that member to another member. A fillet-welded hole shall not be construed as conforming to this definition.

porosity. Cavity-type discontinuities formed by gas entrapment during solidification or in a thermal spray deposit.

positioned weld. A weld made in a joint that has been placed to facilitate making the weld.

***postweld heat treatment.** Any heat treatment after welding.

preheating. The application of heat to the base metal immediately before welding, brazing, soldering, thermal spraying, or cutting.

preheat temperature, *welding*. The temperature of the base metal in the volume surrounding the point of welding immediately before welding is started. In a multiple-pass weld, it is also the temperature immediately before the second and subsequent passes are started.

***Liquid penetrant testing (PT).**

***Postweld heat treatment (PWHT).**

Q

qualification. See welder performance qualification and **WPS qualification.**

R

random sequence. A longitudinal sequence in which the weld bead increments are made at random.

***reference level (UT).** The decibel reading obtained for a horizontal reference-line height indication from a reference reflector.

***reference reflector (UT).** The reflector of known geometry contained in the IIW reference block or other approved blocks.

reinforcement of weld. See **weld reinforcement.**

***resolution (UT).** The ability of UT equipment to give separate indications from closely spaced reflectors.

root face. That portion of the groove face within the joint root.

root gap. A nonstandard term for **root opening. root of joint.** See **joint root**.

root of weld. See **weld root.**

root opening. A separation at the joint root between the workpieces.

***Radiographic testing (RT).**

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S

*single electrode. One electrode connected exclusively to one power source which may consist of one or more power units.

*parallel electrode. Two electrodes connected electrically in parallel and exclusively to the same power source. Both electrodes are usually fed by means of a single electrode feeder. Welding current, when specified, is the total for the two.

*multiple electrodes. The combination of two or more single or parallel electrode systems. Each of the component systems has its own independent power source and its own electrode feeder.

***scanning level (UT).** The dB setting used during scanning, as described in Tables 8.2 and 8.3.

semiautomatic welding. Manual welding with equipment that automatically controls one or more of the welding conditions.

***shelf bar.** Steel plates, bars, or similar elements used to support the overflow of excess weld metal deposited in a horizontal groove weld joint.

Shielded metal arc welding (SMAW). An arc welding process with an arc between a covered electrode and the weld pool. The process is used with shielding from the decomposition of the electrode covering, without the application of pressure, and with filler metal from the electrode.

shielding gas. Protective gas used to prevent or reduce atmospheric contamination.

single-welded joint. A joint that is welded from one side only.

size of weld. See **weld size**.

slot weld. A weld made in an elongated hole in one member of a joint fusing that member to another member. The hole may be open at one end. A fillet welded slot shall not be construed as conforming to this definition.

***sound beam distance (UT).** See **sound path distance.**

***sound path distance (UT).** The distance between the search unit test material interface and the reflector as measured along the centerline of the sound beam.

***storage phosphor imaging plate (SPIP).**

spatter. The metal particles expelled during fusion welding that do not form a part of the weld.

stringer bead. A type of weld bead made without appreciable weaving motion.

***stud base.** The stud tip at the welding end, including flux and container, and 1/8 in [3 mm] of the body of the stud adjacent to the tip.

***stud welding (SW).** An arc welding process that produces coalescence of metals by heating them with an arc between a metal stud, or similar part, and the other workpiece. When the surfaces to be joined are properly heated, they are brought together under pressure. Partial shielding may be obtained by the use of a ceramic ferrule surrounding the stud. Shielding gas or flux may or may not be used.

Submerged arc welding (SAW). An arc welding process that uses an arc or arcs between a bare metal electrode or electrodes and the weld pool. The arc and molten metal are shielded by a blanket of granular flux on the workpieces. The process is used without pressure and with filler metal from the electrode and sometimes from a supplemental source (welding rod, flux, or metal granules).

T

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

***tack welder.** A fitter, or someone under the direction of a fitter, who tack welds parts of a weldment to hold them in proper alignment until the final welds are made.

***tandem.** Refers to a geometrical arrangement of electrodes in which a line through the arcs is parallel to the direction of welding.

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thermal gouging. A thermal cutting process variation that removes metal by melting or burning the entire removed portion, to form a bevel or groove.

throat of a fillet weld.

actual throat. The shortest distance between the weld root and the face of a fillet weld.

theoretical throat. The distance from the beginning of the joint root perpendicular to the hypotenuse of the largest right triangle that can be inscribed within the cross section of a fillet weld. This dimension is based on the assumption that the root opening is equal to zero.

throat of a groove weld. A nonstandard term for **groove weld size.**

T-joint. A joint between two members located approximately at right angles to each other in the form of a T.

toe of weld. See **weld toe.**

***transverse discontinuity.** A weld discontinuity whose major dimension is in a direction perpendicular to the weld axis "X," see Annex P, Form P-11.

total instantaneous energy (TIE), *waveform-controlled welding.* The sum of products of amperages, voltages and time intervals determined at sampling frequencies sufficient to quantify waveform changes during a welding interval.

***tubular.** A generic term that refers to sections including pipe products (see **pipe**) and the family of square, rectangular, and round hollow-section products produced or manufactured in accordance with a tubular product specification. Also referred to as hollow structural section (HSS).

***tubular connection.** A connection in the portion of a structure that contains two or more intersecting members, at least one of which is a tubular member.

***tubular joint.** A joint in the interface created by a tubular member intersecting another member (which may or may not be tubular).

U

***unacceptable discontinuity**. See **defect.**

undercut. A groove melted into the base metal adjacent to the weld toe or weld root and left unfilled by weld metal.

***Ultrasonic testing (UT).**

V

***Verification Inspector.** The duly designated person who acts for, and in behalf of, the Owner on all inspection and quality matters designated by the Engineer.

vertical welding position. The welding position in which the weld axis, at the point of welding, is approximately vertical, and the weld face lies in an approximately vertical plane (see Figures 6.1, 6.2, 6.3, and 6.4).

***vertical position (pipe welding).** The position of a pipe joint in which welding is performed in the horizontal position and the pipe is not rotated during welding (see Figures 6.1, 6.2, and 10.12).

***V-path (UT).** The distance a shear wave sound beam travels from the search unit test material interface to the other face of the test material and back to the original surface.

W

weave bead. A type of weld bead made with transverse oscillation.

weld. A localized coalescence of metals or nonmetals produced by heating the materials to the welding temperature, with or without the application of pressure or by the applications of pressure alone and with or without the use of filler material.

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weldability. The capacity of a material to be welded under the imposed fabrication conditions into a specific, suitably designed structure and to perform satisfactorily in the intended service.

weld axis. A line through the length of a weld, perpendicular to and at the geometric center of its cross section.

weld bead. A weld resulting from a pass. See **stringer bead** and **weave bead**.

welder. One who performs a manual or semiautomatic welding operation.

welder certification. Written certification that a welder has produced welds meeting a prescribed standard of welder performance.

welder performance qualification. The demonstration of a welder's ability to produce welds meeting prescribed standards.

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

welding. A joining process that produces coalescence of materials by heating them to the welding temperature, with or without the application of pressure or by the application of pressure alone, and with or without the use of filler metal. See also the Master Chart of Welding and Allied Processes in the latest edition of AWS A3.0.

welding machine. Equipment used to perform the welding operation. For example, spot welding machine, arc welding machine, and seam welding machine.

welding operator. One who operates adaptive control, automatic, mechanized, or robotic welding equipment.

welding sequence. The order of making the welds in a weldment.

weld pass. A single progression of welding along a joint. The result of a pass is a weld bead or layer.

weld reinforcement. Weld metal in excess of the quantity required to fill a joint.

weld root. The points, as shown in cross section, at which the root surface intersects the base metal surfaces.

weld size.

fillet weld size. For equal leg fillet welds, the leg lengths of the largest isosceles right triangle that can be inscribed within the fillet weld cross section. For unequal leg fillet welds, the leg lengths of the largest right triangle that can be inscribed within the fillet weld cross section.

NOTE: When one member makes an angle with the other member greater than 105°, the leg length (size) is of less significance than the effective throat, which is the controlling factor for the strength of the weld.

groove weld size. The joint penetration of a groove weld.

weld tab. Additional material that extends beyond either end of the joint, on which the weld is started or terminated.

weld toe. The junction of the weld face and the base metal.

weldment. An assembly whose component parts are joined by welding.

WPS qualification. The demonstration that welds made by a specific procedure can meet prescribed standards.

***welding procedure specification (WPS).** A document providing the detailed methods and practices involved in the production of a weldment.

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4. Design of Welded Connections

4.1 Scope

This clause contains requirements for design of welded connections. It is divided into three parts as follows:

Part A—Common Requirements for Design of Welded Connections (Nontubular and Tubular Members)

Part B—Specific Requirements for Design of Nontubular Connections (Statically or Cyclically Loaded). The requirements shall apply in addition to the requirements of Part A.

Part C—Specific Requirements for Design of Nontubular Connections (Cyclically Loaded). When applicable, the requirements shall apply in addition to the requirements of Parts A and B.

Part A
Common Requirements for Design of Welded Connections (Nontubular and Tubular Members)

4.2 General

This part contains requirements applicable to the design of all welded connections of nontubular and tubular structures, independent of loading.

4.3 Contract Plans and Specifications

4.3.1 Plan and Drawing Information. Complete information regarding base metal specification designation (see 5.3 and 6.8.3) and location, type, size, and extent of all welds shall be clearly shown on the contract plans and specifications, hereinafter referred to as the contract documents. If the Engineer requires specific welds to be performed in the field, they shall be designated in the contract documents. The fabrication and erection drawings, hereinafter referred to as the shop drawings, shall clearly distinguish between shop and field welds.

4.3.2 Notch Toughness Requirements. If notch toughness of welded joints is required, the Engineer shall specify the minimum absorbed energy with the corresponding test temperature for the filler metal classification to be used, or the Engineer shall specify that the WPSs be qualified with CVN tests. If WPSs with CVN tests are required, the Engineer shall specify the minimum absorbed energy, the test temperature and whether the required CVN test performance is to be in the weld metal, or both in the weld metal and the HAZ (see 6.2.1.3 and Clause 6, Part D).

4.3.3 Specific Welding Requirements. The Engineer, in the contract documents, and the Contractor, in the shop drawings, shall indicate those joints or groups of joints in which the Engineer or Contractor require a specific assembly order, welding sequence, welding technique or other special precautions. See 7.4.1 and C-7.4.1 for limitations on the application of ESW and EGW welding.

4.3.4 Weld Size and Length. Contract design drawings shall specify the effective weld length and, for PJP groove welds, the required weld size "(S)." For fillet welds and skewed T-joints, the following shall be provided on the contract documents.

(1) For fillet welds between parts with surfaces meeting at an angle between 80° and 100°, contract documents shall specify the fillet weld leg size.

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(2) For welds between parts with the surfaces meeting at an angle less than 80° or greater than 100°, the contract documents shall specify the effective throat.

End returns and hold-backs for fillet welds, if required by design, shall be indicated on the contract documents.

4.3.5 Shop Drawing Requirements. Shop drawings shall clearly indicate by welding symbols or sketches the details of groove welded joints and the preparation of base metal required to make them. Both width and thickness of steel backing shall be detailed.

4.3.5.1 PJP Groove Welds. Shop drawings shall indicate the weld groove depths "D" needed to attain weld size "(S)" required for the welding process and position of welding to be used.

4.3.5.2 Fillet Welds and Welds in Skewed T-Joints.

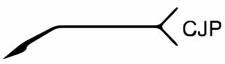
The following shall be provided on the shop drawings:

(1) For fillet welds between parts with surfaces meeting at an angle between 80° and 100°, shop drawings shall show the fillet weld leg size,

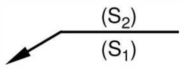
(2) For welds between parts with surfaces meeting at an angle less than 80° or greater than 100°, the shop drawings shall show the detailed arrangement of welds and required leg size to account for effects of joint geometry and, where appropriate, the Z-loss reduction for the process to be used and the angle,

(3) End returns and hold-backs.

4.3.5.3 Welding Symbols. The contract documents shall show CJP or PJP groove weld requirements. Contract documents do not need to show groove type or groove dimensions. The welding symbol without dimensions and with "CJP" in the tail designates a CJP weld as follows:



The welding symbol without dimension and without CJP in the tail designates a weld that will develop the adjacent base metal strength in tension and shear. A welding symbol for a PJP groove weld shall show dimensions enclosed in parentheses below "(S_1)" and/or above "(S_2)" the reference line to indicate the groove weld sizes on the arrow and other sides of the weld joint, respectively, as shown below:



4.3.5.4 Prequalified Detail Dimensions. The joint details described in 5.4.2 and 10.9 (PJP) and 5.4.1 and 10.10 (CJP) have repeatedly demonstrated their adequacy in providing the conditions and clearances necessary for depositing and fusing sound weld metal to base metal. However, the use of these details shall not be interpreted as implying consideration of the effects of welding process on base metal beyond the fusion boundary nor suitability of the joint detail for a given application.

4.3.5.5 Special Details. When special groove details are required, they shall be detailed in the contract documents.

4.3.5.6 Specific Inspection Requirements. Any specific inspection requirements shall be noted on the contract documents.

4.4 Effective Areas

4.4.1 Groove Welds

4.4.1.1 Effective Length. The maximum effective weld length of any groove weld, regardless of orientation, shall be the width of the part joined, perpendicular to the direction of tensile or compressive stress. For groove welds transmitting shear, the effective length is the length specified.

4.4.1.2 Effective Size of CJP Groove Welds. The weld size of a CJP groove weld shall be the thickness of the thinner part joined. An increase in the effective area for design calculations for weld reinforcement shall be prohibited. Groove weld sizes for T-, Y-, and K-connections in tubular construction are shown in Table 10.7.

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4.4.1.3 Minimum Size of PJP Groove Welds. PJP groove welds shall be equal to or greater than the size "(S)" specified in 5.4.2.3(1) unless the WPS is qualified in conformance with Clause 6.

4.4.1.4 Effective Size of Flare-Groove Welds. The effective size of flare-groove welds when filled flush shall be as shown in Table 4.1, except as allowed by 6.12.4. For flare-groove welds not filled flush, the underfill U shall be deducted. For flare-V-groove welds to surfaces with different radii R, the smaller R shall be used. For flare-groove welds to rectangular tubular sections, R shall be taken as two times the wall thickness.

4.4.1.5 Effective Area of Groove Welds. The effective area of groove welds shall be the effective length multiplied by the effective weld size.

4.4.2 Fillet Welds

4.4.2.1 Effective Length (Straight). The effective length of a straight fillet weld shall be the overall length of the full size fillet, including end returns. No reduction in effective length shall be assumed in design calculations to allow for the start or stop crater of the weld.

4.4.2.2 Effective Length (Curved). The effective length of a curved fillet weld shall be measured along the centerline of the effective throat.

4.4.2.3 Minimum Length. The minimum length of a fillet weld shall be at least four times the nominal size, or the effective size of the weld shall be considered not to exceed 25% of its effective length.

4.4.2.4 Intermittent Fillet Welds (Minimum Length). The minimum length of segments of an intermittent fillet weld shall be 1-1/2 in [38 mm].

4.4.2.5 Maximum Effective Length. For end-loaded fillet welds with a length up to 100 times the leg dimension, it is allowed to take the effective length equal to the actual length. When the length of end-loaded fillet welds exceeds 100 but not more than 300 times the weld size, the effective length shall be determined by multiplying the actual length by the reduction coefficient β.

$$\beta = 1.2 - 0.2\left(\frac{L}{100w}\right) \leq 1.0$$

where

β = reduction coefficient
L = actual length of end-loaded weld, in [mm]
w = weld leg size, in [mm]

When the length exceeds 300 times the leg size, the effective length shall be taken as 180 times the leg size.

4.4.2.6 Calculation of Effective Throat. For fillet welds between parts meeting at angles between 80° and 100° the effective throat shall be taken as the shortest distance from the joint root to the weld face of a 90° diagrammatic weld (see Figure 4.1). For welds in acute angles between 60° and 80° and for welds in obtuse angles greater than 100°, the weld leg size required to provide the specified effective throat shall be calculated to account for geometry (see Annex A). For welds in acute angles between 60° and 30°, leg size shall be increased by the Z loss dimension to account for the uncertainty of sound weld metal in the root pass of the narrow angle for the welding process to be used (see 4.4.3).

4.4.2.7 Reinforcing Fillet Welds. The effective throat of a combination PJP bevel groove weld and a fillet weld shall be the shortest distance from the joint root to the weld face of the diagrammatic weld minus 1/8 in [3 mm] for any groove detail requiring such deduction (see Figures 4.2, 4.3, 4.4 and 5.2).

The effective throat of a combination of PJP flare bevel groove weld and a fillet weld shall be the shortest distance from the joint root to the weld face of the diagrammatic weld minus the deduction for incomplete joint penetration (see Table 4.1, Figures 4.5, 4.6 and 5.2).

4.4.2.8 Minimum Size. The minimum size fillet weld shall not be smaller than the size required to transmit the applied load nor that provided in 7.13.

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4.4.2.9 Maximum Weld Size in Lap Joints. The maximum fillet weld size detailed along the edges of base metal in lap joints shall be the following:

(1) the thickness of the base metal, for metal less than 1/4 in [6 mm] thick (see Figure 4.7, Detail A).

(2) 1/16 in [2 mm] less than the thickness of the base metal, for metal 1/4 in [6 mm] or more in thickness (see Figure 4.7, Detail B), unless the weld is designated on the shop drawing to be built out to obtain full throat thickness for a leg size equal to the base metal thickness. In the as-welded condition, the distance between the edge of the base metal and the toe of the weld may be less than 1/16 in [2 mm] provided the weld size is clearly verifiable.

4.4.2.10 Effective Area. The effective area shall be the effective weld length multiplied by the effective throat.

4.4.3 Skewed T-Joints

4.4.3.1 General. T-joints in which the angle between joined parts is greater than 100° or less than 80° shall be defined as skewed T-joints. Prequalified skewed T-joint details are shown in Figure 5.4. The details of joints for the obtuse and acute sides may be used together or independently depending upon service conditions and design with proper consideration for effects of eccentricity.

4.4.3.2 Welds in Acute Angles Between 80° and 60° and in Obtuse Angles Greater than 100°. When welds are deposited in angles between 80° and 60° or in angles greater than 100° the contract documents shall specify the required effective throat. The shop drawings shall clearly show the placement of welds and the required leg dimensions to satisfy the required effective throat (see Annex A).

4.4.3.3 Welds in Angles Between 60° and 30°. When welding is required in an acute angle that is less than 60° but equal to or greater than 30° [Figure 5.4(D)], the effective throat shall be increased by the Z-loss allowance (Table 4.2). The contract documents shall specify the required effective throat. The shop drawings shall show the required leg dimensions to satisfy the required effective throat, increased by the Z-loss allowance (Table 4.2) (see Annex A for calculation of effective throat).

4.4.3.4 Welds in Angles Less than 30°. Welds deposited in acute angles less than 30° shall not be considered as effective in transmitting applied forces except as modified for tubular structures in 10.14.4.2.

4.4.3.5 Effective Length. The effective length of skewed T-joints shall be the overall length of the full size weld. No reduction shall be assumed in design calculations to allow for the start or stop of the weld.

4.4.3.6 Minimum Weld Size. The requirements of 4.4.2.8 shall apply.

4.4.3.7 Effective Throat. The effective throat of a skewed T-joint in angles between 60° and 30° shall be the minimum distance from the root to the diagrammatic face, less the Z loss reduction dimension. The effective throat of a skewed T-joint in angles between 80° and 60° and in angles greater than 100° shall be taken as the shortest distance from the joint root to the weld face.

4.4.3.8 Effective Area. The effective area of skewed T-joints shall be the specified effective throat multiplied by the effective length.

4.4.4 Fillet Welds in Holes and Slots

4.4.4.1 Diameter and Width Limitations. The minimum diameter of the hole or the width of slot in which a fillet weld is to be deposited shall be no less than the thickness of the part in which it is made plus 5/16 in [8 mm].

4.4.4.2 Slot Ends. Except for those ends which extend to the edge of the part, the ends of the slot shall be semicircular or shall have the corners rounded to a radius not less than the thickness of the part in which it is made.

4.4.4.3 Effective Length. For fillet welds in holes or slots, the effective length shall be the length of the weld along the centerline of the throat.

4.4.4.4 Effective Area. The effective area shall be the effective length multiplied by the effective throat. In the case of fillet welds of such size that they overlap at the centerline when deposited in holes or slots, the effective area shall not be taken as greater than the cross-sectional area of the hole or slot in the plane of the faying surface.

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4.4.5 Plug and Slot Welds

4.4.5.1 Diameter and Width Limitations. The minimum diameter of the hole or the width of slot in which a plug or slot weld is to be deposited shall be no less than the thickness of the part in which it is made plus 5/16 in [8 mm.]. The maximum diameter of the hole or width of slot shall not exceed the minimum diameter plus 1/8 in [3 mm] or 2-1/4 times the thickness of the part, whichever is greater.

4.4.5.2 Slot Length and Shape. The length of the slot in which slot welds are to be deposited shall not exceed ten times the thickness of the part in which it is made. The ends of the slot shall be semicircular or shall have the corners rounded to a radius not less than the thickness of the part in which it is made.

4.4.5.3 Effective Area. The effective area of plug and slot welds shall be the nominal area of the hole or slot in the plane of the faying surface.

4.4.5.4 Minimum Depth of Filling. The minimum depth of filling of plug and slot welds shall meet the following requirements:

(1) for slot or plug welds in material 5/8 in [16 mm] thick or less, the thickness of the material.

(2) for slot or plug welds in materials over 5/8 in [16 mm] thick, one-half the thickness of the material or 5/8 in [16 mm], whichever is greater.

In no case is the minimum depth of filling required to be greater than the thickness of the thinner part being joined.

Part B
Specific Requirements for Design of Nontubular Connections (Statically or Cyclically Loaded)

4.5 General

The specific requirements of Part B together with the requirements of Part A shall apply to all connections of nontubular members subject to static loading. The requirements of Parts A and B, except as modified by Part C, shall also apply to cyclic loading.

4.6 Stresses

4.6.1 Calculated Stresses. The calculated stresses to be compared with the allowable stresses shall be nominal stresses determined by appropriate analysis or stresses determined from the minimum joint strength requirements that may be specified in the applicable design specifications which invoke this code for design of welded connections.

4.6.2 Calculated Stresses Due to Eccentricity. In the design of welded joints, the calculated stresses to be compared with allowable stresses, shall include those due to design eccentricity, if any, in alignment of connected parts and the position, size and type of welds, except as provided in the following:

For statically loaded structures, the location of fillet welds to balance the forces about the neutral axis or axes for end connections of single-angle, double-angle, and similar members is not required. In such members, weld arrangements at the heel and toe of angle members may be distributed to conform to the length of the various available edges.

4.6.3 Allowable Base Metal Stresses. The calculated base metal stresses shall not exceed the allowable stresses specified in the applicable design specifications.

4.6.4 Allowable Weld Metal Stresses. The calculated stresses on the effective area of welded joints shall not exceed the allowable stresses given in Table 4.3 except as allowed by 4.6.4.2, 4.6.4.3, and 4.6.4.4. The use of 4.6.4.2 shall be limited to the analysis of a single linear fillet weld or fillet weld groups consisting of parallel linear fillet welds all loaded at the same angle.

4.6.4.1 Stress in Fillet Welds. Stress in fillet welds shall be considered as shear applied to the effective area for any direction of applied load.

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4.6.4.2 Alternative Allowable Fillet Weld Stress. For a single linear fillet weld or fillet weld groups consisting of parallel linear fillet welds all loaded at the same angle and loaded in plane through the centroid of the weld group, the allowable stress may be determined by Formula (1):

Formula (1)

$F_v = 0.30\ F_{EXX}\ (1.0 + 0.50\ \sin^{1.5}\Theta)$

where

F_v = allowable unit stress
F_{EXX} = electrode classification number, i.e., electrode strength classification
Θ = angle between the direction of force and the axis of the weld element, degrees

4.6.4.3 Instantaneous Center of Rotation. The allowable stresses in weld elements within a weld group that are loaded in-plane and analyzed using an instantaneous center of rotation method to maintain deformation compatibility and the nonlinear load-deformation behavior of variable angle loaded welds shall be the following:

$F_{vx} = \Sigma\ F_{vix}$
$F_{vy} = \Sigma\ F_{viy}$
$F_{vi} = 0.30\ F_{EXX}\ (1.0 + 0.50\ \sin^{1.5}\Theta)\ F(\rho)$
$F(\rho) = [\rho\ (1.9 - 0.9\rho)]^{0.3}$
$M = \Sigma\ [F_{viy}\ (x) - F_{vix}\ (y)]$

where

F_{vx} = Total internal force in x direction
F_{vy} = Total internal force in y direction
F_{vix} = x component of stress F_{vi}
F_{viy} = y component of stress F_{vi}
M = Moment of internal forces about the instantaneous center of rotation
ρ = Δ_i/Δ_m ratio of element "i" deformation to deformation in element at maximum stress
Δ_m = $0.209\ (\Theta + 6)^{-0.32}$ W, deformation of weld element at maximum stress, in [mm]
Δ_u = $1.087\ (\Theta + 6)^{-0.65}$ W, <0.17 W, deformation of weld element at ultimate stress (fracture), usually in element furthest from the instantaneous center of rotation, in [mm]
W = leg size of the fillet weld, in [mm]
Δ_i = deformation of weld elements at intermediate stress levels, linearly proportioned to the critical deformation based on distance from instantaneous center of rotation, in [mm] = $r_i\Delta_u/r_{crit.}$
x = x_i component of r_i
y = y_i component of r_i
$r_{crit.}$ = distance from instantaneous center of rotation to weld element with minimum Δ_u/r_i ratio, in [mm]

4.6.4.4 Concentrically Loaded Weld Groups. Alternatively, for the special case of a concentrically loaded weld group, the allowable shear stress for each weld element may be determined using Formula (2) and the allowable loads of all elements calculated and added.

Formula (2) $F_v = 0.30\ C\ F_{EXX}$

where
F_v = allowable unit stress
F_{EXX} = nominal tensile strength of filler metal
C = the equivalent strength coefficient for obliquely loaded fillet weld, chosen from Table 4.4.

4.6.5 Allowable Stress Increase. Where the applicable design specifications allow the use of increased stresses in the base metal for any reason, a corresponding increase shall be applied to the allowable stresses given herein but not to the stress ranges allowed for base metal or weld metal subject to cyclic loading.

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4.7 Joint Configuration and Details

4.7.1 General Considerations. Welded connections shall be designed to satisfy the strength and stiffness or flexibility requirements of the general invoking specifications.

4.7.2 Compression Member Connections and Splices

4.7.2.1 Connections and Splices Designed to Bear Other than Connections to Base Plates. Unless otherwise specified in contract documents, column splices which are finished to bear shall be connected by PJP groove welds or by fillet welds sufficient to hold the parts in place. Where compression members other than columns are finished to bear at splices or connections welds shall be designed to hold all parts in alignment and shall be proportioned for 50% of the force in the member. The requirements of Table 5.5 or Table 7.7 shall apply.

4.7.2.2 Connections and Splices Not Finished to Bear Except for Connections to Base Plates. Welds joining splices in columns and splices and connections in other compression members which are not finished to bear, shall be designed to transmit the force in the members, unless CJP welds or more restrictive requirements are specified in contract documents or governing specifications. The requirements of Table 5.5 or Table 7.7 shall apply.

4.7.2.3 Connections to Base Plates. At base plates of columns and other compression members, the connection shall be adequate to hold the members securely in place.

4.7.3 Base Metal Through-Thickness Loading. T and corner joints whose function is to transmit stress normal to the surface of a connected part, especially when the base metal thickness of the branch member or the required weld size is 3/4 in [20 mm] or greater, shall be given special attention during design, base metal selection and detailing. Joint details which minimize stress intensity on base metal subject to stress in the through-thickness direction shall be used where practical. Specifying weld sizes larger than necessary to transmit calculated stress shall be avoided.

4.7.4 Combinations of Welds. Except as provided herein, if two or more welds of different type (groove, fillet, plug, slot) are combined to share the load in a single connection, the capacity of the connection shall be calculated as the sum of the individual welds determined relative to the direction of applied load. This method of adding individual capacities of welds does not apply to fillet welds reinforcing PJP groove welds (see Figures 4.3, 4.4, and 4.6).

4.7.5 Butt, Corner, and T-Joint Surface Contouring. Fillet welds may be applied over CJP and PJP groove welds in butt joints joining parts of unequal width or thickness, corner, and T-joints for the purpose of contouring weld face or to reduce stress concentrations. When such surface contouring fillet welds are used in statically loaded applications, the size need not be more than 5/16 in [8 mm]. The fillet-like reinforcement on the surface of T and corner joint groove welds that naturally occurs shall not be cause for rejection nor need it be removed provided it does not interfere with other elements of the construction. No minimum contour radius need be provided.

4.7.6 Weld Access Holes. When weld access holes are required, they shall be sized to provide clearances necessary for deposition of sound weld metal. The shape and size requirements of 7.16.1 shall apply. The designer and detailer shall recognize that holes of the minimum required size may affect the maximum net area available in the connected base metal.

4.7.7 Welds with Rivets or Bolts. Connections that are welded to one member and bolted or riveted to the other shall be allowed. When bolts and welds share the load on a common faying surface, strain compatibility between the bolts and welds shall be considered (see commentary).

4.8 Joint Configuration and Details—Groove Welds

4.8.1 Transitions in Thicknesses and Widths. For statically loaded structures, surface contouring fillet welds need not be provided. When surface contouring fillet welds are required by the Engineer, they shall be specified in the contract documents (see Figure 4.8).

4.8.2 Partial Length CJP Groove Weld Prohibition. Intermittent or partial length CJP groove welds shall be prohibited except that members built-up of elements connected by fillet welds may have groove welds of limited length at points of localized load application to participate in the transfer of localized load. The groove weld shall extend at uniform size for at least the length required to transfer the load. Beyond this length, the groove shall be made with a transition in depth to zero over a distance not less than four times its depth. The groove shall be filled flush before application of the fillet weld.

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4.8.3 Intermittent PJP Groove Welds. Intermittent PJP groove welds, flare bevel, and flare-groove welds may be used to transfer shear stress between connected parts.

4.8.4 Weld Tab Removal. For statically loaded nontubular structures, weld tabs need not be removed. When removal is required, or when finishing to surface requirements other than that described by 7.14.8, the requirements shall be specified in the contract documents.

4.9 Joint Configuration and Details—Fillet Welded Joints

4.9.1 Lap Joints

4.9.1.1 Transverse Fillet Welds. Transverse fillet welds in lap joints transferring stress between axially loaded parts shall be double-fillet welded (see Figure 4.9) except where deflection of the joint is sufficiently restrained to prevent opening under load.

4.9.1.2 Minimum Overlap. The minimum overlap of parts in stress-carrying lap joints shall be five times the thickness of the thinner part, but not less than 1 in [25 mm]. Unless out-of-plane deflection of the parts is prevented, they shall be double fillet welded (see Figure 4.9) or joined by at least two transverse lines of plug or slot welds or two or more longitudinal fillet or slot welds.

4.9.2 Longitudinal Fillet Welds. If longitudinal fillet welds are used alone in lap joints of end connections of flat bar or plate members, the length of each fillet weld shall be no less than the perpendicular distance between them (see Figure 4.10). The transverse spacing of longitudinal fillet welds used in end connections shall not exceed 16 times the thickness of the thinner connected part unless suitable provision is made (as by intermediate plug or slot welds) to prevent buckling or separation of the parts. The longitudinal fillet welds may be either at the edges of the member or in slots. The design of connections using longitudinal fillet welds for members other than flat bar cross sections shall be as provided in the general design specifications.

4.9.3 Fillet Weld Terminations

4.9.3.1 General. Fillet weld terminations may extend to the ends or sides of parts or may be stopped short or may have end returns except as limited by the following cases:

4.9.3.2 Lap Joints Subject to Tension. In lap joints in which one part extends beyond the edge or side of a part subject to calculated tensile stress, fillet welds shall terminate not less than the size of the weld from the start of the extension (see Figure 4.11).

4.9.3.3 Maximum End Return Length. Welded joints shall be arranged to allow the flexibility assumed in the connection design. If the outstanding legs of connection base metal are attached with end returned welds, the length of the end return shall not exceed four times the nominal size of the weld (see Figure 4.12 for examples of flexible connections).

4.9.3.4 Transverse Stiffener Welds. Except where the ends of stiffeners are welded to the flange, fillet welds joining transverse stiffeners to girder webs shall start or terminate not less than four times nor more than six times the thickness of the web from the web toe of the web-to-flange welds.

4.9.3.5 Opposite Sides of a Common Plane. Fillet welds on the opposite sides of a common plane shall be interrupted at the corner common to both welds (see Figure 4.13), except as follows:

When joints are required to be sealed, or when a continuous weld is needed for other reasons, the contract documents shall specify where these welds are required to be continuous.

4.9.4 Fillet Welds in Holes or Slots. Fillet welds in holes or slots in lap joints may be used to transfer shear or to prevent buckling or separation of lapped parts. Minimum spacing and dimensions of holes or slots for fillet welds shall conform to the requirements of 4.4.4.1, 4.4.4.2, 4.9.1, 4.9.2, and 4.10. These fillet welds may overlap subject to the limitation provisions of 4.4.4.4. Fillet welds in holes or slots are not considered to be plug or slot welds.

4.9.5 Intermittent Fillet Welds. Intermittent fillet welds may be used to transfer stress between connected parts.

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4.10 Joint Configuration and Details—Plug and Slot Welds

4.10.1 Minimum Spacing (Plug Welds). The minimum center-to-center spacing of plug welds shall be four times the diameter of the hole.

4.10.2 Minimum Spacing (Slot Welds). The minimum center-to-center spacing of lines of slot welds in a direction transverse to their length shall be four times the width of the slot. The minimum center-to-center spacing in a longitudinal direction shall be two times the length of the slot.

4.10.3 Prequalified Dimensions. Dimensions for prequalified plug and slot welds are described in 4.4.5 and 5.4.4.

4.10.4 Prohibition in Quenched and Tempered Steels. Plug and slot welds shall be prohibited in quenched and tempered steels with specified minimum F_y greater than 70 ksi [490 MPa].

4.11 Filler Plates

Wherever it is necessary to use filler plates in joints required to transfer applied force, the filler plates and the connecting welds shall conform to the requirements of 4.11.1 or 4.11.2, as applicable.

4.11.1 Thin Filler Plates. Filler plates less than 1/4 in [6 mm] thick shall not be used to transfer stress. When the thickness of the filler plate is less than 1/4 in [6 mm], or when the thickness of the filler plate is greater than 1/4 in [6 mm] but not adequate to transfer the applied force between the connected parts, the filler plate shall be kept flush with the edge of the outside connected part, and the size of the weld shall be increased over the required size by an amount equal to the thickness of the filler plate (see Figure 4.14).

4.11.2 Thick Filler Plates. When the thickness of the filler plate is adequate to transfer the applied force between the connected parts, the filler plate shall extend beyond the edges of the outside connected base metal. The welds joining the outside connected base metal to the filler plate shall be sufficient to transmit the force to the filler plate, and the area subject to applied force in the filler plate shall be adequate to avoid overstressing the filler plate. The welds joining filler plate to the inside connected base metal shall be sufficient to transmit the applied force (see Figure 4.15).

4.11.3 Shop Drawing Requirement. Joints requiring filler plates shall be completely detailed on shop and erection drawings.

4.12 Built-Up Members

4.12.1 Minimum Required Welding. If two or more plates or rolled shapes are used to build up a member, sufficient welding (fillet, plug, or slot type) shall be provided to make the parts act in unison but not less than that which may be required to transmit the calculated stress between the parts joined.

4.12.2 Maximum Spacing of Intermittent Welds

4.12.2.1 General. Except as may be provided by 4.12.2.2 or 4.12.2.3, the maximum longitudinal spacing of intermittent welds connecting a plate component to other components shall not exceed 24 times the thickness of the thinner plate nor exceed 12 in [300 mm]. The longitudinal spacing between intermittent fillet welds connecting two or more rolled shapes shall not exceed 24 in [600 mm].

4.12.2.2 Compression Members. In built-up compression members, except as provided in 4.12.2.3, the longitudinal spacing of intermittent fillet weld segments along the edges of an outside plate component to other components shall not exceed 12 in [300 mm] nor the plate thickness times $0.730\sqrt{E/Fy}$ (Fy = specified minimum yield strength and E is Young's modulus of elasticity for the type of steel being used.) When intermittent fillet weld segments are staggered along opposite edges of outside plate components narrower than the width provided by the next sentence, the spacing shall not exceed 18 in [460 mm] nor the plate thickness times $1.10\sqrt{E/Fy}$. The unsupported width of web, cover plate, or diaphragm plates, between adjacent lines of welds, not exceed the plate thickness times $1.46\sqrt{E/Fy}$. When unsupported transverse spacing exceeds this limit, but a portion of its width no greater than $1.46\sqrt{E/Fy}$ times the thickness would satisfy the stress requirement, the member shall be considered acceptable.

4.12.2.3 Unpainted Weathering Steel. For members of unpainted weathering steel exposed to atmospheric corrosion, if intermittent fillet welds are used, the spacing shall not exceed 14 times the thickness of the thinner plate nor 7 in [180 mm].

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Part C
Specific Requirements for Design of Nontubular Connections (Cyclically Loaded)

4.13 General

4.13.1 Applicability. Part C applies only to nontubular members and connections subject to cyclic load, within the elastic range, of frequency and magnitude sufficient to initiate cracking and progressive failure (fatigue). The provisions of Part C provide a method for assessing the effects of repeated fluctuations of stress on welded nontubular structural elements which shall be applied to minimize the possibility of a fatigue failure.

4.13.2 Other Pertinent Provisions. The provisions of Parts A and B shall apply to the design of members and connections subject to the requirements of Part C.

4.13.3 Engineer's Responsibility. The Engineer shall provide either complete details, including weld sizes, or shall specify the planned cycle life and the maximum range of moments, shears, and reactions for the connections in contract documents.

4.14 Limitations

4.14.1 Stress Range Threshold. No evaluation of fatigue resistance shall be required if the live load stress range is less than the threshold stress range, FTH (see Table 4.5).

4.14.2 Low Cycle Fatigue. Provisions of Part C are not applicable to low-cycle loading cases which induce calculated stresses into the inelastic range of stress.

4.14.3 Corrosion Protection. The fatigue strengths described in Part C are applicable to structures with suitable corrosion protection, or subject only to mildly corrosive environments such as normal atmospheric conditions.

4.14.4 Redundant–Nonredundant Members. This code no longer recognizes a distinction between redundant and nonredundant members.

4.15 Calculation of Stresses

4.15.1 Elastic Analysis. Calculated stresses and stress ranges shall be nominal, based upon elastic stress analysis at the member level. Stresses need not be amplified by stress concentration factors for local geometrical discontinuities.

4.15.2 Axial Stress and Bending. In the case of axial stress combined with bending, the maximum combined stress shall be that for concurrent applied load cases.

4.15.3 Symmetrical Sections. For members having symmetrical cross sections, the connection welds shall preferably be arranged symmetrically about the axis of the member, or if symmetrical arrangement is not practical, the total stresses including those resulting from joint eccentricity shall be included in the calculation of the stress range.

4.15.4 Angle Members. For axially stressed angle members, the center of gravity of the connecting welds shall lie between the line of the center of gravity of the angle's cross section and the center of the connected leg, in which case the effects of eccentricity may be ignored. If the center of gravity of the connecting weld lies outside this zone, the total stresses, including those resulting from eccentricity of the joint from the center of gravity of the angle, shall be included in the calculation of the stress range.

4.16 Allowable Stresses and Stress Ranges

4.16.1 Allowable Stresses. The calculated unit stresses in welds shall not exceed the allowable stresses described in Table 4.3.

4.16.2 Allowable Stress Ranges. Stress range is defined as the magnitude of fluctuation in stress that results from the repeated application and removal of the live load. In the case of stress reversal, the stress range shall be computed as the

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numerical sum of the maximum repeated tensile and compressive stresses or the sum of maximum shearing stresses of opposite direction at a given point, resulting from differing arrangement of live load. The calculated range of stress shall not exceed the maximum computed by Formulas (3) through (6), as applicable (see Figure 4.16 for graphical plot of Formulas (3) through (6) for stress categories A, B, B', C, D, E, E', and F).

For categories A, B, B', C, D, E, and E', the stress range shall not exceed F_{SR} as determined by Formula (3).

Formula (3)

$$F_{SR} = \left(\frac{C_f}{N}\right)^{0.333} \geq F_{TH}\,(\text{ksi})$$

$$F_{SR} = \left[\left(\frac{C_f \times 329}{N}\right)^{0.333} \geq F_{TH}\,(\text{MPa})\right]$$

in which:

F_{SR} = Allowable stress range, ksi [MPa]

C_f = Constant from Table 4.5 for all categories except category F.

N = Number of cycles of stress range in design life.

= Cycles per day × 365 × years of design life.

F_{TH} = Threshold fatigue stress range, that is the maximum stress range for infinite life, ksi [MPa]

For stress category F, the stress range shall not exceed F_{SR} as determined by Formula (4).

Formula (4)

$$F_{SR} = \left(\frac{C_f}{N}\right)^{0.167} \geq F_{TH}\,)\text{ksi})$$

$$F_{SR} = \left[\left(\frac{C_f \times 11 \times 10^4}{N}\right)^{0.167} \geq F_{TH}\,(\text{MPa})\right]$$

in which:

C_f = Constant from Table 4.5 for Category F

For tension-loaded plate elements at cruciform, T and corner joint details with CJP welds, PJP welds, fillet welds or combinations of the preceding, transverse to the direction of stress, the maximum stress range on the cross section of the tension-loaded plate element shall be determined by (a), (b), or (c) as follows:

(a) For the cross section of a tension-loaded plate element, the maximum stress range on the base metal cross section at the toe of the weld governed by consideration of crack initiation from the toe of the weld, the stress range shall not exceed FSR as determined by Formula (3), Category C, which shall be equal to:

$$F_{SR} = \left(\frac{44 \times 10^8}{N}\right)^{0.333} \geq 10\,(\text{ksi})$$

$$F_{SR} = \left[\left(\frac{14.4 \times 10^{11}}{N}\right)^{0.333} \geq 68.9\,(\text{MPa})\right]$$

(b) For end connections of tension-loaded plate elements using transverse PJP welds, with or without reinforcing or contouring fillet welds, the maximum stress range on the base metal cross section at the toe of the weld governed by consideration of crack initiation from the root of the weld shall not exceed FSR as determined by Formula (5).

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Formula (5)

$$F_{SR} = \left|R_{PJP}\left(\frac{44\times 10^{8}}{N}\right)^{0.333}\right. \text{(ksi)}$$

$$F_{SR} = \left[R_{PJP}\left(\frac{14.4\times 10^{11}}{N}\right)^{0.333} \text{(MPa)}\right]$$

In which:

R_{PJP} = Reduction factor for reinforced or nonreinforced PJP joints

R_{PJP} =

$$\frac{0.65 - 0.59(2a/t_p) + 0.72(w/t_p)}{t_p^{0.167}} \leq 1.0 \text{ (for in)}$$

$$\frac{1.12 - 1.01(2a/t_p) + 1.24(w/t_p)}{t_p^{0.167}} \leq 1.0 \text{ (for mm)}$$

2a = the length of the nonwelded root face in the direction of the thickness of the tension-loaded plate

t_p = the thickness of tension loaded plate element (in or mm)

w = the leg size of the reinforcing or contouring fillet, if any, in the direction of the thickness of the tension-loaded plate (in or mm)

(c) For end connections of tension-loaded plate elements using a pair of fillet welds, the maximum stress range on the base metal cross section at the toe of the weld governed by consideration of crack initiation from the root of the weld due to tension on the root shall not exceed F_{SR} as determined by Formula (6). Additionally, the shear stress range on the throat of the weld shall not exceed F_{SR} by Formula (4) for Category F.

Formula (6)

$$F_{SR} = R_{FIL}\left(\frac{44\times 10^{8}}{N}\right)^{0.333} \text{(ksi)}$$

$$F_{SR} = \left[R_{FIL}\left(\frac{14.4\times 10^{11}}{N}\right)^{0.333} \text{(MPa)}\right]$$

In which:

R_{FIL} = Reduction Factor for joints using a pair of transverse fillet welds only

$$R_{FIL} = \frac{0.06 + 0.72\left(\frac{w}{t_p}\right)}{t_p^{0.167}} \leq 1.0 \text{ (for in)}$$

$$R_{FIL} = \frac{0.10 + 1.24\left(\frac{w}{t_p}\right)}{t_p^{0.167}} \leq 1.0 \text{ (for mm)}$$

4.17 Detailing, Fabrication, and Erection

4.17.1 Transitions in Thickness and Width

4.17.1.1 Butt-Joint Thickness Transitions. Butt joints between parts having unequal thicknesses and subject to cyclic tensile stress shall have smooth transitions between offset surfaces at a slope of no more than 1 in 2-1/2 with the

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surface of either part. The transition may be accomplished by sloping the weld surfaces, by chamfering the thicker part, or by a combination of the two methods (see Figure 4.17).

4.17.1.2 Butt-Joint Width Transitions. Butt joints between parts of unequal width subject to cyclic stress into the tensile range shall have a smooth transition between the offset edges at a slope of not more than 1 in 2-1/2 with the edge of either part or shall be provided with a transition having a 24 in [600 mm] minimum radius tangent to the narrower part at the center of the butt joint (see Figure 4.18). An increased stress range may be used for steels having a yield strength greater than 90 ksi [620 MPa] with details incorporating the radius.

4.17.2 Backing

4.17.2.1 Welds for Attaching Steel Backing. Requirements for welds for attaching steel backing and whether the backing shall be removed or left in place shall be determined as described in 4.17.2.2, 4.17.2.3, 4.17.2.4, and the stress range categories of Table 4.5. The Engineer shall note the fatigue stress category on the contract drawings. The Contractor shall note on the shop drawings the required location, the weld detail to be used, whether the tack welds shall be inside the groove or shall be allowed to be outside the groove, and whether the backing shall be allowed to remain in place or are to be removed to provide for the intended stress range category.

4.17.2.2 CJP T and Corner Joints Made from One Side. Welds for attaching backing may be made inside or outside the joint groove. Backing for joints subject to cyclic transverse tension (fatigue) loading shall be removed and the back side of the joint finished consistent with face weld. Any unacceptable discontinuity discovered or caused by removal shall be repaired to the acceptance criteria of this code.

4.17.2.3 CJP Butt Joints. Welds for attaching backing may be inside or outside the groove unless restricted in the stress category description. Tack welds located outside the joint groove shall terminate not closer than 1/2 in [12 mm] from the edge of the connected part. Backing may remain in place or be removed unless restricted in the stress category used in design.

4.17.2.4 Longitudinal Groove Welds and Corner Joints. Steel backing, if used, shall be continuous for the full length of the joint. Welds for attaching backing may be inside or outside the groove (see 7.9.1.2).

4.17.3 Contouring Weld at Corner and T-Joints. In transverse corner and T-joints subject to tension or tension due to bending, a single pass contouring fillet weld, not less than 1/4 in [6 mm] in size shall be added at reentrant corners.

4.17.4 Flame Cut Edges. Flame cut edges need not be dressed provided they meet the roughness provisions of 7.14.8.3.

4.17.5 Transversely Loaded Butt Joints. For transversely loaded butt joints, weld tabs shall be used to provide for cascading the weld termination outside the finished joint. End dams shall not be used. Weld tabs shall be removed and the end of the weld finished flush with the edge of the member.

4.17.6 Fillet Weld Terminations. In addition to the requirements of 4.9.3.3 the following applies to weld terminations subject to cyclic (fatigue) loading. For connections and details with cyclic forces on outstanding elements of a frequency and magnitude that would tend to cause progressive failure initiating at a point of maximum stress at the end of the weld, fillet welds shall be returned around the side or end for a distance not less than two times the nominal weld size (see Figure 4.12).

4.18 Prohibited Joints and Welds

4.18.1 One-Sided Groove Welds. Groove welds, made from one side only without backing or made with backing, other than steel, that has not been qualified in conformance with Clause 6 shall be prohibited except that these prohibitions for groove welds made from one side shall not apply to the following:

(1) Secondary or nonstress carrying members.

(2) Corner joints parallel to the direction of calculated stress between components of built-up members

4.18.2 Flat Position Groove Welds. Bevel-groove and J-groove welds in butt joints welded in the flat position shall be prohibited where V-groove or U-groove joints are practicable.

4.18.3 Fillet Welds Less than 3/16 in [5 mm]. Fillet welds less than 3/16 in [5 mm] shall be prohibited.

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4.18.4 T- and Corner CJP Welds with Backing Left in Place. T- and corner CJP welds subject to cyclic transverse tension stress with the backing bar left in place shall be prohibited.

4.19 Inspection

Fatigue categories B and C require that the Engineer ensure that CJP groove welds subject to cyclic transverse applied stress into the tensile range be inspected using radiographic testing (RT) or ultrasonic testing (UT).

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Table 4.1
Effective Size of Flare-Groove Welds Filled Flush (see 4.4.1.4)

Welding Process	Flare-Bevel-Groove	Flare-V-Groove
SMAW and FCAW-S	5/16 R	5/8 R
GMAW[a] and FCAW-G	5/8 R	3/4 R
SAW	5/16 R	1/2 R

[a] Except GMAW-S

Note: R = radius of outside surface

Table 4.2
Z Loss Dimension (Nontubular) (See 4.4.3.3)

	Position of Welding—V or OH			Position of Welding—H or F		
Dihedral Angle Ψ	Process	Z(in)	Z(mm)	Process	Z(in)	Z(mm)
60° > Ψ ≥ 45°	SMAW	1/8	3	SMAW	1/8	3
	FCAW-S	1/8	3	FCAW-S	0	0
	FCAW-G	1/8	3	FCAW-G	0	0
	GMAW	N/A	N/A	GMAW	0	0
45° > Ψ ≥ 30°	SMAW	1/4	6	SMAW	1/4	6
	FCAW-S	1/4	6	FCAW-S	1/8	3
	FCAW-G	3/8	10	FCAW-G	1/4	6
	GMAW	N/A	N/A	GMAW	1/4	6

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Table 4.3
Allowable Stresses (see 4.6.4 and 4.16.1)

Type of Applied Stress	Allowable Stress	Required Filler Metal Strength Level
CJP Groove Welds		
Tension normal to the effective area[a]	Same as base metal	Matching filler metal shall be used[b]
Compression normal to effective area	Same as base metal	Filler metal with a strength level equal to or one classification (10 ksi [70 MPa]) less than matching filler metal may be used.
Tension or compression parallel to axis of the weld[c]	Not a welded joint design consideration	Filler metal with a strength level equal to or less than matching filler metal may be used
Shear on effective area	0.30 × classification tensile strength of filler metal except shear on the base metal shall not exceed 0.40 × yield strength of the base metal	
PJP Groove Welds		
Tension normal to the effective area	0.30 × classification tensile strength of filler metal	Filler metal with a strength level equal to or less than matching filler metal may be used
Compression normal to effective area of weld in joints designed to bear	0.90 × classification tensile strength of filler metal, but not more than 0.90 × yield strength of the connected base metal	
Compression normal to effective area of weld in joints not designed to bear	0.75 × classification tensile strength of filler metal	
Tension or compression parallel to axis of the weld[c]	Not a welded joint design consideration	
Shear parallel to axis of effective area	0.30 × classification tensile strength of filler metal except shear on the base metal shall not exceed 0.40 × yield strength of the base metal	
Fillet Welds		
Shear on effective area or weld	0.30 × classification tensile strength of filler metal except that the base metal net section shear area stress shall not exceed 0.40 × yield strength of the base metal[d, e]	Filler metal with a strength level equal to or less than matching filler metal may be used
Tension or compression parallel to axis of the weld[c]	Not a welded joint design consideration	
Plug and Slot Welds		
Shear parallel to the faying surface on the effective area[f]	0.30 × classification tensile strength of filler metal	Filler metal with a strength level equal to or less than matching filler metal may be used

[a] For definitions of effective areas, see 4.4.
[b] For matching filler metal to base metal strength for code approved steels, see Table 5.3, Table 5.4, and Table 6.9.
[c] Fillet welds and groove welds joining components of built-up members are allowed to be designed without regard to the tension and compression stresses in the connected components parallel to the weld axis although the area of the weld normal to the weld axis may be included in the cross-sectional area of the member.
[d] The limitation on stress in the base metal to 0.40 × yield point of base metal does not apply to stress on the diagrammatic weld leg; however, a check shall be made to assure that the strength of the connection is not limited by the thickness of the base metal on the net area around the connection, particularly in the case of a pair of fillet welds on opposite sides of a plate element.
[e] Alternatively, see 4.6.4.2, 4.6.4.3, and 4.6.4.4. Footnote d (above) applies.
[f] The strength of the connection shall also be limited by the tear-out load capacity of the thinner base metal on the perimeter area around the connection.

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Table 4.4
Equivalent Strength Coefficients for Obliquely Loaded Fillet Welds (see 4.6.4.4)

Load Angle for the Element Being Analyzed	Load Angle for Weld Element with Lowest Deformation Capability						
Θ	**C (90)**	**C (75)**	**C (60)**	**C (45)**	**C (30)**	**C (15)**	**C (0)**
0	0.825	0.849	0.876	0.909	0.948	0.994	1
15	1.02	1.04	1.05	1.07	1.06	0.883	
30	1.16	1.17	1.18	1.17	1.10		
45	1.29	1.30	1.29	1.26			
60	1.40	1.40	1.39				
75	1.48	1.47					
90	1.50						

Note: The weld element with the lowest deformation capability will be the element with the greatest load angle. Linear interpolation between adjacent load angles is permitted.

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Table 4.5
Fatigue Stress Design Parameters (see 4.14.1)

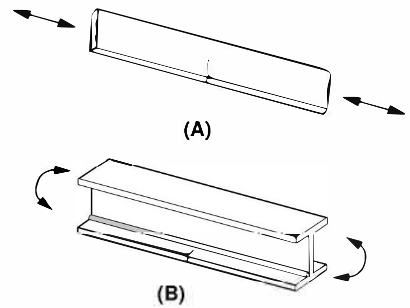
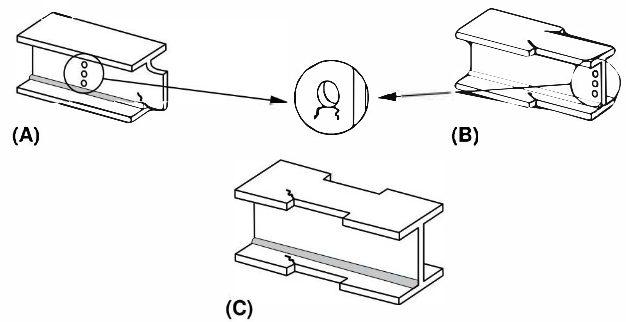
Description	Stress Category	Constant C_f	Threshold F_{TH} ksi [MPa]	Potential Crack Initiation Point	Illustrative Examples
Section 1—Plain Material Away from Any Welding					
1.1 Base metal, except non-coated weathering steel, with as-rolled or cleaned surfaces. Flame cut edges with surface roughness value of 1000 µin [25 µm] or less, but without reentrant corners.	A	250×10^8	24 [165]	Away from all welds or structural connections	1.1/1.2 
1.2 Non-coated weathering steel base metal with as-rolled or cleaned surfaces. Flame cut edges with surface roughness value of 1000 µin [25 µm] or less, but without reentrant corners.	B	120×10^8	16 [110]	Away from all welds or structural connections	
1.3 Member with reentrant corners at copes, cuts, block-outs or other geometrical discontinuities, except weld access holes. R ≥ 1 in [25 mm] with radius formed by predrilling, subpunching and reaming or thermally cut and ground to a bright metal surface R ≥ 3/8 in [10 mm] and the radius need not be ground to a bright metal surface	 C E'	 44×10^8 3.9×10^8	 10 [69] 2.6 [18]	At any external edge or at hole perimeter	1.3 

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Table 4.5 (Continued)
Fatigue Stress Design Parameters (see 4.14.1)

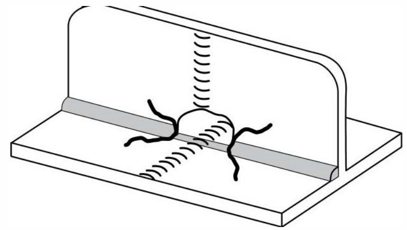
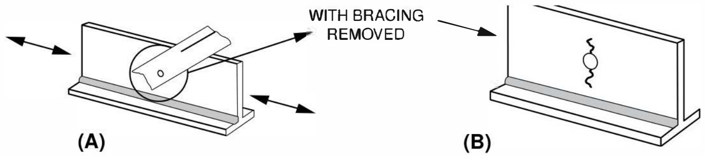
Description	Stress Category	Constant C_f	Threshold F_{TH} ksi [MPa]	Potential Crack Initiation Point	Illustrative Examples
Section 1—Plain Material Away from Any Welding (Cont'd)					
1.4 Rolled cross sections with weld access holes made to the requirements of 4.17.4 and 7.16.1.				At reentrant corner of weld access hole	1.4 
Access hole R ≥ 1 in [25 mm] with radius formed by predrilling, subpunching and reaming or thermally cut and ground to a bright metal surface	C	44×10^8	10 [69]		
Access hole R ≥ 3/8 in [10 mm] and the radius need not be ground to a bright metal surface	E'	3.9×10^8	2.6 [18]		
1.5 Members with drilled or reamed holes.				In net section originating at side of the hole	1.5 
Holes containing pre-tensioned bolts	C	44×10^8	10 [69]		
Open holes without bolts	D	22×10^8	7 [48]		
Section 2—Connected Material in Mechanically Fastened Joints—Not Used[a]					

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Table 4.5 (Continued)
Fatigue Stress Design Parameters (see 4.14.1)

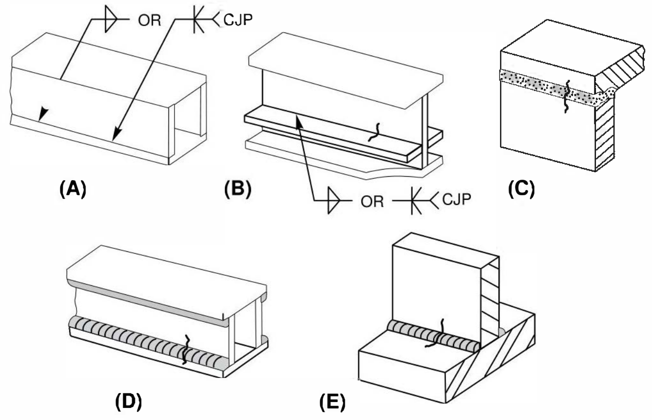
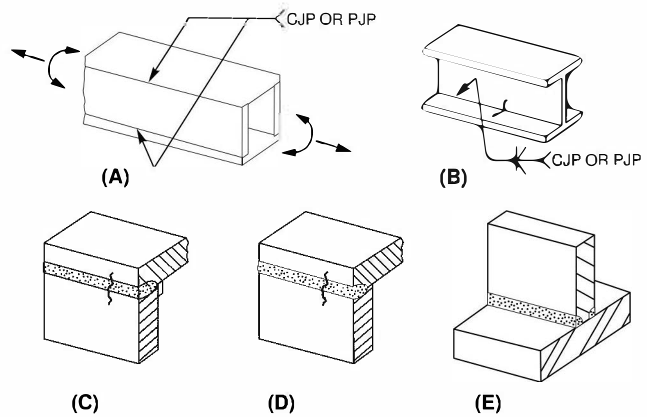
Description	Stress Category	Constant C_f	Threshold F_{TH} ksi [MPa]	Potential Crack Initiation Point	Illustrative Examples
Section 3—Welded Joints Joining Components of Built-Up Members					
3.1 Base metal and weld metal in members without attachments built-up of plates or shapes connected by continuous longitudinal CJP groove welds, backgouged and welded from second side, or by continuous fillet welds.	B	120×10^8	16 [110]	From surface or internal discontinuities in weld	3.1 
3.2 Base metal and weld metal in members without attachments built up of plates or shapes, connected by continuous longitudinal CJP groove welds with left-in place continuous steel backing, or by continuous PJP groove welds.	B'	61×10^8	12 [83]	From surface or internal discontinuities in weld	3.2 

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Table 4.5 (Continued)
Fatigue Stress Design Parameters (see 4.14.1)

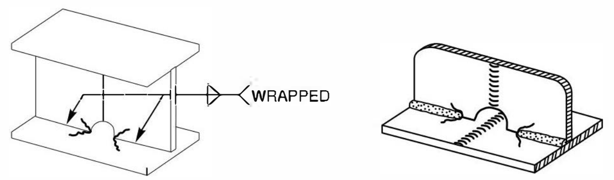
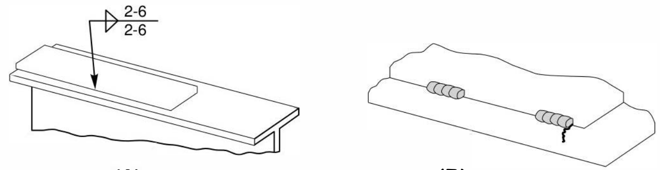
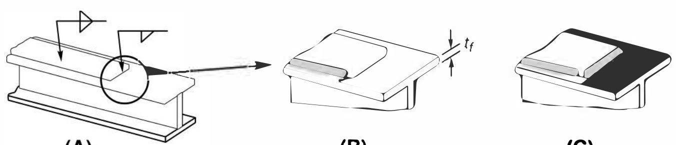
Description	Stress Category	Constant C_f	Threshold F_{TH} ksi [MPa]	Potential Crack Initiation Point	Illustrative Examples
Section 3—Welded Joints Joining Components of Built-Up Members (Cont'd)					
3.3 Base metal at the ends of longitudinal welds that terminate at weld access holes in connected built-up members, as well as weld toes of fillet welds that wrap around ends of weld access holes.				From the weld termination into the web or flange	3.3  (A) (B)
Access hole R ≥ 1 in [25 mm] with radius formed by predrilling, subpunching and reaming or thermally cut and ground to a bright metal surface	D	22×10^8	7 [48]		
Access hole R ≥ 3/8 in [10 mm] and the radius need not be ground to a bright metal surface	E'	3.9×10^8	2.6 [18]		
3.4 Base metal at ends of longitudinal intermittent fillet weld segments.	E	11×10^8	4.5 [31]	In connected material at start and stop locations of any weld	3.4  (A) (B)
3.5 Base metal at ends of partial length welded cover plates narrower than the flange having square or tapered ends, with or without welds across the ends.				In flange at toe of end weld (if present) or in flange at termination of longitudinal weld	3.5  (A) (B) (C)
Flange thickness ≤ 0.8 in [20 mm]	E	11×10^8	4.5 [31]		
Flange thickness > 0.8 in [20 mm]	E'	3.9×10^8	2.6 [18]		

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Table 4.5 (Continued)
Fatigue Stress Design Parameters (see 4.14.1)

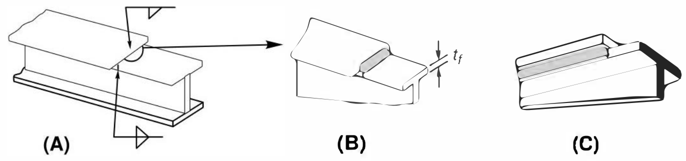
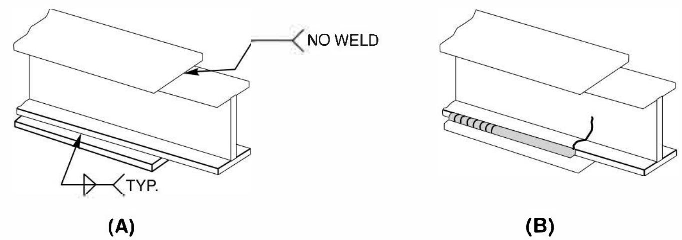
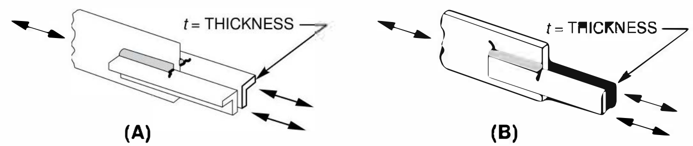
Description	Stress Category	Constant C_f	Threshold F_{TH} ksi [MPa]	Potential Crack Initiation Point	Illustrative Examples
Section 3—Welded Joints Joining Components of Built-Up Members (Cont'd)					
3.6 Base metal at ends of partial length welded cover plates or other attachments wider than the flange with welds across the ends.				In flange at toe of end weld or in flange at termination of longitudinal weld or in edge of flange	3.6 
Flange thickness ≤ 0.8 in [20 mm]	E	11×10^8	4.5 [31]		
Flange thickness > 0.8 in [20 mm]	E'	3.9×10^8	2.6 [18]		
3.7 Base metal at ends of partial length welded cover plates wider than the flange without welds across the ends.				In edge of flange at end of cover plate weld	3.7 
Flange thickness ≤ 0.8 in [20 mm]	E'	3.9×10^8	2.6 [18]		
Flange thickness > 0.8 in [20 mm] is not permitted					
Section 4—Longitudinal Fillet Welded End Connections					
4.1 Base metal at junction of axially loaded members with longitudinally welded end connections. Welds are on each side of the axis of the member to balance weld stresses.				Initiating from end of any weld termination extending into the base metal	4.1 
t ≤ 0.5 in [12 mm]	E	11×10^8	4.5 [31]		
t > 0.5 in [12 mm]	E'	3.9×10^8	2.6 [18]		

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Table 4.5 (Continued)
Fatigue Stress Design Parameters (see 4.14.1)

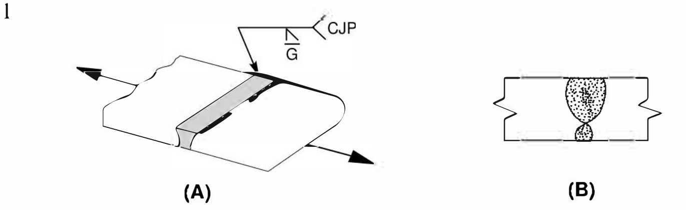
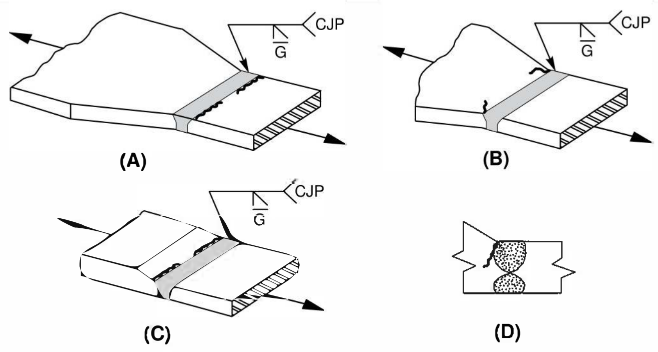
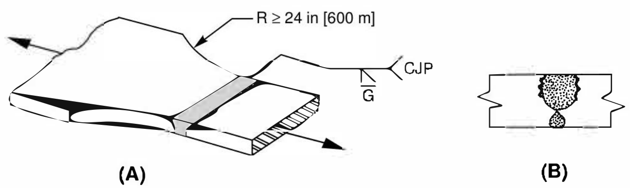
Description	Stress Category	Constant C_f	Threshold F_{TH} ksi [MPa]	Potential Crack Initiation Point	Illustrative Examples
Section 5—Welded Joints Transverse to Direction of Stress					
5.1 Weld metal and base metal in or adjacent to CJP groove welded splices in plate, rolled shapes or built-up cross sections with no change in cross section with welds ground essentially parallel to the direction of stress and inspected in accordance with 4.19.	B	120×10^8	16 [110]	From internal discontinuities in weld metal or along fusion boundary	5.1 
5.2 Weld metal and base metal in or adjacent to CJP groove welded splices with welds ground essentially parallel to the direction of stress at transitions in thickness or width made on a slope no greater than 1:2-1/2 and inspected in accordance with 4.19. $F_y < 90$ ksi [620 MPa] $F_y \geq 90$ ksi [620 MPa]	 B B’	 120×10^8 61×10^8	 16 [110] 12 [83]	From internal discontinuities in weld metal or along fusion boundary or at start of transition when $F_y \geq 90$ ksi [620 MPa]	5.2 
5.3 Base metal and weld metal in or adjacent to CJP groove welded splices with welds ground essentially parallel to the direction of stress at transitions in width made on a radius of not less than 24 in [600 mm] with the point of tangency at the end of the groove weld and inspected in accordance with 4.19.	B	120×10^8	16 [110]	From internal discontinuities in weld metal or along the fusion boundary	5.3 

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Table 4.5 (Continued)
Fatigue Stress Design Parameters (see 4.14.1)

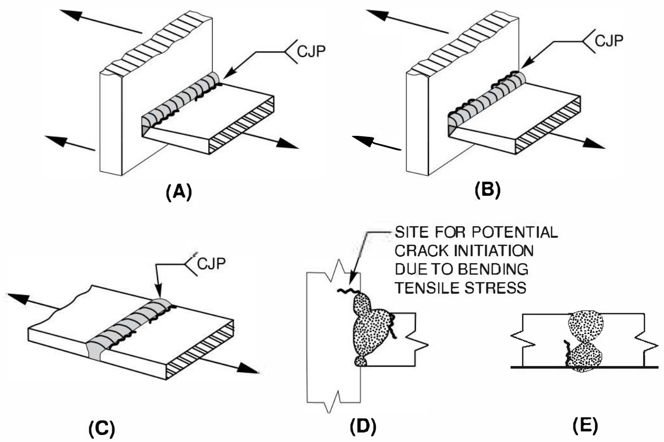
Description	Stress Category	Constant C_f	Threshold F_{TH} ksi [MPa]	Potential Crack Initiation Point	Illustrative Examples
Section 5—Welded Joints Transverse to Direction of Stress (Cont'd)					
5.4 Weld metal and base metal in or adjacent to CJP groove welds in T- or corner joints or splices, without transitions in thickness or with transition in thickness having slopes no greater than 1:2-1/2, when weld reinforcement is not removed and inspected in accordance with 4.19.	C	44×10^8	10 [69]	From weld extending into base metal or along weld metal	5.4 

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Table 4.5 (Continued)
Fatigue Stress Design Parameters (see 4.14.1)

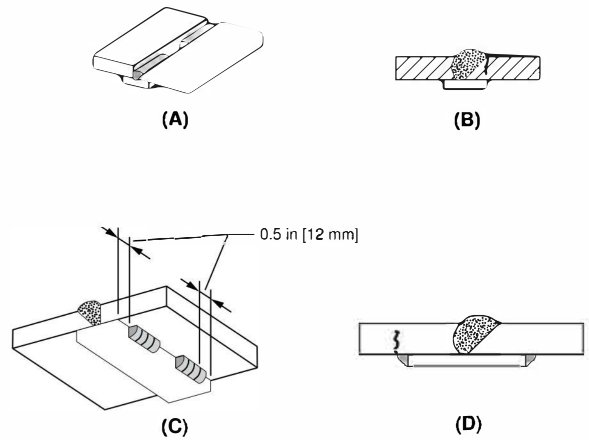
Description	Stress Category	Constant C_f	Threshold F_{TH} ksi [MPa]	Potential Crack Initiation Point	Illustrative Examples
Section 5—Welded Joints Transverse to Direction of Stress (Cont'd)					
5.5 Base metal and weld metal in or adjacent to transverse CJP groove welded butt splices with backing left in place.				From the toe of the groove weld or the toe of the weld attaching backing when applicable	5.5 
Tack welds inside groove	D	22×10^8	7 [48]		
Tack welds outside the groove and not closer than 1/2 in [12 mm] to edge of base metal	E	11×10^8	4.5 [31]		

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Table 4.5 (Continued)
Fatigue Stress Design Parameters (see 4.14.1)

Description	Stress Category	Constant C_f	Threshold F_{TH} ksi [MPa]	Potential Crack Initiation Point	Illustrative Examples
Section 5—Welded Joints Transverse to Direction of Stress (Cont'd)					
5.6 Base metal and weld metal at transverse end connections of tension-loaded plate elements using PJP groove welds in butt. T- or corner joints, with reinforcing or contouring fillets. F_{SR} shall be the smaller of the toe crack or root crack stress range.					5.6 (see figure below)
Crack initiating from weld toe:	C	44×10^8	10 [69]	Initiating from weld toe extending into base metal	
Crack initiating from weld root:	C'	Formula (4)	None	Initiating at weld root extending into and through weld	

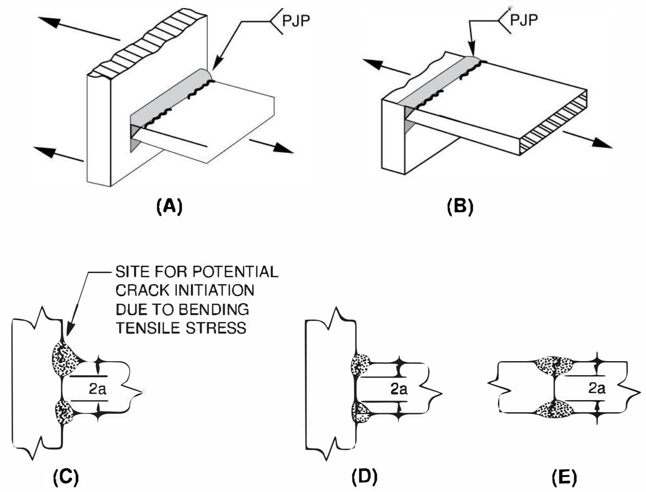

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Table 4.5 (Continued)
Fatigue Stress Design Parameters (see 4.14.1)

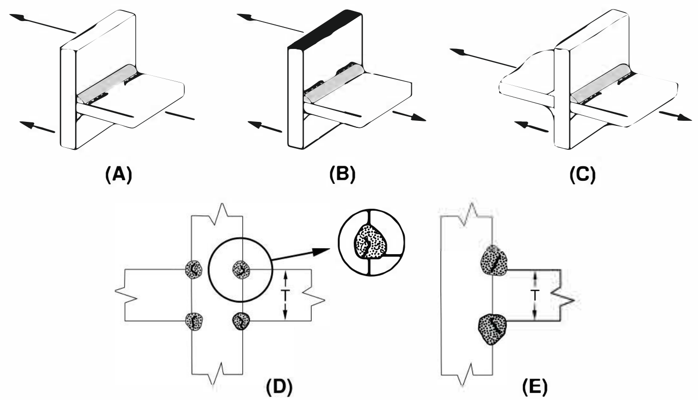
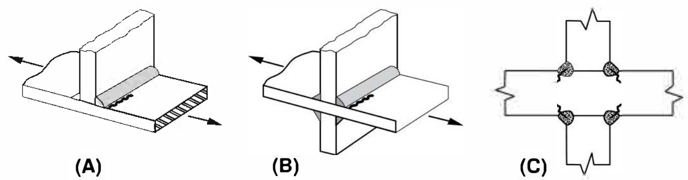
Description	Stress Category	Constant C_f	Threshold F_{TH} ksi [MPa]	Potential Crack Initiation Point	Illustrative Examples
Section 5—Welded Joints Transverse to Direction of Stress (Cont'd)					
5.7 Base metal and weld metal at transverse end connections of tension-loaded plate elements using a pair of fillet welds on opposite sides of the plate. F_{SR} shall be the smaller of the toe crack or root crack allowable stress range.					5.7 
Crack initiating from weld toe:	C	44×10^8	10 [69]	Initiating from weld toe extending into base metal	
Crack initiating from weld root:	C"	Formula (4)	None	Initiating at weld root extending into and through weld	
5.8 Base metal of tension loaded plate elements and on built-up shapes and rolled beam webs or flanges at toe of transverse fillet welds, adjacent to welded transverse stiffeners.	C	44×10^8	10 [69]	From geometrical discontinuity at toe of fillet extending into base metal	5.8 

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Table 4.5 (Continued)
Fatigue Stress Design Parameters (see 4.14.1)

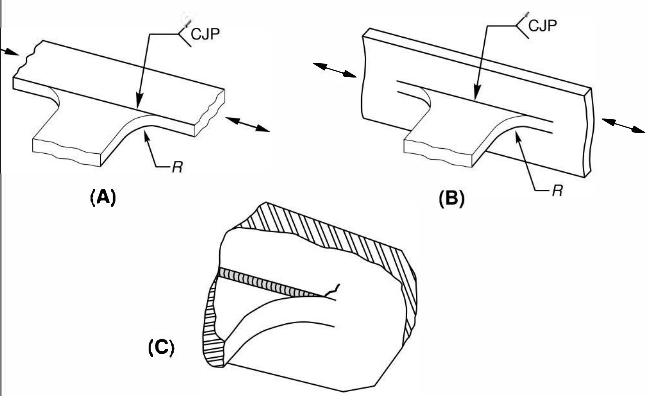
Description	Stress Category	Constant C_f	Threshold F_{TH} ksi [MPa]	Potential Crack Initiation Point	Illustrative Examples
Section 6—Base Metal at Welded Transverse Member Connections					
6.1 Base metal of equal or unequal thickness at details attached by CJP groove welds subject to longitudinal loading only when the detail embodies a transition radius, R, with the weld termination ground smooth and inspected in accordance with 4.19.				Near point of tangency of radius at edge of member	6.1 
$R \geq 24$ in [600 mm]	B	120×10^8	16 [110]		
6 in $\leq R < 24$ in [150 mm $\leq R <$ 600 mm]	C	44×10^8	10 [69]		
2 in $\leq R < 6$ in [50 mm $\leq R <$ 150 mm]	D	22×10^8	7 [48]		
$R < 2$ in [50 mm]	E	11×10^8	4.5 [31]		

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Table 4.5 (Continued)
Fatigue Stress Design Parameters (see 4.14.1)

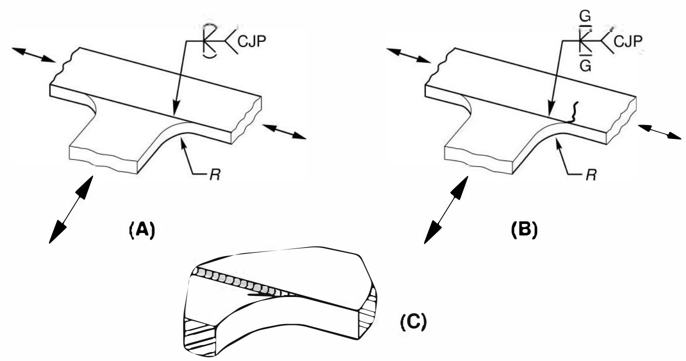
Description	Stress Category	Constant C_f	Threshold F_{TH} ksi [MPa]	Potential Crack Initiation Point	Illustrative Examples
Section 6—Base Metal at Welded Transverse Member Connections (Cont'd)					
6.2 Base metal at details of equal thickness attached by CJP groove welds subject to transverse loading with or without longitudinal loading when the detail embodies a transition radius, R, with the weld termination ground smooth and inspected in accordance with 4.19.					6.2 
6.2(a) When weld reinforcement is removed: $R \geq 24$ in [600 mm]	B	120×10^8	16 [110]	Near points of tangency of radius or in the weld or at fusion boundary of member or attachment	
6 in $\leq R < 24$ in [150 mm $\leq R < 600$ mm]	C	44×10^8	10 [69]		
2 in $\leq R < 6$ in [50 mm $\leq R < 150$ mm]	D	22×10^8	7 [48]		
$R < 2$ in [50 mm]	E	11×10^8	4.5 [31]		
6.2(b) When weld reinforcement not removed:				At toe of the weld either along edge of member or the attachment	
$R \geq 6$ in [150 mm]	C	44×10^8	10 [69]		
2 in $\leq R < 6$ in [50 mm $\leq R < 150$ mm]	D	22×10^8	7 [48]		
$R < 2$ in [50 mm]	E	11×10^8	4.5 [31]		

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Table 4.5 (Continued)
Fatigue Stress Design Parameters (see 4.14.1)

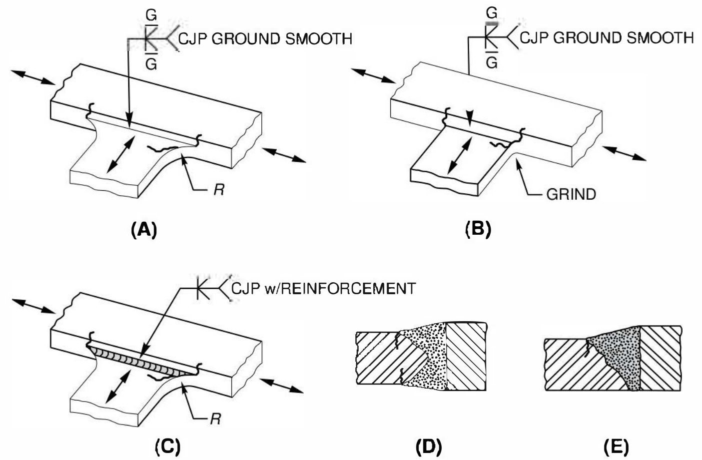
Description	Stress Category	Constant C_f	Threshold F_{TH} ksi [MPa]	Potential Crack Initiation Point	Illustrative Examples
Section 6—Base Metal at Welded Transverse Member Connections (Cont'd)					
6.3 Base metal at details of unequal thickness attached by CJP groove welds, subject to transverse loading with or without longitudinal loading, when the detail embodies a transition radius, R, with the weld termination ground smooth and inspected in accordance with 4.19.					6.3 
6.3(a) When weld reinforcement is removed:					
R > 2 in [50 mm]	D	22×10^8	7 [48]	At toe of weld along edge of thinner material	
R ≤ 2 in [50 mm]	E	11×10^8	4.5 [31]	In weld termination in small radius	
6.3(b) When weld reinforcement is not removed:					
Any radius	E	11×10^8	4.5 [31]	At toe of weld along edge of thinner material	

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Table 4.5 (Continued)
Fatigue Stress Design Parameters (see 4.14.1)

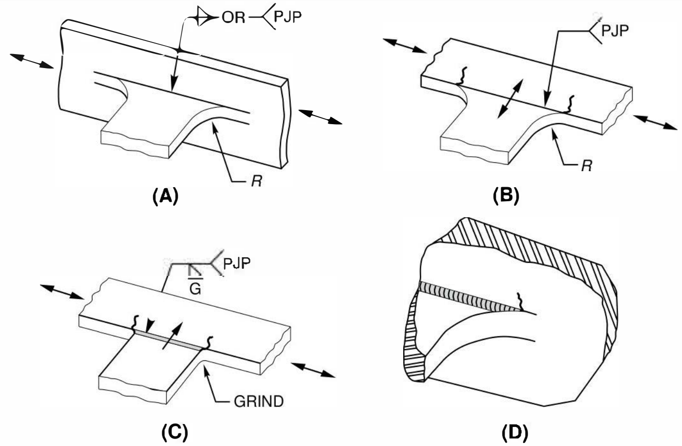
Description	Stress Category	Constant C_f	Threshold F_{TH} ksi [MPa]	Potential Crack Initiation Point	Illustrative Examples
Section 6 — Base Metal at Welded Transverse Member Connections (Cont'd)					
6.4 Base metal of equal or unequal thickness, subject to longitudinal stress at transverse members, with or without transverse stress, attached by fillet or PJP groove welds parallel to direction of stress when the detail embodies a transition radius, R, with weld termination ground smooth.				Initiating in base metal at the weld termination or at the toe of the weld, extending into the base metal	6.4 
R ≥ 2 in [50 mm]	D	22×10^8	7 [48]		
R ≤ 2 in [50 mm]	E	11×10^8	4.5 [31]		

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Table 4.5 (Continued)
Fatigue Stress Design Parameters (see 4.14.1)

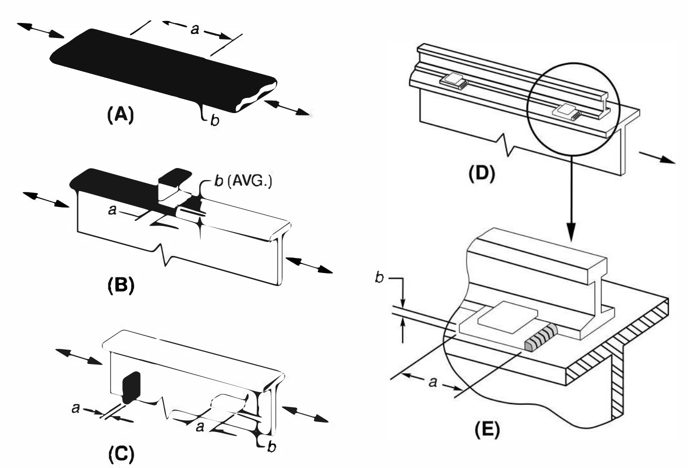
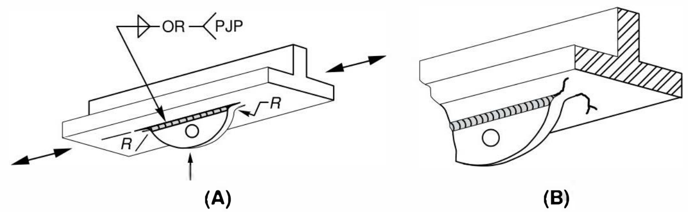
Description	Stress Category	Constant C_f	Threshold F_{TH} ksi [MPa]	Potential Crack Initiation Point	Illustrative Examples
Section 6—Base Metal at Welded Transverse Member Connections (Cont'd)					
7.1 Base metal subject to longitudinal loading at details with welds parallel or transverse to the direction of stress with or without transverse load on the detail, where the detail embodies no transition radius, and with detail length, a, in direction of stress and thickness of the attachment, b:				Initiating in base metal at the weld termination or at the toe of the weld, extending into the base metal	7.1 
a < 2 in [50 mm] for any thickness, b	C	44×10^8	10 [69]		
2 in [50 mm] ≤ a ≤ lesser of 12b or 4 in [100 mm]	D	22×10^8	7 [48]		
a > lesser of 12b or 4 in [100 mm] when b ≤ 0.8 in [20 mm]	E	11×10^8	4.5 [31]		
a > 4 in [100 mm] when b > 0.8 in [20 mm]	E'	3.9×10^8	2.6 [18]		
7.2 Base metal subject to longitudinal stress at details attached by fillet or PJP groove welds, with or without transverse load on detail, when the detail embodies a transition radius, R, with weld termination ground smooth.				Initiating in base metal at the weld termination, extending into the base metal	7.2 
R > 2 in [50 mm]	D	22×10^8	7 [48]		
R ≤ 2 in [50 mm]	E	11×10^8	4.5 [31]		

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Table 4.5 (Continued)
Fatigue Stress Design Parameters (see 4.14.1)

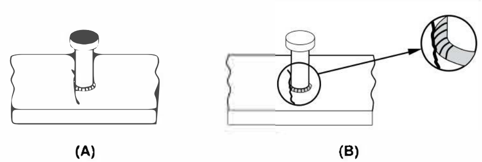
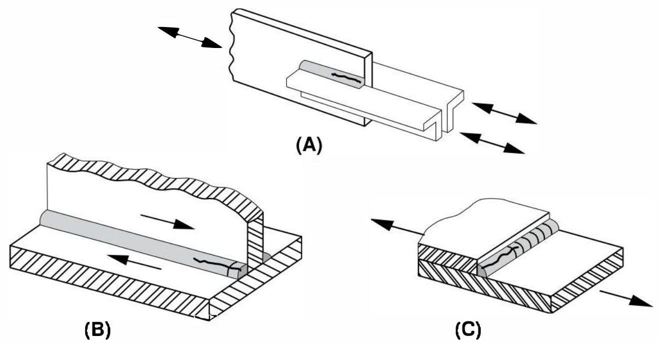
Description	Stress Category	Constant C_f	Threshold F_{TH} ksi [MPa]	Potential Crack Initiation Point	Illustrative Examples
Section 6—Base Metal at Welded Transverse Member Connections (Cont'd)					
8.1 Base at steel headed stud anchors attached by fillet weld or automatic stud welding.	C	44×10^8	10 [69]	At toe of weld in base metal	8.1 
8.2 Shear on throat of any fillet weld, continuous or intermittent, longitudinal or transverse.	F	150×10^{10} Formula (3)	8 [55]	Initiating at the root of the fillet weld, extending into the weld	8.2 

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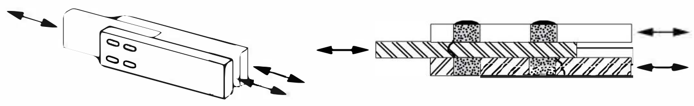
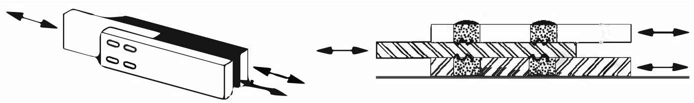
Table 4.5 (Continued)
Fatigue Stress Design Parameters (see 4.14.1)

Description	Stress Category	Constant C_f	Threshold F_{TH} ksi [MPa]	Potential Crack Initiation Point	Illustrative Examples
Section 6—Base Metal at Welded Transverse Member Connections (Cont'd)					
8.3 Base metal at plug or slot welds.	E	11×10^8	4.5 [31]	Initiating in the base metal at the end of the plug or slot weld, extending into the base metal	8.3  (A) (B)
8.4 Shear on plug or slot welds.	F	150×10^{10} Formula (3)	8 [55]	Initiating in the weld at the faying surface, extending into the weld	8.4  (A) (B)
8.5 Description 8.5 deals only with mechanically fastened details not pertinent to D1.1.					

[a] AWS D1.1/D1.1M deals only with welded details. To maintain consistency and to facilitate cross referencing with other governing specifications, Section 2—Connected Material in Mechanically Fastened Joints, and Description 8.5 are not used in this table.

[b] "Attachment" as used herein is defined as any steel detail welded to a member, which causes a deviation in the stress flow in the member and thus reduces the fatigue resistance. The reduction is due to the presence of the attachment, not due to the loading on the attachment.

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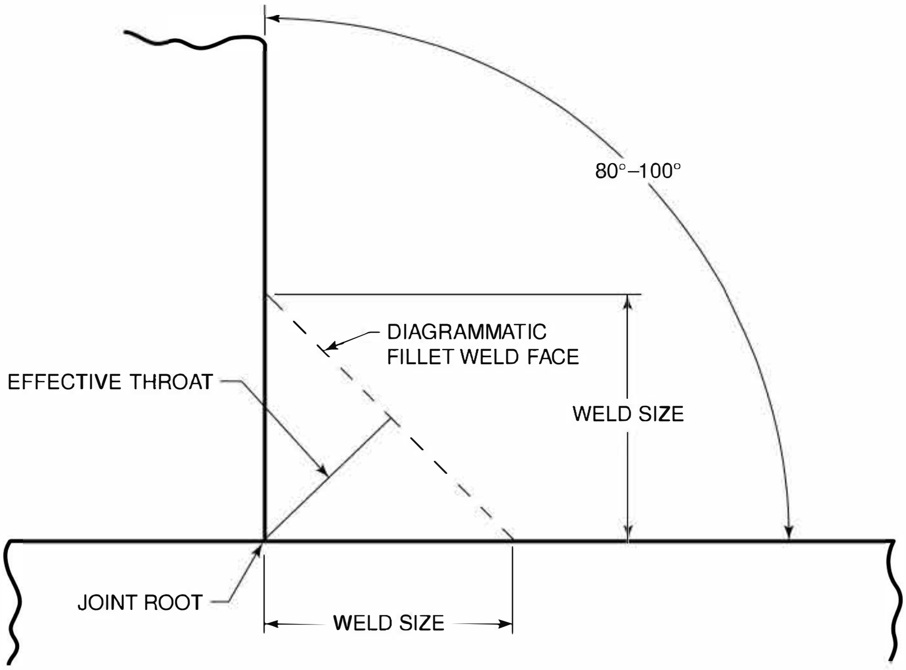

Figure 4.1—Fillet Weld (see 4.4.2.6)

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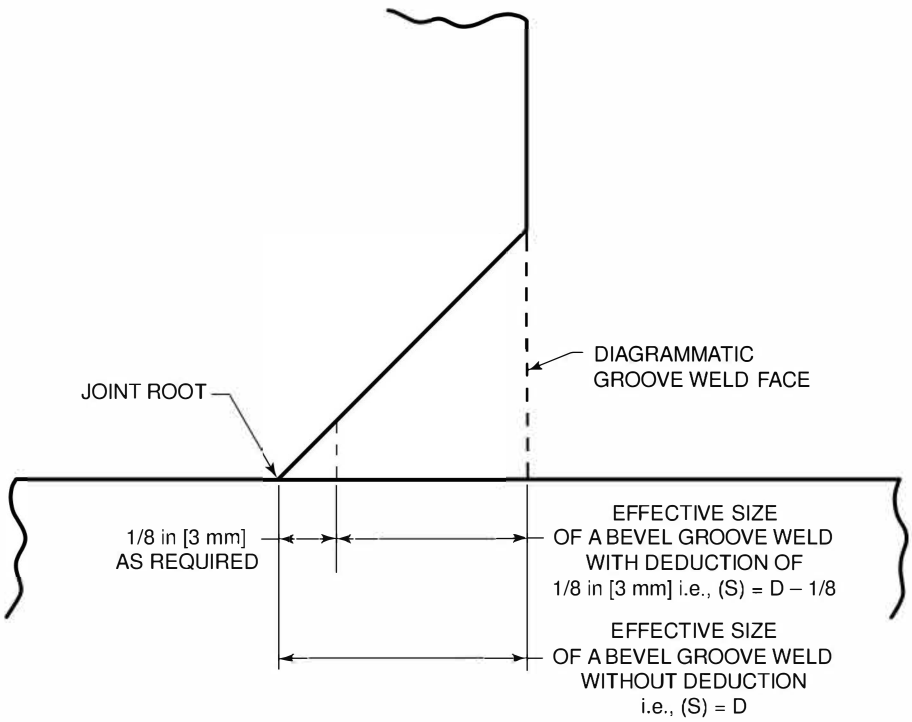

Figure 4.2—Unreinforced Bevel Groove Weld (see 4.4.2.7)

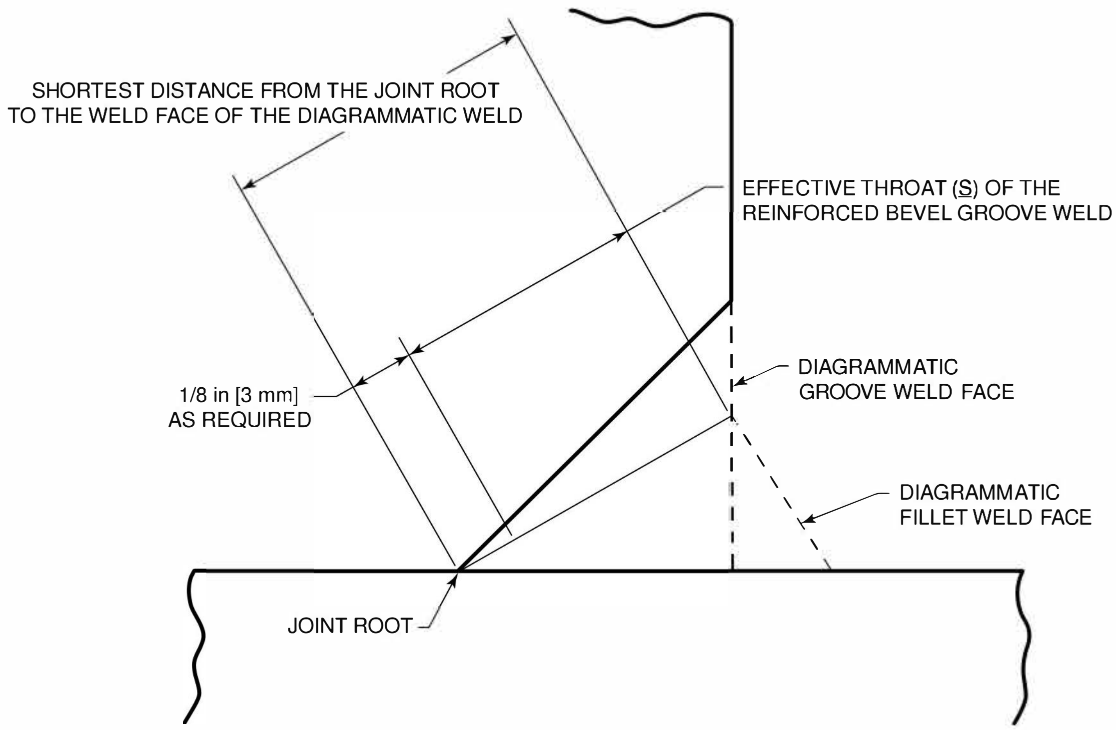

Figure 4.3—Bevel Groove Weld with Reinforcing Fillet Weld (see 4.4.2.7)

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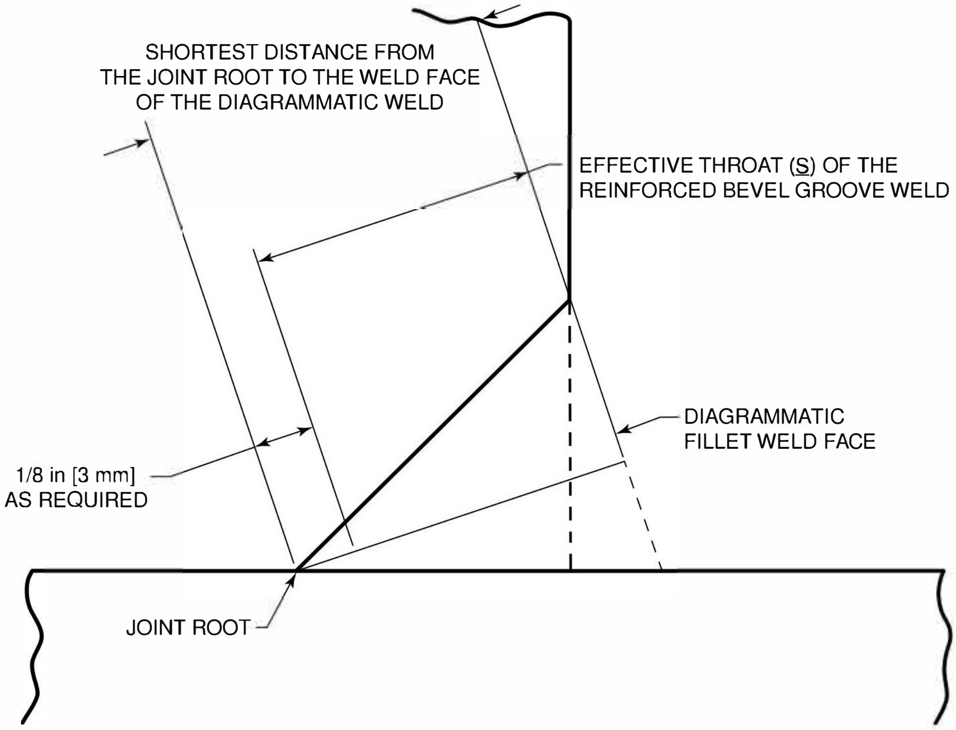

Figure 4.4—Bevel Groove Weld with Reinforcing Fillet Weld (see 4.4.2.7)

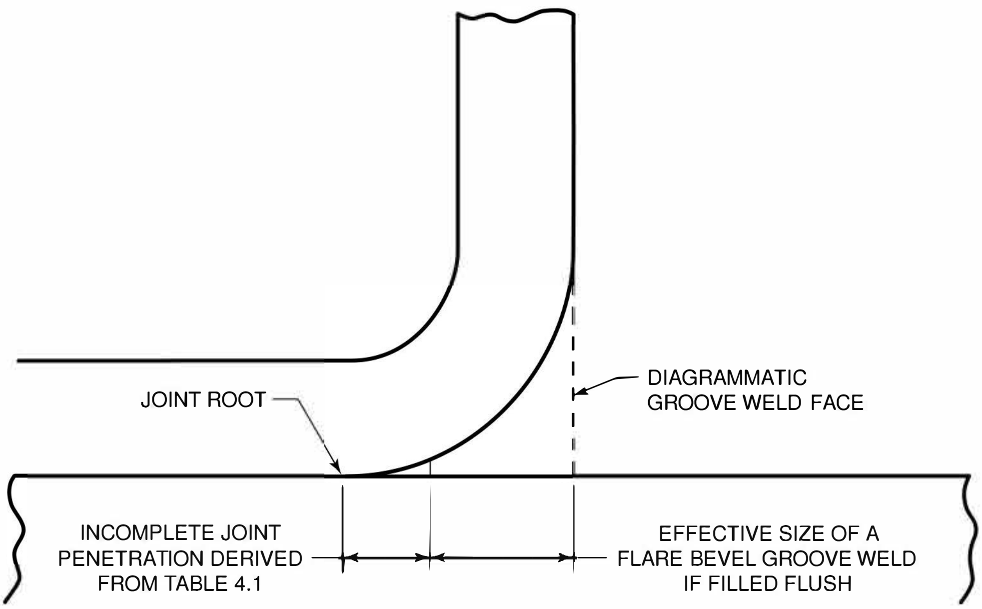

Figure 4.5—Unreinforced Flare Bevel Groove Weld (see 4.4.2.7)

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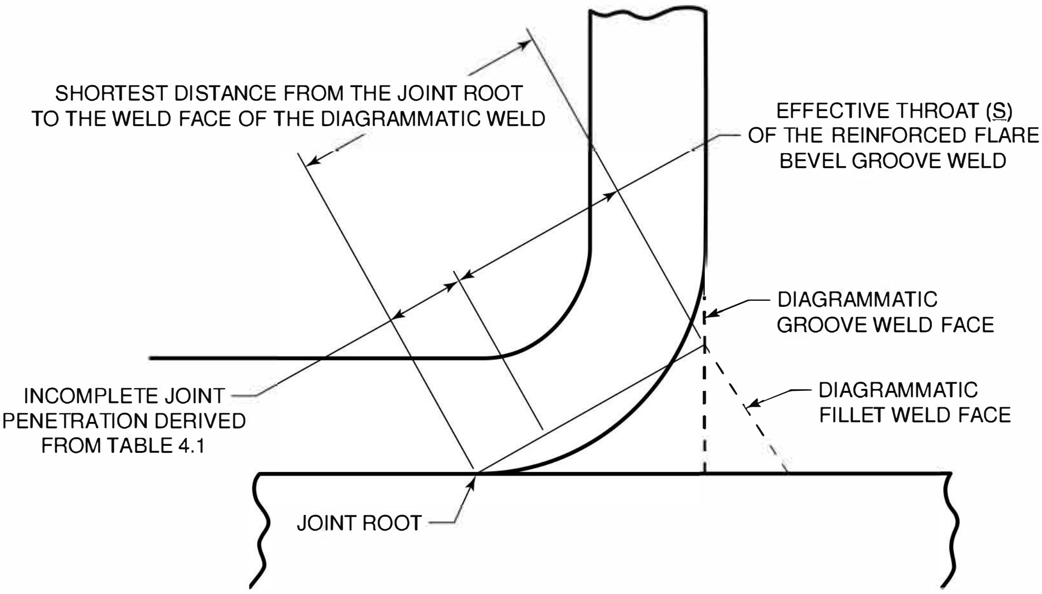

Figure 4.6—Flare Bevel Groove Weld with Reinforcing Fillet Weld (see 4.4.2.7)

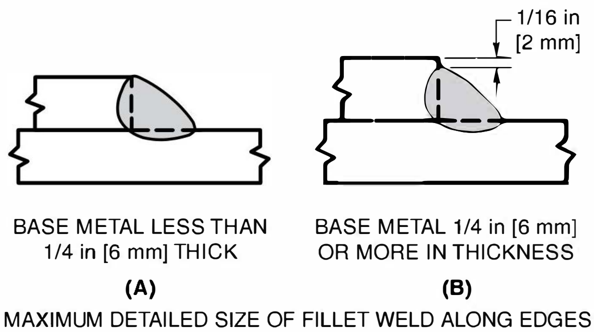

Figure 4.7—Maximum Fillet Weld Size Along Edges in Lap Joints (see 4.4.2.9)

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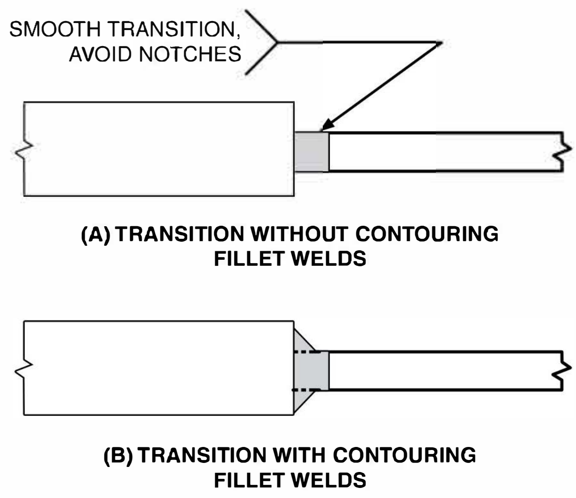
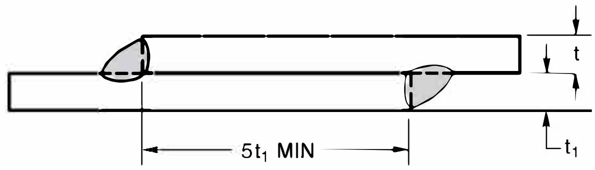


Figure 4.8—Transition of Thickness (Statically Loaded Nontubular) (see 4.7.5 and 4.8.1)



Note: t = thicker member, t_1 = thinner member.

Figure 4.9—Transversely Loaded Fillet Welds (see 4.9.1.1 and 4.9.1.2)

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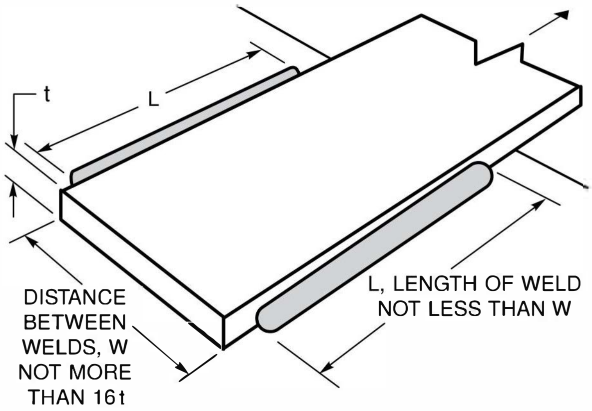

Figure 4.10—Minimum Length of Longitudinal Fillet Welds at End of Plate or Flat Bar Members (see 4.9.2)

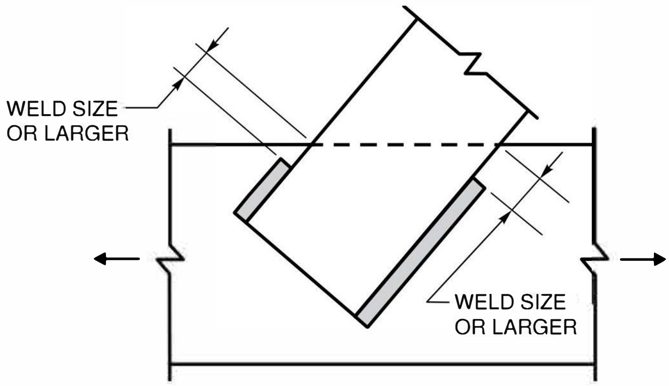

Figure 4.11—Termination of Welds Near Edges Subject to Tension (see 4.9.3.2)

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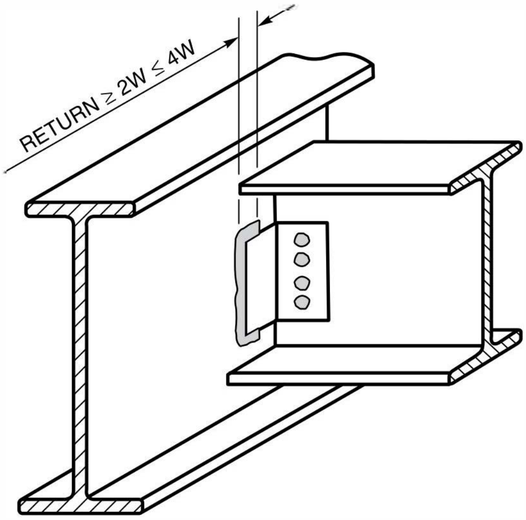

Note: W = nominal size of the weld.

Figure 4.12—End Return at Flexible Connections (see 4.9.3.3 and 4.17.6)

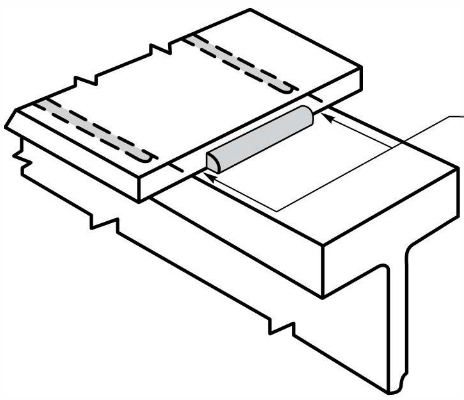

Figure 4.13—Fillet Welds on Opposite Sides of a Common Plane (see 4.9.3.5)

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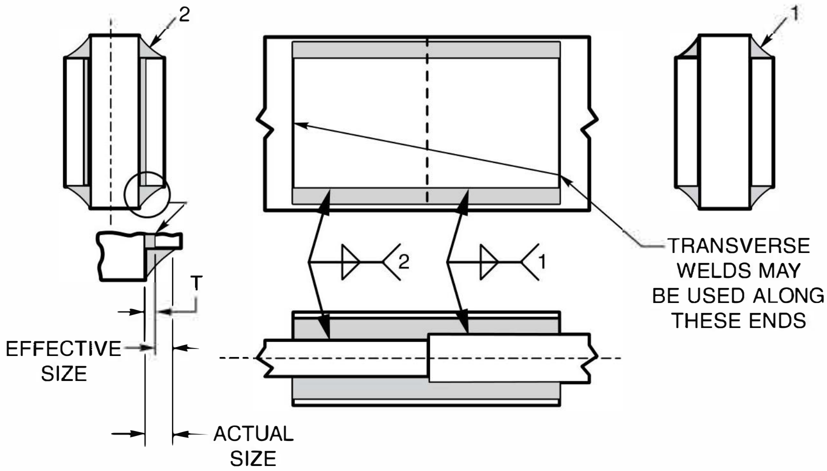
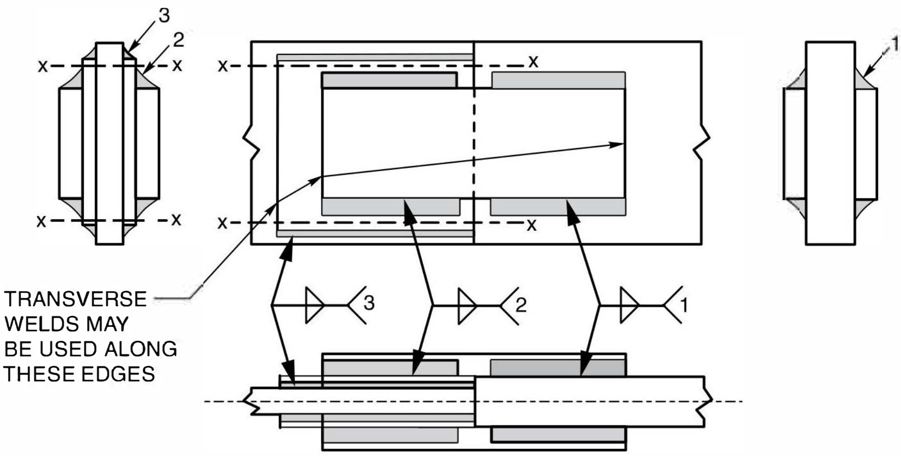


Note: The effective area of weld 2 shall equal that of weld 1, but its size shall be its effective size plus the thickness of the filler plate T.

Figure 4.14—Thin Filler Plates in Splice Joint (see 4.11.1)



Note: The effective areas of welds 1, 2, and 3 shall be adequate to transmit the design force, and the length of welds 1 and 2 shall be adequate to avoid overstress of filler plate in shear along planes x-x.

Figure 4.15—Thick Filler Plates in Splice Joint (see 4.11.2)

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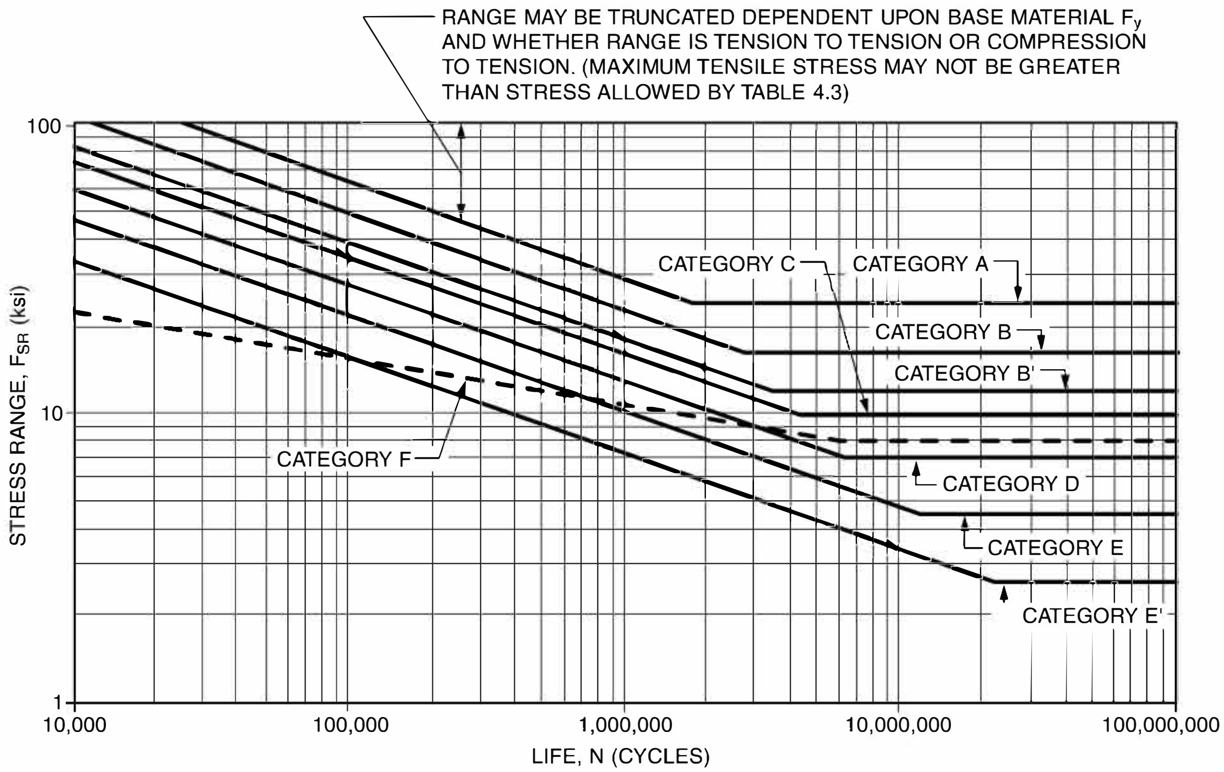
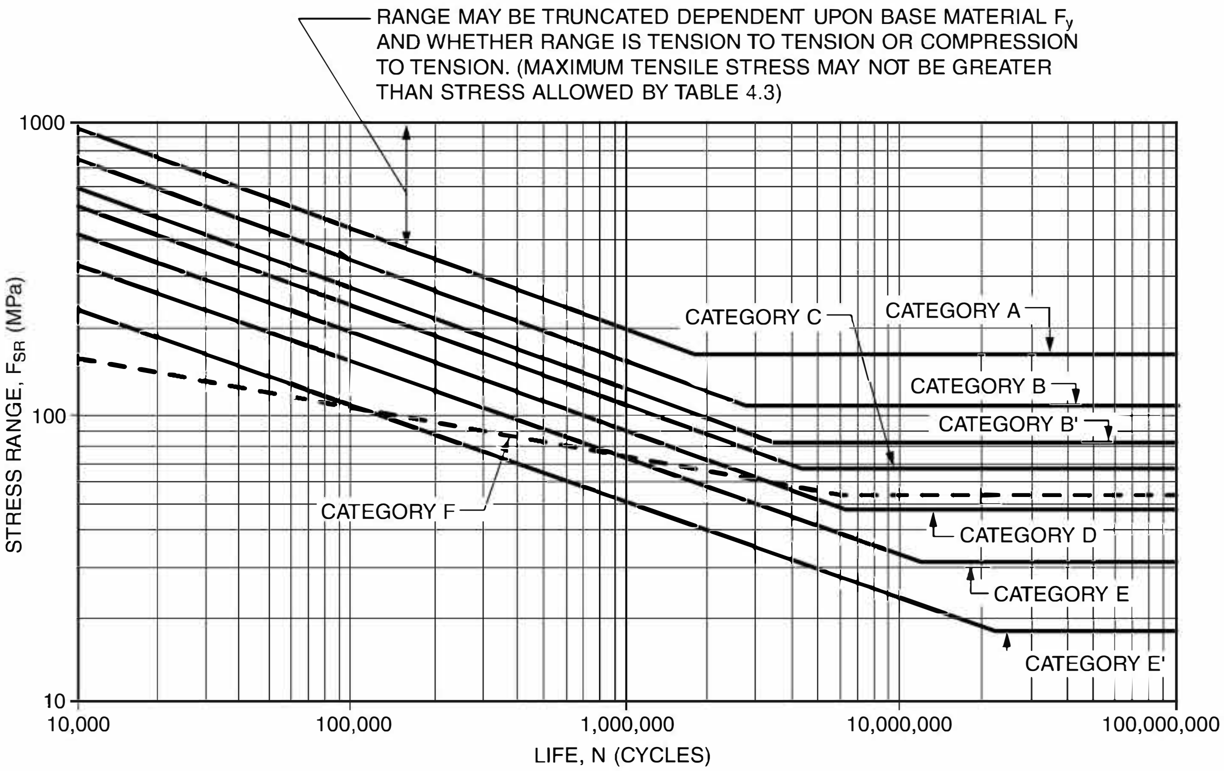


(A) U.S. CUSTOMARY UNITS



(B) METRIC UNITS

Figure 4.16—Allowable Stress Range for Cyclically Applied Load (Fatigue) in Nontubular Connections (Graphical Plot of Table 4.5) (see 4.16.2)

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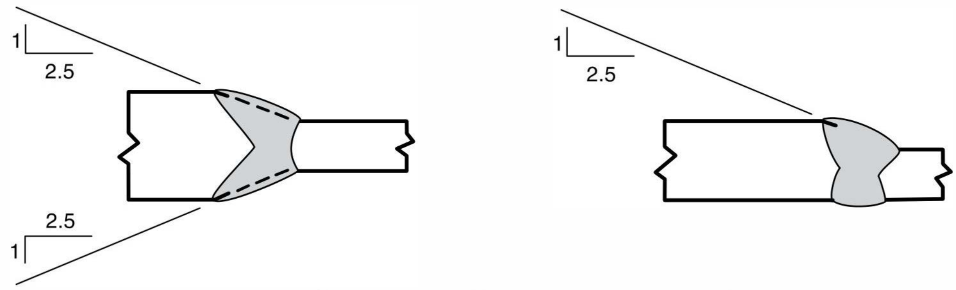
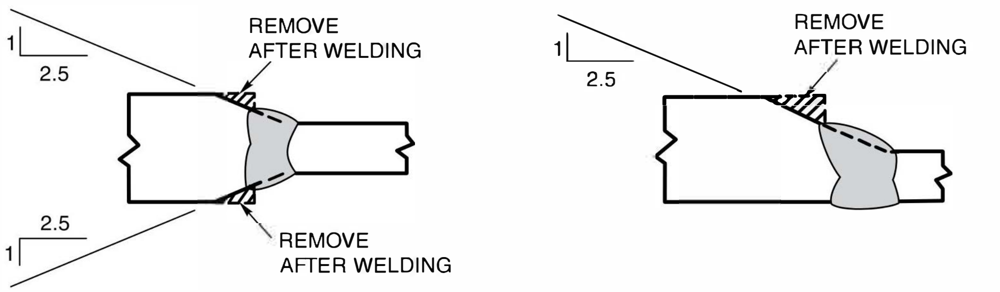
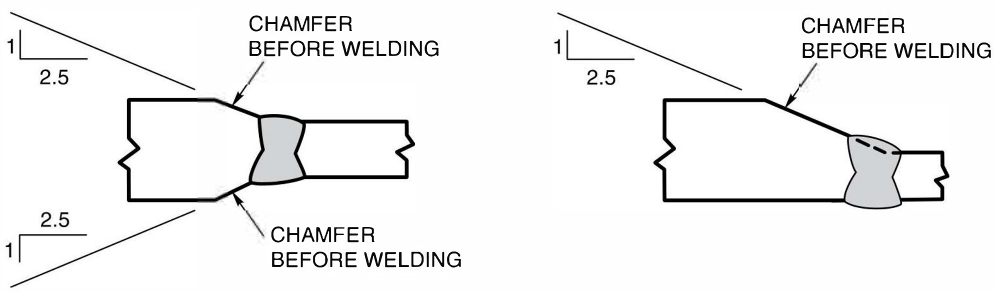


(A) TRANSITION BY SLOPING WELD SURFACE



(B) TRANSITION BY SLOPING WELD SURFACE AND CHAMFERING



(C) TRANSITION BY CHAMFERING THICKER PART

CENTERLINE ALIGNMENT
(PARTICULARLY APPLICABLE
TO WEB PLATES)

OFFSET ALIGNMENT
(PARTICULARLY APPLICABLE
TO FLANGE PLATES)

Figure 4.17—Transition of Butt Joints in Parts of Unequal Thickness (Cyclically Loaded Nontubular) (see 4.17.1.1)

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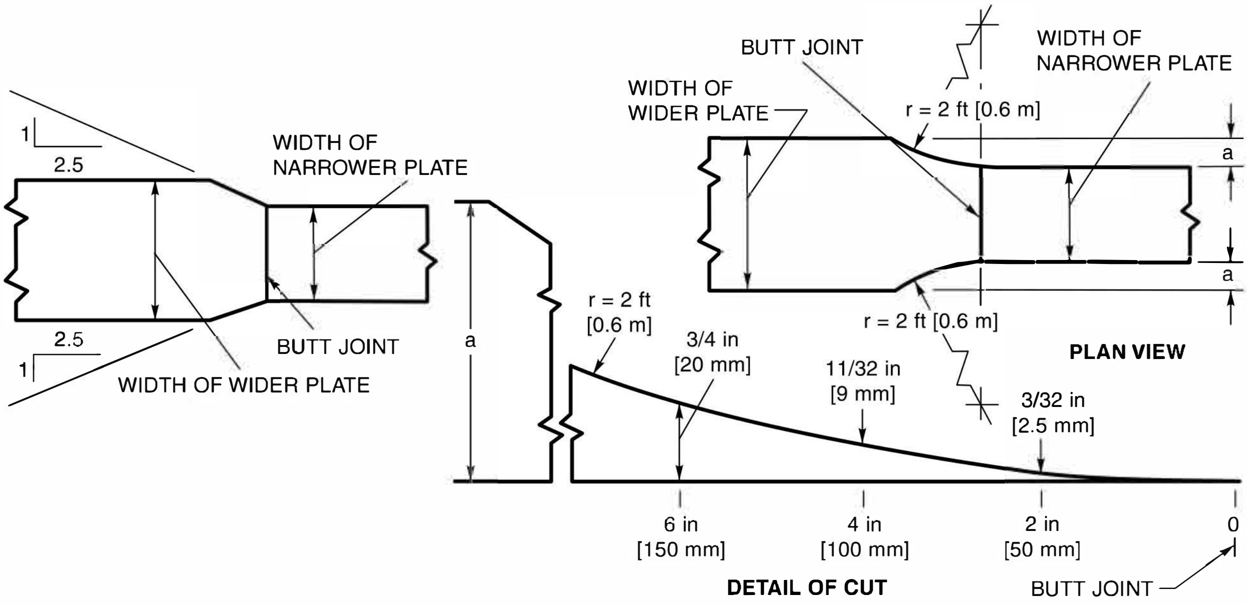

Figure 4.18—Transition of Width (Cyclically Loaded Nontubular) (see 4.17.1.2)

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5. Prequalification of WPSs

5.1 Scope

This clause contains requirements for prequalified Welding Procedure Specifications (WPSs). These WPSs are exempt from the requirements for testing required for qualification of WPSs per Clause 6.

It is divided into eight parts as follows:

Part A – WPS Development

Part B – Base Metal

Part C – Weld Joints

Part D – Welding Processes

Part E – Filler Metals and Shielding Gases

Part F – Preheat and Interpass Temperature Requirements

Part G – WPS Requirements

Part H – Post Weld Heat Treatment

Prequalification of WPSs (Welding Procedure Specifications) shall be defined as exempt from the WPS qualification testing required in Clause 6. All prequalified WPSs shall be written. In order for a WPS to be prequalified, conformance with all of the applicable requirements of Clause 5 shall be required. WPSs that do not conform to the requirements of Clause 5 may be qualified by tests in conformance with Clause 6. For convenience, Annex K lists provisions to be included in a prequalified WPS, and which should be addressed in the fabricator's or Contractor's welding program.

Welders, welding operators and tack welders that use prequalified WPSs shall be qualified in conformance with Clause 6, Part C or Clause 10, Part D for tubulars.

Part A
WPS Development

5.2 General WPS Requirements

All the requirements of Table 5.1 shall be met for prequalified WPSs.

5.2.1 All prequalified WPSs to be used shall be prepared by the manufacturer, fabricator, or Contractor as written prequalified WPSs. The written WPS may follow any convenient format (see Annex J for examples). The welding parameters set forth in Table 5.2 shall be specified on the written WPS, and for variables with limits, within the range shown. Changes to the essential variables beyond those permitted by Table 5.2 shall require a new or revised prequalified WPS, or shall require that the WPS be qualified by test in accordance with Clause 6.

5.2.2 Combination of WPSs. A combination of qualified and prequalified WPSs may be used without qualification of the combination, provided the limitation of essential variables applicable to each process is observed.

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Part B
Base Metal

5.3 Base Metal

Only base metals listed in Table 5.3 may be used in prequalified WPSs. (For the qualification of listed base metals, and for base metals not listed in Table 5.3, see 6.2.1.)

5.3.1 Engineer's Approval for Auxiliary Attachments. As an alternative to WPS qualification, unlisted materials for auxiliary attachments which fall within the chemical composition range of a steel listed in Table 5.3 may be used in a prequalified WPS when approved by the Engineer. The filler metal of Table 5.4 and minimum preheat shall be in conformance with 5.7, based upon the similar material strength and chemical composition.

Part C
Weld Joints

5.4 Weld Joints

5.4.1 Complete Joint Penetration (CJP) Groove Weld Details.

CJP groove welds which may be used without performing the WPS qualification test described in Clause 6 shall be as detailed in Figure 5.1 and are subject to the limitations described in 5.4.1.1.

5.4.1.1 Joint Dimensions. Dimensions of groove welds specified in 5.4.1 may vary on design or detail drawings within the limits or tolerances shown in the "As Detailed" column in Figure 5.1.

5.4.1.2 Backing. Prequalified CJP groove welds made from one side only, except as allowed for tubular structures, shall have steel backing.

5.4.1.3 Prequalified CJP groove welds detailed without steel backing or spacers may use backing other than steel as listed in 7.9.3 when the following conditions are met:

(1) The backing is removed after welding, and,

(2) The back side of the weld is backgouged to sound metal and backwelded.

Welding procedures for joints welded with backing other than steel in which the weld is to be left in the as welded condition without backgouging and welding from the other side are not prequalified.

5.4.1.4 Double-Sided Groove Preparation. J and U-grooves and the other side of partially welded double-V and double-bevel grooves may be prepared before or after assembly. After backgouging, the other side of partially welded double-V or double-bevel joints should resemble a prequalified U or J-joint configuration at the joint root.

5.4.1.5 GMAW/FCAW in SMAW Joints. Groove preparations detailed for prequalified SMAW joints may be used for prequalified GMAW or FCAW.

5.4.1.6 Corner Joint Preparation. For corner joints, the outside groove preparation may be in either or both members, provided the basic groove configuration is not changed and adequate edge distance is maintained to support the welding operations without excessive melting.

5.4.1.7 Root Openings. Joint root openings may vary as noted in 5.4.1.1and 5.4.1.8. However, for automatic or mechanized welding using FCAW, GMAW, and SAW processes, the maximum root opening variation (minimum to maximum opening as fit-up) may not exceed 1/8 in [3 mm]. Variations greater than 1/8 in [3 mm] shall be locally corrected prior to automatic or mechanized welding.

5.4.1.8 Fit-up Tolerances. Fit-up tolerances of Figure 5.1 may be applied to the dimensions shown on the detail drawing.

5.4.1.9 J and U-Groove Preparation. J and U-grooves may be prepared before or after assembly.

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5.4.2 Partial Joint Penetration (PJP) Groove Weld Details. WPSs for PJP welds which may be used without performing the WPS qualification test described in Clause 6 shall be "As Detailed" in Figure 5.2 and are subject to the limitations described in 5.4.2.

5.4.2.1 Definition. Except as provided in 10.10.2 and Figure 5.1 (B-L1-S), groove welds without steel backing, welded from one side, and groove welds welded from both sides, but without backgouging, are considered PJP groove welds.

5.4.2.2 Joint Dimensions. Dimensions of groove welds specified in 5.4.2 may vary on design or detail drawings within the limits of tolerances shown in the "As Detailed" column in Figure 5.2.

5.4.2.3 Prequalified Weld Size. The weld size (S) of a prequalified PJP groove shall be as shown in Figure 5.2 for the particular welding process, joint designation, groove angle, and welding position proposed for use in welding fabrication.

(1) The minimum weld size of PJP single or double V, bevel-, J-, and U-groove welds, types 2 through 9, shall be as shown in Table 5.5. The base metal thickness shall be sufficient to incorporate the requirements of the joint details selected, conforming to the variances outlined in 5.4.2.2 and the requirements of Table 5.5.

(2) The maximum base metal thickness shall not be limited.

(3) For PJP square groove weld B-P1 and flare-bevel groove welds BTC-P10 and B-P11, minimum weld sizes shall be calculated from Figure 5.2.

(4) Shop or working drawings shall specify the design groove depth "D" applicable for the weld size "(S)" required per 5.4.2.2. (Note that this requirement shall not apply to the B-P1, BTC-P10, and B-P11 details.)

5.4.2.4 GMAW/FCAW in SMAW Joints. Groove preparations detailed for prequalified SMAW joints may be used for prequalified GMAW or FCAW.

5.4.2.5 Corner Joint Preparation. For corner joints, the outside groove preparation may be in either or both members, provided the basic groove configuration is not changed and adequate edge distance is maintained to support the welding operations without excessive melting.

5.4.2.6 Root Openings. Joint root openings may vary as noted in 5.4.2.2 and 5.4.2.7. However, for automatic or mechanized welding using GMAW, FCAW, and SAW processes, the maximum root opening variation (minimum to maximum opening as fit-up) may not exceed 1/8 in [3 mm]. Variations greater than 1/8 in [3 mm] shall be locally corrected prior to automatic or mechanized welding.

5.4.2.7 Fit-up Tolerances. Fit-up tolerances of Figure 5.2 may be applied to the dimensions shown on the detail drawing. However, the use of fit-up tolerances does not exempt the user from meeting the minimum weld size requirements of 5.4.2.3(1).

5.4.2.8 J and U-Groove Preparation. J and U-grooves may be prepared before or after assembly.

5.4.3 Fillet Weld Details. See Table 7.7 for minimum fillet weld sizes and Figure 5.3 for prequalified fillet weld joint details.

5.4.3.1 Details (Nontubular). See Figures 4.1, 4.7, and 4.9 for the limitations for prequalified fillet welds.

5.4.3.2 Skewed T-Joints. Skewed T-joints shall be in conformance with Figures 5.4 and 5.5.

5.4.3.3 Dihedral Angle Limitations. The obtuse side of skewed T-joints with dihedral angles greater than 100° shall be prepared as shown in Figure 5.4, Detail C, to allow placement of a weld of the required size. The amount of machining or grinding, etc., of Figure 5.4, Detail C, should not be more than that required to achieve the required weld size (W).

5.4.3.4 Minimum Weld Size for Skewed T-Joints. For skewed T-joints, the minimum weld size for Details A, B, and C in Figure 5.4 shall be in conformance with Table 7.7.

5.4.4 Plug and Slot Weld Requirements The details of plug and slot welds made by the SMAW, GMAW (except GMAW-S), or FCAW processes are described in 4.4.5.1, 4.4.5.2, 4.4.5.4, and 4.10 and they may be used without performing the WPS qualification described in Clause 6, provided the technique provisions of 7.24 are met.

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Part D
Welding Processes

5.5 Welding Processes

5.5.1 Prequalified Processes. SMAW, SAW, GMAW (except GMAW-S), and FCAW WPSs which conform to all of the provisions of Clause 5 shall be deemed as prequalified and are therefore approved for use without performing WPS qualification tests for the process. For WPS prequalification, conformance with all of the applicable provisions of Clause 5 shall be required (see 5.1).

5.5.2 Code Approved Processes. ESW, EGW, GTAW, and GMAW-S welding may be used, provided the WPSs are qualified in conformance with the requirements of Clause 6. Note that the essential variable limitations in Table 6.5 for GMAW shall also apply to GMAW-S.

5.5.3 Other Welding Processes. Other welding processes not covered by 5.5.1 and 5.5.2 may be used, provided the WPSs are qualified by applicable tests as described in Clause 6.

5.5.4 GMAW and FCAW Power Sources. GMAW and FCAW that is done with prequalified WPSs shall be performed using constant voltage (CV) power supplies.

5.5.5 Common Requirements for GMAW Root Pass followed by Parallel Electrode and Multiple Electrode SAW. Welds may also be made in the root of groove or fillet welds using GMAW, followed by parallel or multiple electrode submerged arcs, provided that:

(1) The GMAW conforms to the requirements of this section, and

(2) The spacing between the GMAW arc and the following SAW arc does not exceed 15 in [380 mm].

Part E
Filler Metals and Shielding Gases

5.6 Filler Metal and Shielding Gas

Only filler metals listed in Table 5.4 may be used in prequalified WPSs. For the qualification of listed filler metals, and for filler metals not listed in Table 5.4, see 6.2.1.

5.6.1 Filler Metal Matching. The base metal/filler metal strength relationships below shall be used in conjunction with Tables 5.3 and 5.4 to determine whether matching or undermatching filler metals are required.

Relationship	Base Metal(s)	Filler Metal Strength Relationship Required
Matching	Any steel to itself or any steel to another in the same group	Any filler metal listed in the same group
	Any steel in one group to any steel in another	Any filler metal listed for either strength group. SMAW electrodes shall be the low-hydrogen classification
Undermatching	Any steel to any steel in any group	Any filler metal listed in a strength group below the lower strength group. SMAW electrodes shall be the low-hydrogen classification

Note: See Table 4.3 or 10.2 to determine the filler metal strength requirements to match or undermatch base metal strength.

5.6.2 Weathering Steel Requirements. For exposed, bare, unpainted applications of weathering steel requiring weld metal with atmospheric corrosion resistance and coloring characteristics similar to that of the base metal, the electrode or electrode-flux combination shall conform to Table 5.6.

The exceptions to this requirement are as follows:

5.6.2.1 Single-Pass Groove Welds. Groove welds made with a single pass or a single pass on each side may be made using any of the filler metals for Group II base metals in Table 5.4.

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5.6.2.2 Single-Pass Fillet Welds. Single-pass fillet welds up to the following sizes may be made using any of the filler metals for Group II base metals listed in Table 5.4:

SMAW	1/4 in [6 mm]
SAW	5/16 in [8 mm]
GMAW/FCAW	5/16 in [8 mm]

5.6.3 Shielding Gas. Shielding gases for GMAW and FCAW-G shall conform to AWS A5.32M/A5.32 and one of the following:

(1) The shielding gas shall be that used for electrode classification per the applicable AWS A5 specifications, AWS A5.18/A5.18M, A5.20/A5.20M, A5.28/A5.28M, or A5.29/A5.29M.

(2) For AWS A5.36/A5.36M fixed classifications of carbon steel gas shielded FCAW and GMAW, and low-alloy steel FCAW qualified with M21 shielding gas, they shall be limited to the mixed shielding gas requirements of AWS A5.18/A5.18M, A5.20/A5.20M, or A5.29/A5.29M, M21-ArC-20/25(SG-AC-20-25).

(3) The classification shielding gas for all AWS A5.36/A5.36M open classifications shall be limited to the shielding gas designator used for classification(s) and not the range of the shielding gas classification.

(4) For electrodes classified per AWS A5.18/A5.18M, Table 5.7 provides acceptable shielding gases or gas mixtures for production welding.

(5) The electrode/shielding gas combination shall have been tested in accordance with the applicable A5 filler metal specification. The tests shall demonstrate that the electrode/shielding gas combination is capable of meeting all the mechanical and chemical property and NDT requirements for the electrode classification. For FCAW-G and GMAW composite (metal cored) electrodes, tests shall be performed for each electrode manufacturer's brand and trade name to be used. Testing shall be performed by the filler metal manufacturer or gas producer. For FCAW-G, the filler metal shall have been classified by the filler metal manufacturer as an "–M" (i.e. mixed gas) product.

Part F
Preheat and Interpass Temperature Requirements

5.7 Preheat and Interpass Temperature Requirements

5.7.1 Minimum Preheat and Interpass Temperature Requirements. Table 5.8 shall be used to determine the minimum preheat and interpass temperatures for steels listed in the code.

5.7.2 Base Metal/Thickness Combination. The minimum preheat or interpass temperature applied to a joint composed of base metals with different minimum preheats from Table 5.8 (based on category and thickness) shall be the highest of these minimum preheats.

5.7.3 Alternate SAW Preheat and Interpass Temperatures. Preheat and interpass temperatures for parallel or multiple electrode SAW shall be selected in conformance with Table 5.8. For single-pass groove or fillet welds, for combinations of metals being welded and the heat input involved, and with the approval of the Engineer, preheat and interpass temperatures may be established which are sufficient to reduce the hardness in the HAZs of the base metal to less than 225 Vickers hardness number for steel having a minimum specified tensile strength not exceeding 60 ksi [415 MPa], and 280 Vickers hardness number for steel having a minimum specified tensile strength greater than 60 ksi [415 MPa], but not exceeding 70 ksi [485 MPa].

The Vickers hardness number shall be determined in conformance with ASTM E92. If another method of hardness is to be used, the equivalent hardness number shall be determined from ASTM E140, and testing shall be performed according to the applicable ASTM specification.

5.7.3.1 Hardness Requirements. Hardness determination of the HAZ shall be made on the following:

(1) Initial macroetch cross sections of a sample test specimen.

(2) The surface of the member during the progress of the work. The surface shall be ground prior to hardness testing:

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(a) The frequency of such HAZ testing shall be at least one test area per weldment of the thicker metal involved in a joint of each 50 ft [15 m] of groove welds or pair of fillet welds.

(b) These hardness determinations may be discontinued after the procedure has been established and the discontinuation is approved by the Engineer.

Part G
WPS Requirements

5.8 WPS Requirements

5.8.1 General WPS Requirements. All the requirements of Table 5.1 shall be met for prequalified WPSs.

5.8.1.1 Vertical-Up Welding Requirements. The progression for all passes in vertical position welding shall be upward, with the following exceptions:

(1) Undercut may be repaired vertically downwards when preheat is in conformance with Table 5.8, but not lower than 70°F [20°C].

(2) When tubular products are welded, the progression of vertical welding may be upwards or downwards, but only in the direction(s) for which the welder is qualified.

5.8.2 Limitation of Variables. Table 5.1 lists WPS variable requirements and limitations by position, weld type, and process.

5.8.2.1 Width/Depth Pass Limitation. Neither the depth nor the maximum width in the cross section of weld metal deposited in each weld pass shall exceed the width at the surface of the weld pass (see Figure 5.6).

Part H
Postweld Heat Treatment

5.9 Postweld Heat Treatment

Postweld heat treatment (PWHT) shall be prequalified provided that it shall be approved by the Engineer and the following conditions shall be met:

(1) The specified minimum yield strength of the base metal shall not exceed 50 ksi [345 MPa].

(2) The base metal shall not be manufactured by quenching and tempering (Q&T), quenching and self-tempering (Q&ST), thermo-mechanical controlled processing (TMCP) or where cold working is used to achieve higher mechanical properties (e.g., certain grades of ASTM A500 tubing).

(3) There shall be no requirements for notch toughness testing of the base metal, HAZ, or weld metal.

(4) There shall be data available demonstrating that the weld metal shall have adequate strength and ductility in the PWHT condition (e.g., as can be found in the relevant AWS A5.X filler metal specification and classification or from the filler metal manufacturer).

(5) PWHT shall be conducted in conformance with 7.8.

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Table 5.1
Prequalified WPS Requirements[a] (see 5.2)

Variable	Position	Weld Type	SMAW	SAW[b]			GMAW/ FCAW[c]
				Single	Parallel	Multiple	
Maximum Electrode Diameter	Flat	Fillet[d]	5/16 in [8.0 mm]	1/4 in [6.4 mm]			1/8 in [3.2 mm]
		Groove[d]	1/4 in [6.4 mm]				
		Root pass	3/16 in [4.8 mm]				
	Horizontal	Fillet	1/4 in [6.4 mm]	1/4 in [6.4 mm]			1/8 in [3.2 mm]
		Groove	3/16 in [4.8 mm]	Requires WPS Qualification Test			
	Vertical	All	3/16 in [4.8 mm][e]				3/32 in [2.4 mm]
	Overhead	All	3/16 in [4.8 mm][e]				5/64 in [2.0 mm]
Maximum Current	All	Fillet	Within the range of operation recommended by the filler metal manufacturer	1000 A	1200A	Unlimited	Within the range of operation recommended by the filler metal manufacturer
	All	Groove weld root pass with opening		600A	700A		
		Groove weld root pass without opening			900A		
		Groove weld fill passes			1200A		
		Groove weld cap pass		Unlimited			
Maximum Root Pass Thickness[b]	Flat	All	3/8 in [10 mm]	Unlimited			3/8 in [10 mm]
	Horizontal		5/16 in [8 mm]				5/16 in [8 mm]
	Vertical		1/2 in [12 mm]				1/2 in [12 mm]
	Overhead		5/16 in [8 mm]				5/16 in [8 mm]
Maximum Fill Pass Thickness	All	All	3/16 in [5 mm]	1/4 in [6 mm]	Unlimited		1/4 in [6 mm]
Maximum Single Pass Fillet Weld Size[f]	Flat	Fillet	3/8 in [10 mm]	Unlimited			1/2 in [12 mm]
	Horizontal		5/16 in [8 mm]	5/16 in [8 mm]	5/16 in [8 mm]	1/2 in [12 mm]	3/8 in [10 mm]
	Vertical		1/2 in [12 mm]				1/2 in [12 mm]
	Overhead		5/16 in [8 mm]				5/16 in [8 mm]
Maximum Single Pass Layer Width	All (for GMAW/ FCAW) F & H (for SAW)	Root opening > 1/2 in [12 mm]		Split layers	Laterally displaced electrodes or split layer	Split layers	Split layers
		Any layer of width, w		Split layers if w > 5/8 in [16 mm]	Split layers with tandem electrodes if w > 5/8 in [16 mm]	Split layers if w > 1 in [25 mm]	(Footnote g)

[a] Shaded area indicates nonapplicability.
[b] See 5.8.2.1 for width–to–depth limitations.
[c] GMAW-S shall not be prequalified.
[d] Except root passes.
[e] 5/32 in [4.0 mm] for EXX14 and low–hydrogen electrodes.
[f] See 5.6.2 for requirements for welding unpainted and exposed ASTM A588.
[g] In the F, H, or OH positions for nontubulars, split layers when the layer width, w > 5/8 in [16 mm]. In the vertical position for nontubulars or the flat, horizontal, vertical, and overhead positions for tubulars, split layers when the width, w > 1 in [25 mm].

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Table 5.2
Essential Variables for Prequalified WPSs (see 5.2.1)

Variables that must be included in a Prequalified WPS

(1) Welding Process(es)[a]
(2) Welding Position(s)
(3) Base Metal Group Number(s) (See Table 5.3)
(4) Base Metal Preheat Category(s) (See Table 5.4)
(5) Filler Metal Classification (SMAW, GMAW, FCAW)
(6) Filler Metal/Flux Classification (SAW)
(7) Nominal Electrode Diameter
(8) Number of Electrodes (SAW)
(9) Electrode Spacing and Orientation (SAW)
(10) Amperage (SAW, FCAW, GMAW)
(11) Voltage (SAW, FCAW, GMAW)
(12) Mode of Transfer (GMAW)
(13) Type of Current (AC or DC)
(14) Current Polarity (AC, DCEN, DCEP)
(15) Wire Feed Speed (SAW, FCAW, GMAW)
(16) Travel Speed
(17) Nominal Shielding Gas Composition (FCAW-G, GMAW)
(18) Shielding Gas Flow Rate (FCAW-G, GMAW)
(19) Weld Type (Fillet, CJP, PJP, Plug, Slot)
(20) Groove Weld Details
(21) Postweld Heat Treatment

Variable Tolerances for Prequalified WPSs

Variable	Allowable tolerance
(22) Amperage (SAW, FCAW, GMAW)	+ or – 10%
(23) Voltage (SAW, FCAW, GMAW)	+ or – 15%
(24) Wire Feed Speed (if not amperage controlled) (SAW, FCAW, GMAW)	+ or – 10%
(25) Travel Speed (SAW, FCAW, GMAW)	+ or – 25%
(26) Shielding Gas Flow Rate (FCAW-G, GMAW)	> 50%, if increase or > 25%, if decrease
(27) Change in the longitudinal spacing of arcs (SAW)	> 10% or 1/8 in [3 mm], whichever is greater
(28) Lateral spacing of arcs (SAW)	> 10% or 1/8 in [3 mm], whichever is greater
(29) The angular orientation of parallel electrodes (SAW)	+ or – 10%
(30) The angle parallel to the direction of travel of the electrode for mechanized or automatic (SAW)	+ or – 10%
(31) The angle of electrode normal to the direction of travel for mechanized or automatic (SAW)	+ or – 10%

[a] A separate WPS shall be required when this variable is changed.

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Table 5.3
Approved Base Metals for Prequalified WPSs (see 5.3)

GROUP	Steel Specification Requirements		Minimum Yield Point/Strength		Tensile Range	
		Steel Specification	ksi	MPa	ksi	MPa
	ASTM A36	≤ 3/4 in [20 mm]	36	250	58–80	400–550
	ASTM A53	Grade B	35	240	60 min.	415 min.
	ASTM A106	Grade B	35	240	60 min.	415 min.
	ASTM A131	Grades A, B, D, E	34	235	58–75	400–520
	ASTM A139	Grade B	35	240	60 min.	415 min.
	ASTM A381	Grade Y35	35	240	60 min.	415 min.
	ASTM A500 (Square/ Rectangular)	Grade A	39	270	45 min.	310 min.
		Grade B	46	315	58 min.	400 min.
		Grade C	50	345	62 min.	425 min.
	ASTM A500 (Round)	Grade A	33	230	45 min.	310 min.
		Grade B	42	290	58 min.	400 min.
		Grade C	46	315	62 min.	425 min.
	ASTM A501	Grade A	36	250	58 min.	400 min.
	ASTM A516	Grade 55	30	205	55–75	380–515
		Grade 60	32	220	60–80	415–550
	ASTM A524	Grade I	35	240	60–85	415–586
		Grade II	30	205	55–80	380–550
I	ASTM A573	Grade 65	35	240	65–77	450–530
		Grade 58	32	220	58–71	400–490
	ASTM A709	Grade 36 ≤ 3/4 in [20 mm]	36	250	58–80	400–550
	ASTM A1008 SS	Grade 30	30	205	45 min.	310 min.
		Grade 33 Type 1	33	230	48 min.	330 min.
		Grade 40 Type 1	40	275	52 min.	360 min.
	ASTM A1011 SS	Grade 30	30	205	49 min.	340 min.
		Grade 33	33	230	52 min.	360 min.
		Grade 36 Type 1	36	250	53 min.	365 min.
		Grade 40	40	275	55 min.	380 min.
		Grade 45 Type 1	45	310	60 min.	410 min.
	ASTM A1018 SS	Grade 30	30	205	49 min.	340 min.
		Grade 33	33	230	52 min.	360 min.
		Grade 36	36	250	53 min.	365 min.
		Grade 40	40	275	55 min.	380 min.
	API 5L	Grade B	35	241	60 min.	414 min.
		Grade X42	42	290	60 min.	414 min.
	ABS	Grades A, B, D, E[b]	34	235	58–75	400–520

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Table 5.3 (Continued)
Approved Base Metals for Prequalified WPSs (see 5.3)

GROUP	Steel Specification		Minimum Yield Point/Strength ksi	Minimum Yield Point/Strength MPa	Tensile Range ksi	Tensile Range MPa
II	ASTM A36	All thicknesses	36	250	58–80	400–550
	ASTM A131	Grades AH32, DH32, EH32	46	315	64–85	440–590
		Grades AH36, DH36, EH36	51	355	71–90	490–620
	ASTM A501	Grade B	50	345	70 min.	485 min.
	ASTM A516	Grade 65	35	240	65–85	450–585
		Grade 70	38	260	70–90	485–620
	ASTM A529	Grade 50	50	345	65–100	450–690
		Grade 55	55	380	70–100	485–690
	ASTM A537 Class 1	≤ 2 ½ in [≤ 65 mm]	50	345	70–90	485–620
		> 2 ½ [65 mm] ≤ 4 in [100 mm]	45	310	65–85	450–585
	ASTM A572	Grade 42	42	290	60 min.	415 min.
		Grade 50	50	345	65 min.	450 min.
		Grade 55	55	380	70 min.	485 min.
	ASTM A588[b]	≤ 4 in [100 mm]	50	345	70 min.	485 min.
		> 4 in [100 mm] ≤ 5 in [125 mm]	46	315	67min.	460 min.
		> 5 in [125 mm] ≤ 8 in [200 mm]	42	290	63 min.	435 min.
		All Shapes	50	345	70 min.	485 min.
	ASTM A595	Grade A	55	380	65 min.	450 min.
		Grades B and C	60	410	70 min.	480 min.
	ASTM A606[b]	Cold-rolled Grade 45	45	310	65 min.	450 min.
		Hot-rolled Grade 50 (AR)	50	340	70 min.	480 min.
		Hot-rolled Grade 50 (A or N)	45	310	65 min.	450 min.
	ASTM A618	Grades Ib, II wall ≤ ¾ in [19 mm]	50	345	70 min.	485 min.
		Grades Ib, II wall > ¾ in ≤ 1-1/2 in [> 19 mm ≤ 38 mm]	46	315	67 min.	460 min.
		Grade III	50	345	65 min.	450 min.
	ASTM A633	Grade A	42	290	63–83	430–570
		Grades C, D ≥ 2-1/2 in [65 mm]	50	345	70–90	485–620
	ASTM A709	Grade 36 Plates ≤ 4 in [100 mm]	36	250	58–80	400–550
		Grade 36 Shapes ≤ 3 in [75 mm]	36	250	58–80	400–550
		Grade 36 Shapes > 3 in [75 mm]	36	250	58 min.	400 min.
		Grade 50	50	345	65 min.	450 min.
		Grade 50W[b]	50	345	70 min.	485 min.
		Grade 50S	50–65	345–450	65 min.	450 min.
		Grade HPS 50W[b]	50	345	70 min.	485 min.
	ASTM A710	Grade A, Class 2 > 2 in ≤ 4 in [> 50 mm ≤ 100 mm]	55	380	65 min.	450 min.
		> 4 in [100 mm]	50	345	60 min.	415 min.
	ASTM A847		50	345	70 min.	485 min.
	ASTM A913	Grade 50	50	345	65 min.	450 min.
	ASTM A992		50–65	345–450	65 min.	450 min.
	ASTM A1008 HSLAS	Grade 45 Class 1	45	310	60 min.	410 min.
		Grade 45 Class 2	45	310	55 min.	380 min.
		Grade 50 Class 1	50	340	65 min.	450 min.
		Grade 50 Class 2	50	340	60 min.	410 min.
		Grade 55 Class 1	55	380	70 min.	480 min.
		Grade 55 Class 2	55	380	65 min.	450 min.

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Table 5.3 (Continued)
Approved Base Metals for Prequalified WPSs (see 5.3)

GROUP	Steel Specification Requirements		Minimum Yield Point/Strength		Tensile Range	
	Steel Specification		ksi	MPa	ksi	MPa
II (cont'd)	ASTM A1008 HSLAS-F	Grade 50	50	340	60 min.	410 min.
	ASTM A1011 HSLAS	Grade 45 Class 1	45	310	60 min.	410 min.
		Grade 45 Class 2	45	310	55 min.	380 min.
		Grade 50 Class 1	50	340	65 min.	450 min.
		Grade 50 Class 2	50	340	60 min.	410 min.
		Grade 55 Class 1	55	380	70 min.	480 min.
		Grade 55 Class 2	55	380	65 min.	450 min.
	ASTM A1011 HSLAS-F	Grade 50	50	340	60 min.	410 min.
	ASTM A1011 SS	Grade 50	50	340	65 min.	450 min.
		Grade 55	55	380	70 min.	480 min.
	ASTM A1018 HSLAS	Grade 45 Class 1	45	310	60 min.	410 min.
		Grade 45 Class 2	45	310	55 min.	380 min.
		Grade 50 Class 1	50	340	65 min.	450 min.
		Grade 50 Class 2	50	340	60 min.	410 min.
		Grade 55 Class 1	55	380	70 min.	480 min.
		Grade 55 Class 2	55	380	65 min.	450 min.
	ASTM A1018 HSLAS-F	Grade 50	50	340	60 min.	410 min.
	ASTM A1066	Grade 50	50	345	65 min.	450 min.
	ASTM A1085		50–70	345–485	65 min.	450 min.
	API 2H	Grade 42	42	289	62–82	427–565
		Grade 50	50	345	70–90	483–620
	API 2MT1	Grade 50	50	345	65–90	488–620
	API 2W	Grade 42	42–67	290–462	62 min.	427 min.
		Grade 50	50–75	345–517	65 min.	448 min.
		Grade 50T	50–80	345–552	70 min.	483 min.
	API 2Y	Grade 42	42–67	290–462	62 min.	427 min.
		Grade 50	50–75	345–517	65 min.	448 min.
		Grade 50T	50–80	345–552	70 min.	483 min.
	API 5L	Grade X52	52	359	66 min.	455 min.
	ABS	Grades AH32, DH32, EH32	46	315	64–85	440–590
		Grades AH36, DH36, EH36[b]	51	355	71–90	490–620
III	API 2W	Grade 60	60–90	414–621	75 min.	517 min.
	API 2Y	Grade 60	60–90	414–621	75 min.	517 min.
	ASTM A537 Class 2[b]	≤ 2 ½ in [65 mm]	60	415	80–100	550–690
		> 2 ½ in [65 mm] ≤ 4 in [100 mm]	55	380	75–95	515–655
		> 4 in [100 mm] ≤ 6 in [150 mm]	46	315	70–90	485–620
	ASTM A572	Grade 60	60	415	75 min.	520 min.
		Grade 65	65	450	80 min.	550 min.
	ASTM A633 Grade E[b]	≤ 4 in [100 mm]	60	415	80–100	550–690
		> 4 in [100 mm] ≤ 6 in [150 mm]	55	380	75–95	515–655
	ASTM A710	Grade A, Class 2 ≤ 1 in [20 mm]	65	450	72 min.	495 min.
		Grade A, Class 2 > 1 in ≤ 2 in [> 25 mm ≤ 50 mm]	60	415	72 min.	495 min.
		Grade A, Class 3 > 2 in ≤ 4 in [> 50 mm ≤ 100 mm]	65	450	75 min.	515 min.
		Grade A, Class 3 > 4 in [100 mm]	60	415	70 min.	485 min.
	ASTM A913[a]	Grade 60	60	415	75 min.	520 min.
		Grade 65	65	450	80 min.	550 min.

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Table 5.3 (Continued)
Approved Base Metals for Prequalified WPSs (see 5.3)

GROUP	Steel Specification Requirements					
			Minimum Yield Point/Strength		Tensile Range	
	Steel Specification		ksi	MPa	ksi	MPa
III (cont'd)	ASTM A1018 HSLAS	Grade 60 Class 2	60	410	70 min.	480 min.
		Grade 70 Class 2	70	480	80 min.	550 min.
	ASTM A1018 HSLAS-F	Grade 60 Class 2	60	410	70 min.	480 min.
		Grade 70 Class 2	70	480	80 min.	550 min.
	ASTM A1066	Grade 60	60	415	75 min.	520 min.
		Grade 65	65	450	80 min.	550 min.
IV	ASTM A709	Grade HPS70W	70	485	85–110	585–760
	ASTM A913[a]	Grade 70	70	485	90 min.	620 min.
	ASTM A1066	Grade 70	70	485	85 min.	585 min.

[a] The heat input limitations of 7.7 shall not apply to ASTM A913 Grades 60,65, or 70.
[b] Special welding materials and WPS (e.g., E80XX-X low-alloy electrodes) may be required to match the notch toughness of base metal (for applications involving impact loading or low temperature), or for atmospheric corrosion and weathering characteristics (see 5.6.2).

Notes:
1. In joints involving base metals of different groups, either of the following filler metals may be used: (1) that which matches the higher strength base metal, or (2) that which matches the lower strength base metal and produces a low-hydrogen deposit.
2. Match API standard 2B (fabricated tubes) according to steel used.
3. When welds are to be postweld heat treated, the deposited weld metal shall not exceed 0.05% vanadium.
4. See Tables 4.3 and 10.2 for allowable stress requirements for matching filler metal.
5. Filler metal strength properties have been moved to nonmandatory Annex L.
6. AWS A5M (SI Units) electrodes of the same classification may be used in lieu of the AWS A5 (U.S. Customary Units) electrode classification.
7. Any of the electrode classifications for a particular Group (located on the right of Table 5.4) may be used to weld any of the base metals in that Group (located on the left of Table 5.3).

Table 5.4
Filler Metals for Matching Strength for Table 5.3, Groups I, II, III, and IV Metals—SMAW and SAW (see 5.6)

Base Metal Group	AWS Electrode Specification	SMAW A5.1, Carbon Steel	SMAW A5.5[a], Low-Alloy Steel	SAW A5.17, Carbon Steel	SAW A5.23[c], Low-Alloy Steel
I	AWS Electrode Classification	E60XX E70XX	E70XX-X	F6XX-EXXX F6XX-ECXXX F7XX-EXXX F7XX-ECXXX	F7XX-EXXX-XX F7XX-ECXXX-XX
II	AWS Electrode Classification	E7015 E7016 E7018 E7028	E7015-X E7016-X E7018-X	F7XX-EXXX F7XX-ECXXX	F7XX-EXXX-XX F7XX-ECXXX-XX
III	AWS Electrode Classification	N/A	E8015-X E8016-X E8018-X	N/A	F8XX-EXXX-XX F8XX-ECXXX-XX
IV	AWS Electrode Classification	N/A	E9015-X E9016-X E9018-X E9018M	N/A	F9XX-EXXX-XX F9XX-ECXXX-XX

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Table 5.4 (Continued)
Filler Metals for Matching Strength for Table 5.3, Group I Metals—FCAW and GMAW Metal Cored (see 5.6)

		WELDING PROCESS(ES)					
		GMAW		FCAW		Carbon Steel GMAW and FCAW	Carbon & Low-Alloy Steel GMAW and FCAW
Base Metal Group	AWS Electrode Specification	A5.18, Carbon Steel	A5.28[a], Low-Alloy Steel	A5.20, Carbon Steel	A5.29[a], Low-Alloy Steel	A5.36, Fixed Classification[b]	A5.36[c] Open Classification[d] See Note 8 for Annex M
I	AWS Electrode Classification	ER70S-X E70C-XC E70C-XM (Electrodes with the –GS suffix shall be excluded)	ER70S-XXX E70C-XXX	E7XT-X E7XT-XC E7XT-XM (Electrodes with the –2C, –2M, –3, –10, –13, –14, and –GS suffix shall be excluded and electrodes with the –11 suffix shall be excluded for thicknesses greater than 1/2 in [12 mm])	E6XTX-X E7XTX-X E6XTX-XC E6XTX-XM E7XTX-XC E7XTX-XM	**FCAW Carbon Steel** E7XT-1C E7XT-1M E7XT-5C E7XT-5M E7XT-9C E7XT-9M E7XT-12C E7XT-12M E70T-4 E7XT-6 E7XT-7 E7XT-8 (Flux Cored Electrodes with the T1S, T3S, T10S, T14S, and –GS suffix shall be excluded and electrodes with the T1l suffix shall be excluded for thicknesses greater than 1/2 in [12 mm]) **GMAW-Metal Cored Carbon Steel** E70C-6M (Electrodes with the –GS suffix shall be excluded) (NOTE: A5.36 does not have fixed classifications for other carbon steel metal cored electrodes or for low-alloy steel flux cored or metal cored electrodes)	**FCAW Carbon Steel** E7XTX-XAX-CS1 E7XTX-XAX-CS2 E7XTX-XAX-CS3 (Flux Cored Electrodes with the T1S, T3S, T10S, T14S, and –GS suffix shall be excluded and electrodes with the T11 suffix shall be excluded for thicknesses greater than 1/2 in [12 mm]) **FCAW Low-Alloy Steel** E6XTX-XAX-XXX E7XTX-XAX-XXX **GMAW-Metal Cored Carbon Steel** E7XTX-XAX-CS1 E7XTX-XAX-CS2 (Electrodes with the –GS suffix shall be excluded) **GMAW-Metal Cored Low-Alloy Steel** E7XTX-XAX-XXX

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Table 5.4 (Continued)
Filler Metals for Matching Strength for Table 5.3, Group II Metals—FCAW and GMAW Metal Cored (see 5.6)

		WELDING PROCESS(ES)					
		GMAW		FCAW		Carbon Steel GMAW and FCAW	Carbon & Low-Alloy Steel GMAW and FCAW
Base Metal Group	AWS Electrode Specification	A5.18, Carbon Steel	A5.28[a], Low-Alloy Steel	A5.20, Carbon Steel	A5.29[a], Low-Alloy Steel	A5.36, Fixed Classification[b]	A5.36[c] Open Classification[d] See Note 8 for Annex M
II	AWS Electrode Classification	ER70S-X E70C-XC E70C-XM (Electrodes with the –GS suffix shall be excluded)	ER70S-XXX E70C-XXX	E7XT-X E7XT-XC E7XT-XM (Electrodes with the –2C, –2M, –3, –10, –13, –14, and –GS suffix shall be excluded and electrodes with the –11 suffix shall be excluded for thicknesses greater than 1/2 in [12 mm])	E7XTX-X E7XTX-XC E7XTX-XM	**FCAW Carbon Steel** E7XT-1C E7XT-1M E7XT-5C E7XT-5M E7XT-9C E7XT-9M E7XT-12C E7XT-12M E70T-4 E7XT-6 E7XT-7 E7XT-8 (Flux Cored Electrodes with the T1S, T3S, T10S, T14S, and –GS suffix shall be excluded and electrodes with the T11 suffix shall be excluded for thicknesses greater than 1/2 in [12 mm]) **GMAW-Metal Cored Carbon Steel** E70C-6M (Electrodes with the –GS suffix shall be excluded) (NOTE: A5.36 does not have fixed classifications for other carbon steel metal cored electrodes or for low-alloy steel flux cored or metal cored electrodes)	**FCAW Carbon Steel** E7XTX-XAX-CS1 E7XTX-XAX-CS2 E7XTX-XAX-CS3 (Flux Cored Electrodes with the T1S, T3S, T10S, T14S, and –GS suffix shall be excluded and electrodes with the T1l suffix shall be excluded for thicknesses greater than 1/2 in [12 mm]) **FCAW Low-Alloy Steel** E7XTX-AX-XXX E7XTX-XAX-XXX **GMAW-Metal Cored Carbon Steel** E7XTX-XAX-CS1 E7XTX-XAX-CS2 (Electrodes with the –GS suffix shall be excluded) **GMAW-Metal Cored Low-Alloy Steel** E7XTX-XAX-XXX

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Table 5.4 (Continued)
Filler Metals for Matching Strength for Table 5.3, Group III and Group IV Metals—FCAW and GMAW Metal Cored (see 5.6)

WELDING PROCESS(ES)							
		GMAW		FCAW		Carbon Steel GMAW and FCAW	Carbon & Low-Alloy Steel GMAW and FCAW
Base Metal Group	AWS Electrode Specification	A5.18, Carbon Steel	A5.28[a], Low-Alloy Steel	A5.20, Carbon Steel	A5.29[a], Low-Alloy Steel	A5.36, Fixed Classification[b]	A5.36[c] Open Classification[d] See Note 8 for Annex M
III	AWS Electrode Classification	N/A	ER80S-XXX E80C-XXX	N/A	E8XTX-X E8XTX-XC E8XTX-XM	**FCAW Carbon Steel** N/A **GMAW-Metal Cored Carbon Steel** N/A	**FCAW Carbon Steel** N/A **FCAW Low-Alloy Steel** E8XTX-AX-XXX E8XTX-XAX-XXX **GMAW-Metal Cored Carbon Steel** N/A **GMAW-Metal Cored Low-Alloy Steel** E8XTX-XAX-XXX
IV	AWS Electrode Classification	N/A	ER90S-XXX E90C-XXX	N/A	E9XTX-X E9XTX-XC E8XTX-XM	**FCAW Carbon Steel** N/A **GMAW-Metal Cored Carbon Steel** N/A	**FCAW Carbon Steel** N/A **FCAW Low-Alloy Steel** E9XTX-AX-XXX E9XTX-XAX-XXX **GMAW-Metal Cored Carbon Steel** N/A **GMAW-Metal Cored Low-Alloy Steel** E9XTX-XAX-XXX

[a] Filler metals of alloy group B3, B3L, B4, B4L, B5, B5L, B6, B6L, B7, B7L, B8, B8L, B9, E9015-C5L, E9015-D1, E9018-D1, E9018-D3, or any BXH grade in AWS A5.5, A5.23, A5.28, or A5.29 are not prequalified for use in the as-welded condition.
[b] The prequalified argon based shielding gases for carbon and low-alloy steel FCAW and carbon steel GMAW-Metal Core fixed classifications shall be M21-ArC-20-25(SG-AC-20/25), see 5.6.3(2).
[c] Filler metals of alloy group B3, B3L, B4, B4L, B5, B5L, B6, B6L, B7, B7L, B8, B8L, and B9 in AWS A5.36/A5.36M may be "PREQUALIFIED" if classified in the "AS-WELDED" condition.
[d] The prequalified shielding gas for open classification shall be limited to the specific shielding gas for the classification of the electrode and not the range of the shielding gas designator, see 5.6.3(3).

Notes:
1. In joints involving base metals of different groups, either of the following filler metals may be used: (1) that which matches the higher strength base metal, or (2) that which matches the lower strength base metal and produces a low-hydrogen deposit. Preheating shall be in conformance with the requirements applicable to the higher strength group.
2. Match API standard 2B (fabricated tubes) according to steel used.
3. When welds are to be stress-relieved, the deposited weld metal shall not exceed 0.05% vanadium except alloy group B9.
4. See Tables 4.3 and 4.6 for allowable stress requirements for matching filler metal.
5. Filler metal properties have been moved to nonmandatory Annex L.
6. AWS A5M (SI Units) electrodes of the same classification may be used in lieu of the AWS A5 (U.S. Customary Units) electrode classification.
7. Any of the electrode classifications for a particular Group in Table 5.4 may be used to weld any of the base metals in that Group in Table 5.3.
8. AWS A5.36/A5.36M open classifications are listed in Annex U.

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Table 5.5
Minimum Prequalified PJP Groove Weld Size (S) (see 5.4.2.3(1))

Base Metal Thickness (T)[a]	Minimum Weld Size[b]	
in [mm]	in	mm
1/8 [3] to 3/16 [5] incl.	1/16	2
Over 3/16 [5] to 1/4 [6] incl.	1/8	3
Over 1/4 [6] to 1/2 [12] incl.	3/16	5
Over 1/2 [12] to 3/4 [20] incl.	1/4	6
Over 3/4 [20] to 1-1/2 [38] incl.	5/16	8
Over 1-1/2 [38] to 2-1/4 [57] incl.	3/8	10
Over 2-1/4 [57] to 6 [150] incl.	1/2	12
Over 6 [150]	5/8	16

[a] For nonlow-hydrogen processes without preheat calculated in conformance with 6.8.4, T equals the thickness of the thicker part joined; single pass welds shall be used. For low-hydrogen processes and nonlow-hydrogen processes established to prevent cracking in conformance with 6.8.4, T equals thickness of the thinner part; single pass requirement does not apply.
[b] Except that the weld size need not exceed the thickness of the thinner part joined.

Table 5.6 (see 5.6.2)
Filler Metal Requirements for Exposed Bare Applications of Weathering Steels

Process	AWS Filler Metal Specification	Approved Electrodes[a]
SMAW	A5.5/A5.5M	All electrodes that deposit weld metal meeting a B2L, C1, C1L, C2, C2L, C3, or WX analysis per A5.5/A5.5M.
SAW	A5.23/A5.23M	All electrode-flux combinations that deposit weld metal with a Ni1, Ni2, Ni3, Ni4, or WX analysis per A5.23/A5.23M.
FCAW	A5.29/A5.29M and A5.36/A5.36M	All electrodes that deposit weld metal with a B2L, K2, Ni1, Ni2, Ni3, Ni4, or WX analysis per A5.29/A5.29M or A5.36/A5.36M.
GMAW	A5.28/A5.28M and A5.36/A5.36M	All electrodes that meet filler metal composition requirements of B2L, G[a], Ni1, Ni2, Ni3, analysis per A5.28/A5.28M or A5.36/A5.36M.

[a] Deposited weld metal shall have a chemical composition the same as that for any one of the weld metals in this table.

Notes:
1. Filler metals shall meet requirements of Table 5.4 in addition to the compositional requirements listed above. The use of the same type of filler metal having next higher tensile strength as listed in AWS filler metal specification may be used.
2. Metal cored electrodes are designated as follows:
SAW: Insert letter "C" between the letters "E" and "X," e.g., E7AX-ECXXX-Ni1.
GMAW: Replace the letter "S" with the letter "C," and omit the letter "R," e.g., E80C-Ni1. AWS A5.36/A5.36M composite electrode designation is either a T15 or T16, e.g., E8XT15-XXX-Ni1, E8XT16-XXX-Ni1.

Table 5.7
Prequalified WPS Shielding Gas Options for GMAW Electrodes Conforming to AWS A5.18/A5.18M (see 5.6.3)

Electrode	Shielding Gas	Composition
ER70S-X (except ER70S-G) and E70C-X metal cored electrodes	Ar/CO_2 combinations	Ar 75–90%/CO_2 10–25%
	Ar/O_2 combinations	Ar 95–98%/O_2 2–5%
	100% CO_2	100% CO_2

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Table 5.8
Prequalified Minimum Preheat and Interpass Temperature (see 5.7)

CATEGORY	Steel Specification		Welding Process	Thickness of Thickest Part at Point of Welding (in)	Thickness of Thickest Part at Point of Welding (mm)	Minimum Preheat and Interpass Temperature (°F)	Minimum Preheat and Interpass Temperature (°C)
	ASTM A36						
	ASTM A53	Grade B					
	ASTM A106	Grade B					
	ASTM A131	Grades A, B, D, E					
	ASTM A139	Grade B					
	ASTM A381	Grade Y35					
	ASTM A500	Grades A, B, C		1/8 to 3/4 incl.	3 to 20 incl.	32[a]	0[a]
	ASTM A501	Grade A					
	ASTM A516	Grades 55, 60		Over 3/4 thru 1-1/2 incl.	Over 20 thru 38 incl.	150	65
	ASTM A524	Grades I, II	SMAW with other than low-hydrogen electrodes				
A	ASTM A573	Grades 58, 65					
	ASTM A709	Grade 36					
	ASTM A1008 SS	Grade 30 Grade 33 Type 1 Grade 40 Type 1		Over 1-1/2 thru 2-1/2 incl.	Over 38 thru 65 incl.	225	110
	ASTM A1011 SS	Grades 30, 33 Grade 36 Type 1 Grade 40 Grade 45 Type 1		Over 2-1/2	Over 65	300	150
	ASTM A1018 SS	Grades 30, 33, 36, 40					
	API 5L	Grades B, X42					
	ABS	Grades A, B, D, E					
	ASTM A36						
	ASTM A53	Grade B					
	ASTM A106	Grade B					
	ASTM A131	Grades A, B, D, E AH 32, 36 DH 32, 36 EH 32, 36					
	ASTM A139	Grade B		1/8 to 3/4 incl.	3 to 20 incl.	32[a]	0[a]
	ASTM A381	Grade Y35					
	ASTM A500	Grades A, B, C					
	ASTM A501	Grades A, B		Over 3/4 thru 1-1/2 incl.	Over 20 thru 38 incl.	50	10
	ASTM A516	Grades 55, 60, 65, 70	SMAW with low-hydrogen electrodes, SAW, GMAW, FCAW				
B	ASTM A524	Grades I, II					
	ASTM A529	Grades 50, 55		Over 1-1/2 thru 2-1/2 incl.	Over 38 thru 65 incl.	150	65
	ASTM A537	Classes 1, 2					
	ASTM A572	Grades 42, 50, 55					
	ASTM A573	Grades 58, 65					
	ASTM A588			Over 2-1/2	Over 65	225	110
	ASTM A595	Grades A, B, C					
	ASTM A606						
	ASTM A618	Grades Ib, II, III					
	ASTM A633	Grades A, C, D					
	ASTM A709	Grades 36, 50, 50S, 50W, HPS50W					

(Continued)

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Table 5.8 (Continued)
Prequalified Minimum Preheat and Interpass Temperature (see 5.7)

CATEGORY	Steel Specification		Welding Process	Thickness of Thickest Part at Point of Welding		Minimum Preheat and Interpass Temperature	
				in	mm	°F	°C
B (cont'd)	ASTM A710	Grade A, Class 2 >2 in [50 mm]	SMAW with low-hydrogen electrodes, SAW, GMAW, FCAW	1/8 to 3/4 incl.	3 to 20 incl.	50	10
	ASTM A847			Over 3/4 thru 1-1/2 incl.	Over 20 thru 38 incl.	50	10
	ASTM A913	Grade 50		Over 1-1/2 thru 2-1/2 incl.	Over 38 thru 65 incl.	225	110
	ASTM A992			Over 2-1/2	Over 65	300	150
	ASTM A1008 HSLAS	Grade 45 Class 1 Grade 45 Class 2 Grade 50 Class 1 Grade 50 Class 2 Grade 55 Class 1 Grade 55 Class 2					
	ASTM A1008 HSLAS-F	Grade 50					
	ASTM A1011 SS	Grades 50, 55					
	ASTM A1011 HSLAS	Grade 45 Class 1 Grade 45 Class 2 Grade 50 Class 1 Grade 50 Class 2 Grade 55 Class 1 Grade 55 Class 2					
	ASTM A1011 HSLAS-F	Grade 50					
	ASTM A1018 HSLAS	Grade 45 Class 1 Grade 45 Class 2 Grade 50 Class 1 Grade 50 Class 2 Grade 55 Class 1 Grade 55 Class 2					
	ASTM A1018 HSLAS-F	Grade 50					
	ASTM A1018 SS	Grades 30, 33, 36, 40					
	ASTM A1066	Grade 50					
	ASTM A1085						
	API 5L	Grades B, X42					
	API Spec. 2H	Grades 42, 50					
	API 2MT1	Grade 50					
	API 2W	Grades 42, 50, 50T					
	API 2Y	Grades 42, 50, 50T					
	ABS	Grades A, B, D, E AH 32, 36 DH 32, 36 EH 32, 36					

(Continued)

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Table 5.8 (Continued)
Prequalified Minimum Preheat and Interpass Temperature (see 5.7)

CATEGORY	Steel Specification		Welding Process	Thickness of Thickest Part at Point of Welding in	Thickness of Thickest Part at Point of Welding mm	Minimum Preheat and Interpass Temperature °F	Minimum Preheat and Interpass Temperature °C
C	ASTM A572	Grades 60, 65	SMAW with low-hydrogen electrodes, SAW, GMAW, FCAW	1/8 to 3/4 incl.	3 to 20 incl	50	10
	ASTM A633	Grade E		Over 3/4 thru 1-1/2 incl.	Over 20 thru 38 incl.	150	65
	ASTM A709[b]	Grade HPS70W		Over 1-1/2 thru 2-1/2 incl.	Over 38 thru 65 incl.	225	110
	ASTM A710	Grade A, Class 2 ≤ 2 in [50 mm]		Over 2-1/2	Over 65	300	150
	ASTM A710	Grade A, Class 3 > 2 in [50 mm]					
	ASTM A913	Grades 60, 65, 70					
	ASTM A1018 HSLAS	Grade 60 Class 2 Grade 70 Class 2					
	ASTM A1018 HSLAS-F	Grade 60 Class 2 Grade 70 Class 2					
	ASTM A1066	Grades 60, 65, 70					
	API 2W	Grade 60					
	API 2Y	Grade 60					
	API 5L	Grade X52					
D	ASTM A710 ASTM A913	Grade A (All classes) Grades 50, 60, 65	SMAW, SAW, GMAW, and FCAW with electrodes or electrode-flux combinations capable of depositing weld metal with a maximum diffusible hydrogen content of 8 ml/100 g (H8), when tested according to AWS A4.3.	All thicknesses Over 1/8 in	All thicknesses Over [3 mm]	32[a]	0[a]
E	ASTM A1066	Grades 50, 60, 65	SMAW, SAW, GMAW, and FCAW with electrodes or electrode-flux combinations capable of depositing weld metal with a maximum diffusible hydrogen content of 8 ml/100 g (H8), when tested according to AWS A4.3.	1/8 to 1 incl.	3 to 25 incl.	50	10
				Over 1	Over 25	120	50

[a] When the base metal temperature is below 32°F [0°C], the base metal shall be preheated to a minimum of 70°F [20°C] and the minimum interpass temperature shall be maintained during welding.
[b] For ASTM A709 Grade HPS70W, the maximum preheat and interpass temperatures shall not exceed 400°F [200°C] for thicknesses up to 1-1/2 in [40 mm], inclusive, and 450°F [230°C] for greater thicknesses.

Notes:
1. For modification of preheat requirements for SAW with parallel or multiple electrodes, see 5.7.3.
2. See 7.11 and 7.6 for ambient and base-metal temperature requirements.
3. ASTM A570 and ASTM A607 have been deleted.
4. When welding base metals from different Categories see 5.7.2.

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Legend for Figures 5.1 and 5.2

Symbols for joint types

B — butt joint
C — corner joint
T — T-joint
BC — butt or corner joint
TC — T- or corner joint
BTC — butt, T-, or corner joint

Welding processes

SMAW — shielded metal arc welding
GMAW — gas metal arc welding
FCAW — flux cored metal arc welding
SAW — submerged arc welding

Symbols for base metal thickness and penetration

P — PJP
L — limited thickness–CJP
U — unlimited thickness–CJP

Welding positions

F — flat
H — horizontal
V — vertical
OH — overhead

Symbol for weld types

1 — square-groove
2 — single-V-groove
3 — double-V-groove
4 — single-bevel-groove
5 — double-bevel-groove
6 — single-U-groove
7 — double-U-groove
8 — single-J-groove
9 — double-J-groove
10 — flare-bevel-groove
11 — flare-V-groove

Dimensions

R = Root Opening
α, β = Groove Angles
f = Root Face
r = J- or U-groove Radius
$\underline{D}$, $\underline{D_1}$, $\underline{D_2}$ = PJP Groove Weld Depth of Groove
$\underline{S}$, $\underline{S_1}$ $\underline{S_2}$ = PJP Groove Weld Sizes corresponding to S, S_1, S_2, respectively

Symbols for welding processes if not SMAW

S — SAW
G — GMAW
F — FCAW

Joint Designation

The lower case letters, e.g., a, b, c, are used to differentiate between joints that would otherwise have the same joint designation.

Notes for Figures 5.1 and 5.2

[a] Not prequalified for GMAW-S or GTAW.
[b] Joint shall be welded from one side only.
[c] Cyclic load application places restrictions on the use of this detail for butt joints in the flat position (see 4.18.2).
[d] Backgouge root to sound metal before welding second side.
[e] SMAW detailed joints may be used for prequalified GMAW (except GMAW-S) and FCAW.
[f] Minimum weld size (S) as shown in Table 5.5. Depth of groove (D) as specified on drawings.
[g] If fillet welds are used in statically loaded structures to reinforce groove welds in corner and T-joints, these shall be equal to $T_1/4$, but need not exceed 3/8 in [10 mm].
[h] Double-groove welds may have grooves of unequal depth, but the depth of the shallower groove shall be no less than one-fourth of the thickness of the thinner part joined.
[i] Double-groove welds may have grooves of unequal depth, provided these conform to the limitations of Note f. Also, the weld size (S) applies individually to each groove.
[j] The orientation of the two members in the joints may vary from 135° to 180° for butt joints, or 45° to 135° for corner joints, or 45° to 90° for T-joints.
[k] For corner joints, the outside groove preparation may be in either or both members, provided the basic groove configuration is not changed and adequate edge distance is maintained to support the welding operations without excessive edge melting.
[l] Weld size (S) shall be based on joints welded flush.
[m] For flare-V-groove welds and flare-bevel-groove welds to rectangular tubular sections, r shall be as two times the wall thickness.
[n] For flare-V-groove welds to surfaces with different radii r, the smaller r shall be used.
[o] For corner and T-joints the member orientation may vary from 90° to less than or equal to 170° provided the groove angle and root opening are maintained, and the angle between the groove faces and the steel backing is at least 90°. See Figure 5.5.

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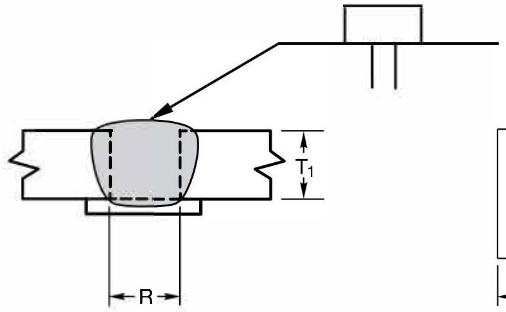
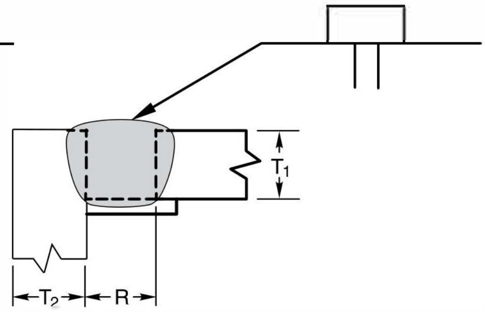
Square-groove weld (1)
Butt joint (B)
Corner joint (C)



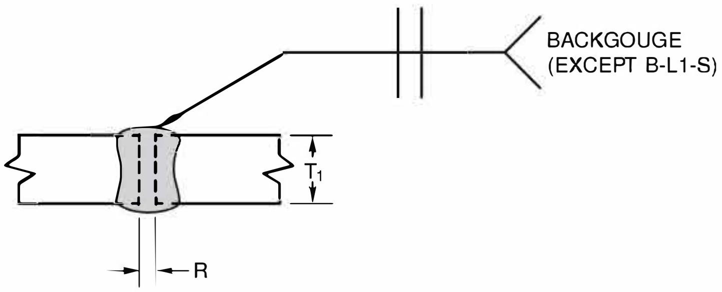
B-L1a



C-L1a

Welding Process	Joint Designation	Base Metal Thickness (U = unlimited)		Groove Preparation			Allowed Welding Positions	Gas Shielding for FCAW	Notes
		T_1	T_2	Root Opening	Tolerances: As Detailed (see 5.4.1.1)	Tolerances: As Fit-Up (see 5.4.1.8)			
SMAW	B-L1a	1/4 max.	—	$R = T_1$	+1/16, –0	+1/4, –1/16	All	—	e, j
SMAW	C-L1a	1/4 max.	U	$R = T_1$	+1/16, –0	+1/4, –1/16	All	—	e, j
FCAW GMAW	B-L1a-GF	3/8 max.	—	$R = T_1$	+1/16, –0	+1/4, –1/16	All	Not required	a, j

Square-groove weld (1)
Butt joint (B)



Welding Process	Joint Designation	Base Metal Thickness (U = unlimited)		Groove Preparation			Allowed Welding Positions	Gas Shielding for FCAW	Notes
		T_1	T_2	Root Opening	Tolerances: As Detailed (see 5.4.1.1)	Tolerances: As Fit-Up (see 5.4.1.8)			
SMAW	B-L1b	1/4 max.	—	$R = \frac{T_1}{2}$	+1/16, –0	+1/16, –1/8	All	—	d, e, j
GMAW FCAW	B-L1b-GF	3/8 max.	—	R = 0 to 1/8	+1/16, –0	+1/16, –1/8	All	Not required	a, d, j
SAW	B-L1-S	3/8 max.	—	R = 0	±0	+1/16, –0	F	—	j
SAW	B-L1a-S	5/8 max.	—	R = 0	±0	+1/16 –0	F	—	d, j

Figure 5.1—Prequalified CJP Groove Welded Joint Details (See 5.4.1) (Dimensions in Inches)

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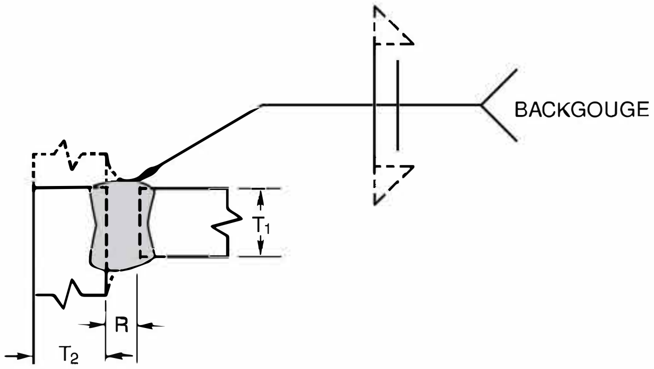
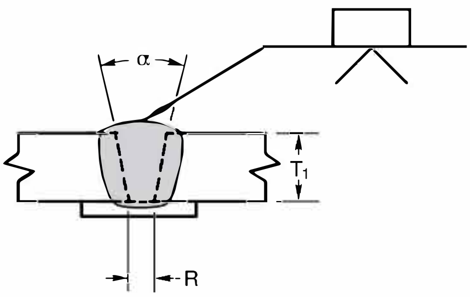
Square-groove weld (1)
T-joint (T)
Corner joint (C)



Welding Process	Joint Designation	Base Metal Thickness (U = unlimited)		Groove Preparation			Allowed Welding Positions	Gas Shielding for FCAW	Notes
				Root Opening	Tolerances				
		T_1	T_2		As Detailed (see 5.4.1.1)	As Fit-Up (see 5.4.1.8)			
SMAW	TC-L1b	1/4 max.	U	$R = \frac{T_1}{2}$	+1/16, –0	+1/16, –1/8	All	—	d, e, g
GMAW FCAW	TC-L1-GF	3/8 max.	U	R = 0 to 1/8	+1/16, –0	+1/16, –1/8	All	Not required	a, d, g
SAW	TC-L1-S	3/8 max.	U	R = 0	±0	+1/16, –0	F	—	d, g

Single-V-groove weld (2)
Butt joint (B)



Tolerances	
As Detailed (see 5.4.1.1)	As Fit-Up (see 5.4.1.8)
R = +1/16, –0	+1/4, –1/16
α = +10°, –0°	+10°, –5°

Welding Process	Joint Designation	Base Metal Thickness (U = unlimited)		Groove Preparation		Allowed Welding Positions	Gas Shielding for FCAW	Notes
		T_1	T_2	Root Opening	Groove Angle			
SMAW	B-U2a	U	—	R = 1/4	α = 45°	All	—	e, j
				R = 3/8	α = 30°	F, V, OH	—	e, j
				R = 1/2	α = 20°	F, V, OH	—	e, j
GMAW FCAW	B-U2a-GF	U	—	R = 3/16	α = 30°	F, V, OH	Required	a, j
				R = 3/8	α = 30°	F, V, OH	Not req.	a, j
				R = 1/4	α = 45°	F, V, OH	Not req.	a, j
SAW	B-L2a-S	2 max.	—	R = 1/4	α = 30°	F	—	j
SAW	B-U2-S	U	—	R = 5/8	α = 20°	F	—	j

Figure 5.1 (Continued)—Prequalified CJP Groove Welded Joint Details (See 5.4.1) (Dimensions in Inches)

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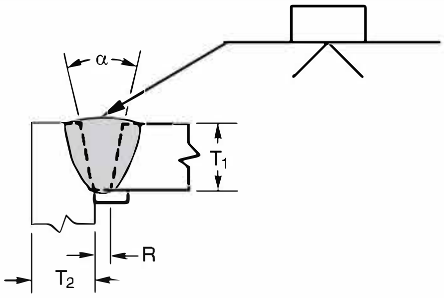
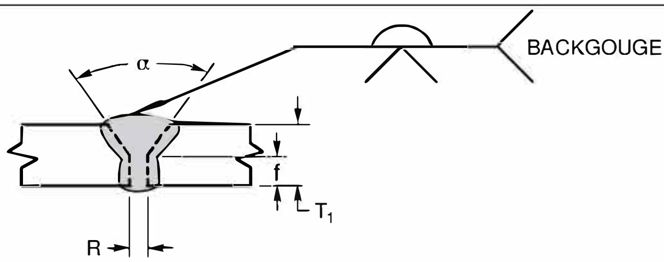
Single-V-groove weld (2)
Corner joint (C)



Tolerances	
As Detailed (see 5.4.1.1)	As Fit-Up (see 5.4.1.8)
R = +1/16, –0	+1/4, –1/16
α = +10° –0°	+10°, –5°

Welding Process	Joint Designation	Base Metal Thickness (U = unlimited) T_1	T_2	Groove Preparation Root Opening	Groove Angle	Allowed Welding Positions	Gas Shielding for FCAW	Notes
SMAW	C-U2a	U	U	R = 1/4	α = 45°	All	—	e, o
				R = 3/8	α = 30°	F, V, OH	—	e, o
				R = 1/2	α = 20°	F, V, OH	—	e, o
GMAW FCAW	C-U2a-GF	U	U	R = 3/16	α = 30°	F, V, OH	Required	a
				R = 3/8	α = 30°	F, V, OH	Not req.	a, o
				R = 1/4	α = 45°	F, V, OH	Not req.	a, o
SAW	C-L2a-S	2 max.	U	R = 1/4	α = 30°	F	—	o
SAW	C-U2-S	U	U	R = 5/8	α = 20°	F	—	o

Single-V-groove weld (2)
Butt joint (B)



Welding Process	Joint Designation	Base Metal Thickness (U – unlimited) T_1	T_2	Groove Preparation: Root Opening Root Face Groove Angle	Tolerances: As Detailed (see 5.4.1.1)	As Fit-Up (see 5.4.1.8)	Allowed Welding Positions	Gas Shielding for FCAW	Notes
SMAW	B-U2	U	—	R = 0 to 1/8 f = 0 to 1/8 α = 60°	+1/16, –0 +1/16, –0 +10°, –0°	+1/16, –1/8 Not limited +10°, –5°	All	—	d, e, j
GMAW FCAW	B-U2-GF	U	—	R = 0 to 1/8 f = 0 to 1/8 α = 60°	+1/16, –0 +1/16, –0 +10°, –0°	+1/16, –1/8 Not limited +10°, –5°	All	Not required	a, d, j
SAW	B-L2c-S	Over 1/2 to 1	—	R = 0 f = 1/4 max. α = 60°	R = ±0 f = +0, –f α = +10°, –0°	+1/16, –0 ±1/16 +10°, –5°	F	—	d, j
		Over 1 to 1-1/2	—	R = 0 f = 1/2 max. α = 60°					
		Over 1-1/2 to 2	—	R = 0 f – 5/8 max. α = 60°					

Figure 5.1 (Continued)—Prequalified CJP Groove Welded Joint Details (See 5.4.1) (Dimensions in Inches)

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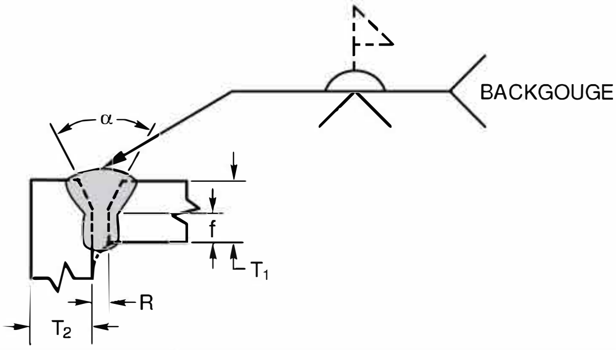
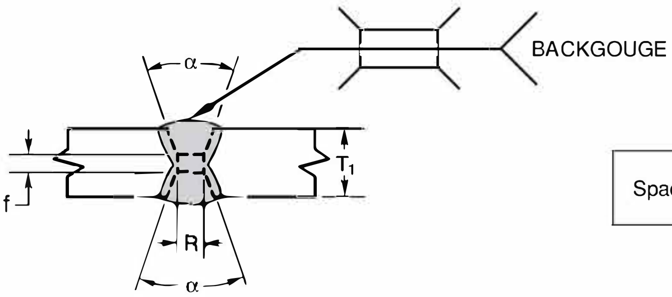
Single-V-groove weld (2)
Corner joint (C)



Welding Process	Joint Designation	Base Metal Thickness (U = unlimited)		Groove Preparation			Allowed Welding Positions	Gas Shielding for FCAW	Notes
		T_1	T_2	Root Opening Root Face Groove Angle	Tolerances: As Detailed (see 5.4.1.1)	Tolerances: As Fit-Up (see 5.4.1.8)			
SMAW	C-U2	U	U	R = 0 to 1/8 f = 0 to 1/8 α = 60°	+1/16, –0 +1/16, –0 +10°, –0°	+1/16, –1/8 Not limited +10°, –5°	All	—	d, e, g, j
GMAW FCAW	C-U2-GF	U	U	R = 0 to 1/8 f = 0 to 1/8 α = 60°	+1/16, –0 +1/16, –0 +10°, –0°	+1/16, –1/8 Not limited +10°, –5°	All	Not required	a, d, g, j
SAW	C-U2b-S	U	U	R = 0 to 1/8 f = 1/4 max. α = 60°	±0 +0, –1/4 +10°, –0°	+1/16, –0 ±1/16 +10°, –5°	F	—	d, g, j

Double-V-groove weld (3)
Butt joint (B)



	Tolerances: As Detailed (see 5.4.1.1)	Tolerances: As Fit-Up (see 5.4.1.8)
	R = ±0	+1/4, –0
	f = ±0	+1/16, –0
	α = +10°, –0°	+10°, –5°
Spacer: SAW	±0	+1/16, –0
Spacer: SMAW	±0	+1/8, –0

Welding Process	Joint Designation	Base Metal Thickness (U – unlimited)		Groove Preparation			Allowed Welding Positions	Gas Shielding for FCAW	Notes
		T_1	T_2	Root Opening	Root Face	Groove Angle			
SMAW	B-U3a	U Spacer = 1/8 × R	—	R = 1/4	f = 0 to 1/8	α = 45°	All	—	d, e, h, j
				R = 3/8	f = 0 to 1/8	α = 30°	F, V, OH	—	
				R = 1/2	f = 0 to 1/8	α = 20°	F, V, OH	—	
SAW	B-U3a-S	U Spacer = 1/4 × R	—	R = 5/8	f = 0 to 1/4	α = 20°	F	—	d, h, j

Figure 5.1 (Continued)—Prequalified CJP Groove Welded Joint Details (See 5.4.1) (Dimensions in Inches)

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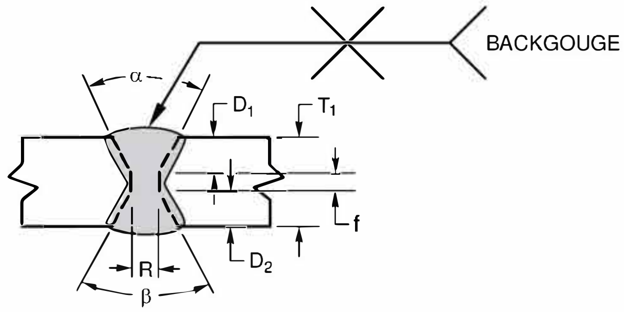
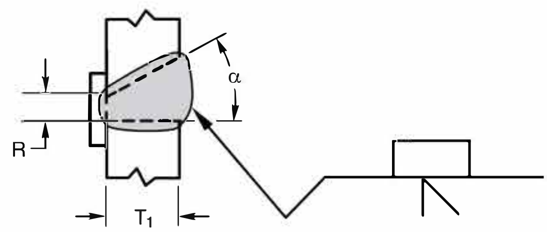
Double-V-groove weld (3)
Butt joint (B)



For B-U3c-S only		
T_1		D_1
Over	to	
2	2-1/2	1-3/8
2-1/2	3	1-3/4
3	3-5/8	2-1/8
3-5/8	4	2-3/8
4	4-3/4	2-3/4
4-3/4	5-1/2	3-1/4
5-1/2	6-1/4	3-3/4
For $T_1 > 6\text{-}1/4$ or $T_1 \le 2$ $D_1 = 2/3\ (T_1 - 1/4)$		

Welding Process	Joint Designation	Base Metal Thickness (U – unlimited) T_1	T_2	Groove Preparation: Root Opening, Root Face, Groove Angle	Tolerances: As Detailed (see 5.4.1.1)	Tolerances: As Fit-Up (see 5.4.1.8)	Allowed Welding Positions	Gas Shielding for FCAW	Notes
SMAW	B-U3b	U	—	R = 0 to 1/8 f = 0 to 1/8 α = β = 60°	+1/16, –0 +1/16, –0 +10°, –0°	+1/16, –1/8 Not limited +10°, –5°	All	—	d, e, h, j
GMAW FCAW	B-U3-GF						All	Not required	a, d, h, j
SAW	B-U3c-S	U	—	R = 0 f = 1/4 min. α = β 60°	+1/16, –0 +1/4, –0 +10°, –0°	+1/16, –0 +1/4, –0 +10°, –5°	F	—	d, h, j
				To find D_1 see table above: $D_2 = T_1 - (D_1 + f)$					

Single-bevel-groove weld (4)
Butt joint (B)



Tolerances	
As Detailed (see 5.4.1.1)	As Fit-Up (see 5.4.1.8)
R = +1/16, –0	+1/4, –1/16
α = +10°, –0°	+10°, –5°

Welding Process	Joint Designation	Bass Metal Thickness (U – unlimited) T_1	T_2	Groove Preparation: Root Opening	Groove Preparation: Groove Angle	Allowed Welding Positions	Gas Shielding for FCAW	Notes
SMAW	B-U4a	U	—	R = 1/4	α = 45°	All	—	c, e, j
				R = 3/8	α = 30°	All	—	c, e, j
GMAW FCAW	B-U4a-GF	U	—	R = 3/16	α = 30°	All	Required	a, c, j
				R = 1/4	α = 45°	All	Not req.	a, c, j
				R = 3/8	α = 30°	F, H	Not req.	a, c, j
SAW	B-U4a-S	U	—	R = 3/8	α = 30°	F	—	c, j
				R = 1/4	α = 45°			

Figure 5.1 (Continued)—Prequalified CJP Groove Welded Joint Details (See 5.4.1)
(Dimensions in Inches)

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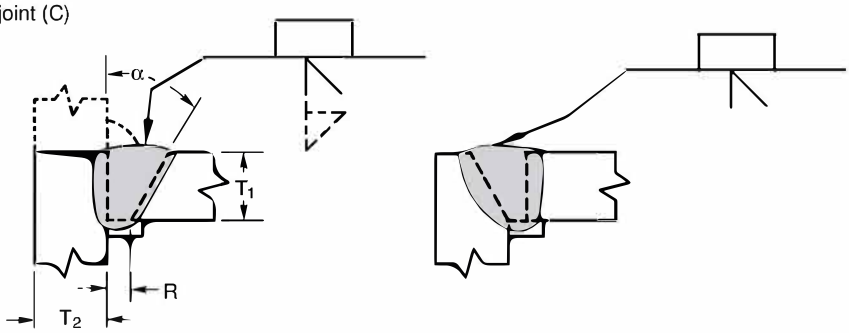
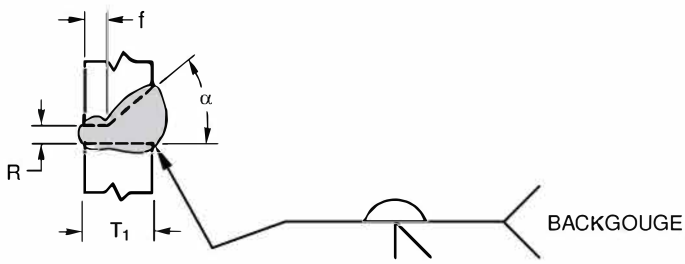
Single-bevel-groove weld (4)
T-joint (T)
Corner joint (C)



Tolerances	
As Detailed (see 5.4.1.1)	As Fit-Up (see 5.4.1.8)
R = +1/16, –0	+1/4, –1/16
α = +10° –0°	+10°, –5°

Welding Process	Joint Designation	Base Metal Thickness (U – unlimited)		Groove Preparation		Allowed Welding Positions	Gas Shielding for FCAW	Notes
		T_1	T_2	Root Opening	Groove Angle			
SMAW	TC-U4a	U	U	R = 1/4	α = 45°	All	—	e, g, k, o
				R = 3/8	α = 30°	F, V, OH	—	e, g, k, o
GMAW FCAW	TC-U4a-GF	U	U	R = 3/16	α = 30°	All	Required	a, g, k, o
				R = 3/8	α = 30°	F	Not req.	a, g, k, o
				R = 1/4	α = 45°	All	Not req.	a, g, k, o
SAW	TC-U4a-S	U	U	R = 3/8	α = 30°	F	—	g, k, o
				R = 1/4	α = 45°			

Single-bevel-groove weld (4)
Butt joint (B)



Welding Process	Joint Designation	Base Metal Thickness (U = unlimited)		Groove Preparation			Allowed Welding Positions	Gas Shielding for FCAW	Notes
				Root Opening Root Face Groove Angle	Tolerances				
		T_1	T_2		As Detailed (see 5.4.1.1)	As Fit-Up (see 5.4.1.8)			
SMAW	B-U4b	U	—	R = 0 to 1/8 f = 0 to 1/8 α = 45°	+1/16, –0 +1/16, –0 +10°, –0°	+1/16, –1/8 Not limited 10°, –5°	All	—	c, d, e, j
GMAW FCAW	B-U4b-GF	U	—				All	Not required	a, c, d, j
SAW	B-U4b-S	U	—	R = 0 f = 1/4 max. α = 60°	±0 +0, –1/8 +10°, –0°	+1/4, –0 ±1/16 10°, –5°	F	—	c, d, j

Figure 5.1 (Continued)—Prequalified CJP Groove Welded Joint Details (See 5.4.1) (Dimensions in Inches)

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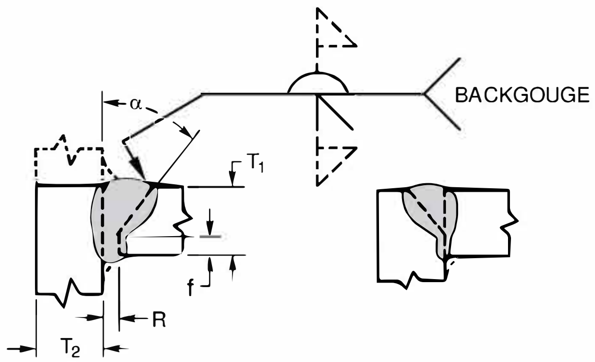
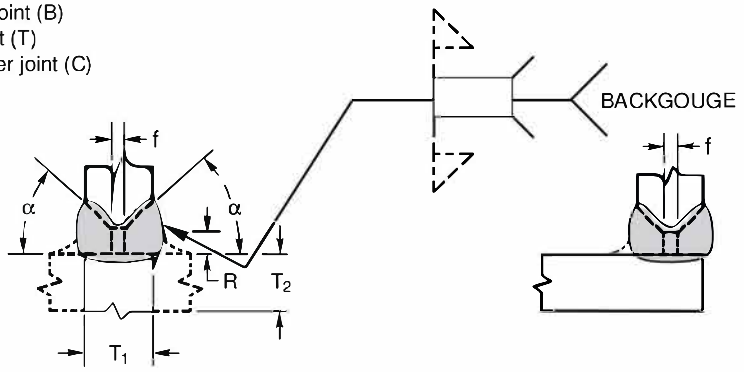
Single-bevel-groove weld (4)
T-joint (T)
Corner joint (C)



ALL DIMENSIONS IN mm

Welding Process	Joint Designation	Base Metal Thickness (U = unlimited) T1	T2	Groove Preparation: Root Opening Root Face Groove Angle	Tolerances: As Detailed (see 5.4.1.1)	As Fit-Up (see 5.4.1.8)	Allowed Welding Positions	Gas Shielding for FCAW	Notes
SMAW	TC-U4b	U	U	R = 0 to 1/8 f = 0 to 1/8 α = 45°	+1/16, −0 +1/16, −0 +10°, −0°	+1/16, −1/8 Not limited +10°, −5°	All	—	d, e, g, j, k
GMAW FCAW	TC-U4b-GF	U	U				All	Not required	a, d, g, j, k
SAW	TC-U4b-S	U	U	R = 0 f = 1/4 max. α = 60°	±0 +0, −1/8 +10°, −0°	+1/4, −0 ±1/16 +10°, −5°	F	—	d, g, j, k

Double-bevel-groove weld (5)
Butt joint (B)
T-joint (T)
Corner joint (C)



	Tolerances: As Detailed (see 5.4.1.1)	As Fit-Up (see 5.4.1.8)
	R = ±0	+1/4, −0
	f = +1/16, −0	±1/16
	α = +10°, −0°	+10°, −5°
Spacer	+1/16, −0	+1/8, −0

Welding Process	Joint Designation	Base Metal Thickness (U = unlimited) T1	T2	Groove Preparation: Root Opening	Root Face	Groove Angle	Allowed Welding Positions	Gas Shielding for FCAW	Notes
SMAW	B-U5b	U Spacer = 1/8 × R	—	R = 1/4	f = 0 to 1/8	α = 45°	All	—	c, d, e, h, j
	TC-U5a	U Spacer = 1/4 × R	U	R = 1/4	f = 0 to 1/8	α = 45°	All	—	d, e, g, h, j, k
				R = 3/8	f = 0 to 1/8	α = 30°	F, OH	—	d, e, g, h, j, k

Figure 5.1 (Continued)—Prequalified CJP Groove Welded Joint Details (See 5.4.1) (Dimensions in Inches)

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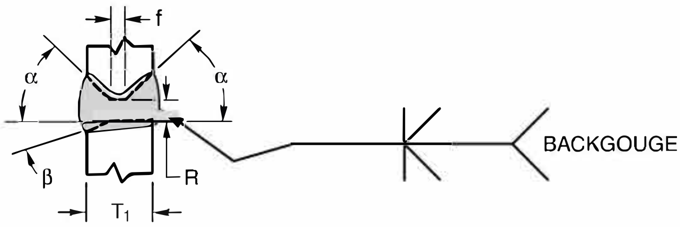
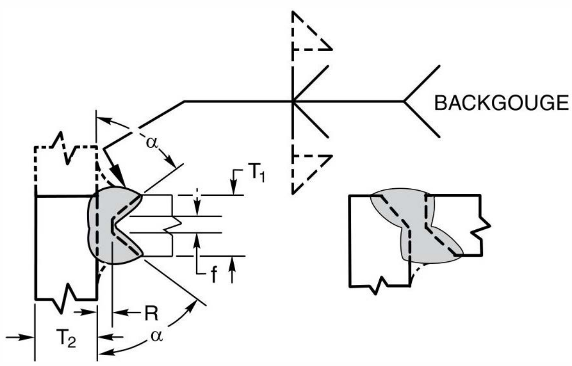
Double-bevel-groove weld (5)
Butt joint (B)



Welding Process	Joint Designation	Base Metal Thickness (U = unlimited) T_1	T_2	Groove Preparation: Root Opening Root Face Groove Angle	Tolerances: As Detailed (see 5.4.1.1)	As Fit-Up (see 5.4.1.8)	Allowed Welding Positions	Gas Shielding for FCAW	Notes
SMAW	B-U5a	U	—	R = 0 to 1/8 f = 0 to 1/8 α = 45° β = 0° to 15°	+1/16, –0 +1/16, –0 α + β = +10°, –0°	+1/16, –1/8 Not limited α + β = +10°, –5°	All	—	c, d, e, h, j
GMAW FCAW	B-U5-GF	U	—	R = 0 to 1/8 f = 0 to 1/8 α = 45° β = 0° to 15°	+1/16, –0 +1/16, –0 α + β = +10°, –0°	+1/16, –1/8 Not limited α + β = +10°, –5°	All	Not required	a, c, d, h, j

Double-bevel-groove weld (5)
T-joint (T)
Corner joint (C)



Welding Process	Joint Designation	Base Metal Thickness (U = unlimited) T_1	T_2	Groove Preparation: Root Opening Root Face Groove Angle	Tolerances: As Detailed (see 5.4.1.1)	As Fit-Up (see 5.4.1.8)	Allowed Welding Positions	Gas Shielding for FCAW	Notes
SMAW	TC-U5b	U	U	R = 0 to 1/8 f = 0 to 1/8 α = 45°	+1/16, –0 +1/16, –0 +10°, –0°	+1/16, –1/8 Not limited +10°, –5°	All	—	d, e, g, h, j, k
GMAW FCAW	TC-U5-GF	U	U				All	Not required	a, d, g, h, j, k
SAW	TC-U5-S	U	U	R = 0 f = 1/4 max. α = 60°	±0 +0, –3/16 +10°, –0°	+1/16, –0 ±1/16 +10°, –5°	F	—	d, g, h, j, k

Figure 5.1 (Continued)—Prequalified CJP Groove Welded Joint Details (See 5.4.1) (Dimensions in Inches)

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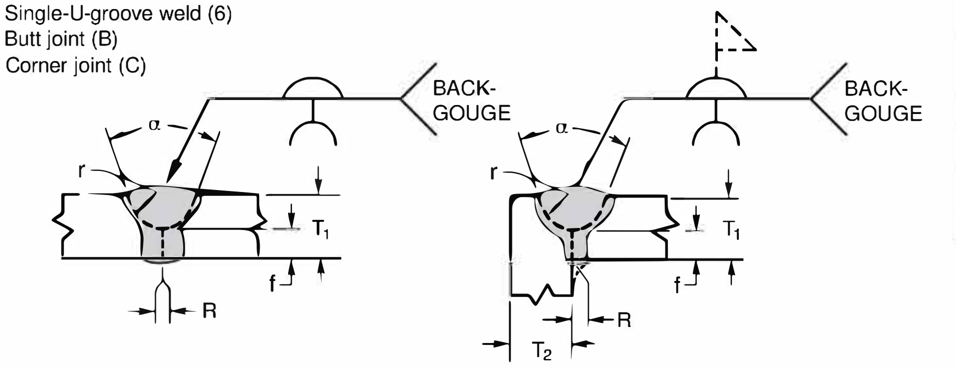
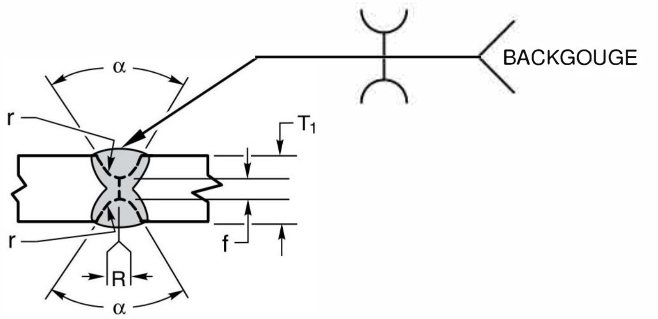
Single-U-groove weld (6)
Butt joint (B)
Corner joint (C)



Tolerances	
As Detailed (see 5.4.1.1)	As Fit-Up (see 5.4.1.8)
R = +1/16, –0	+1/16, –1/8
α = +10°, –0°	+10°, –5°
f = ±1/16	Not Limited
r = +1/8, –0	+1/8, –0

Welding Process	Joint Designation	Base Metal Thickness (U = unlimited) T_1	T_2	Groove Preparation Root Opening	Groove Angle	Root Face	Bevel Radius	Allowed Welding Positions	Gas Shielding for FCAW	Notes
SMAW	B-U6	U	—	R = 0 to 1/8	α = 45°	f = 1/8	r = 1/4	All	—	d, e, j
				R = 0 to 1/8	α = 20°	f = 1/8	r = 1/4	F, OH	—	d, e, j
	C-U6	U	U	R = 0 to 1/8	α = 45°	f = 1/8	r = 1/4	All	—	d, e, g, j
				R = 0 to 1/8	α = 20°	f = 1/8	r = 1/4	F, OH	—	d, e, g, j
GMAW FCAW	B-U6-GF	U	—	R = 0 to 1/8	α = 20°	f = 1/8	r = 1/4	All	Not req.	a, d, j
	C-U6-GF	U	U	R = 0 to 1/8	α = 20°	f = 1/8	r = 1/4	All	Not req.	a, d, g, j

Double-U-groove weld (7)
Butt joint (B)



Tolerances	
As Detailed (see 5.4.1.1)	As Fit-Up (see 5.4.1.8)
For B-U7 and B-U7-GF	
R = +1/16, –0	+1/16, –1/8
α = +10°, –0°	+10°, –5°
f = +1/16, –0	Not Limited
r = +1/4, –0	±1/16
For B-U7-S	
R = +0	+1/16, –0
α = +10°, –0°	+10°, –5°
f = +0, –1/4	±1/16
r = +1/4, –0	±1/16

Welding Process	Joint Designation	Base Metal Thickness (U = unlimited) T_1	T_2	Groove Preparation Root Opening	Groove Angle	Root Face	Bevel Radius	Allowed Welding Positions	Gas Shielding for FCAW	Notes
SMAW	B-U7	U	—	R = 0 to 1/8	α = 45°	f = 1/8	r = 1/4	All	—	d, e, h,j
				R = 0 to 1/8	α = 20°	f = 1/8	r = 1/4	F, OH	—	d, e, h, j
GMAW FCAW	B-U7-GF	U	—	R = 0 to 1/8	α = 20°	f = 1/8	r = 1/4	All	Not required	a, d, j, h
SAW	B-U7-S	U	—	R = 0	α = 20°	f = 1/4 max.	r = 1/4	F	—	d, h, j

Figure 5.1 (Continued)—Prequalified CJP Groove Welded Joint Details (See 5.4.1) (Dimensions in Inches)

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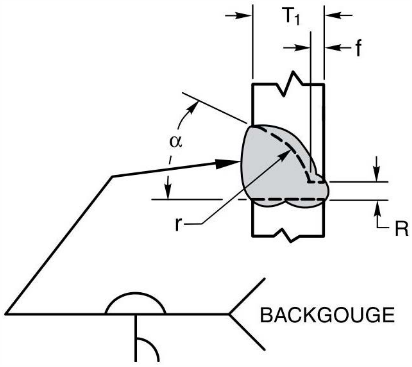
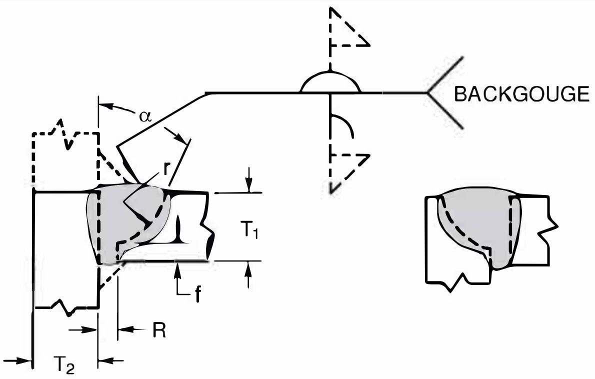
Single-J-groove weld (8)
Butt joint (B)



Tolerances	
As Detailed (see 5.4.1.1)	As Fit-Up (see 5.4.1.8)
B-U8 and B-U8-GF	
R = +1/16, −0	+1/16, −1/8
α = +10°, −0°	+10°, −5°
f = +1/8, −0	Not Limited
r = +1/4, −0	±1/16
B-U8-S	
R = ±0	+1/4, −0
α = +10°, −0°	+10°, −5°
f = +0, −1/8	±1/16
r = +1/4, −0	±1/16

Welding Process	Joint Designation	Base Metal Thickness (U = unlimited) T1	T2	Groove Preparation Root Opening	Groove Angle	Root Face	Bevel Radius	Allowed Welding Positions	Gas Shielding for FCAW	Notes
SMAW	B-U8	U	—	R = 0 to 1/8	α = 45°	f = 1/8	r = 3/8	All	—	c, d, e, j
GMAW FCAW	B-U8-GF	U	—	R = 0 to 1/8	α = 30°	f = 1/8	r = 3/8	All	Not req.	a, c, d, j
SAW	B-U8-S	U	—	R = 0	α = 45°	f = 1/4 max.	r = 3/8	F	—	c, d, j

Single-J-groove weld (8)
T-joint (T)
Corner joint (C)



Tolerances	
As Detailed (see 5.4.1.1)	As Fit-Up (see 5.4.1.8)
TC-U8a and TC-U8a-GF	
R = +1/16, −0	+1/16, −1/8
α = +10°, −0°	+10°, −5°
f = +1/16, −0	Not Limited
r = +1/4, −0	±1/16
TC-U8a-S	
R = ±0	+1/4, −0
α = +10°, −0°	+10°, −5°
f = +0, −1/8	±1/16
r = +1/4, −0	+1/16

Welding Process	Joint Designation	Base Metal Thickness (U = unlimited) T1	T2	Groove Preparation Root Opening	Groove Angle	Root Face	Bevel Radius	Allowed Welding Positions	Gas Shielding for FCAW	Notes
SMAW	TC-U8a	U	U	R = 0 to 1/8	α = 45°	f = 1/8	r = 3/8	All	—	d, e, g, j, k
				R = 0 to 1/8	α = 30°	f = 1/8	r = 3/8	F, OH	—	d, e, g, j, k
GMAW FCAW	TC-U8a-GF	U	U	R = 0 to 1/8	α = 30°	f = 1/8	r = 3/8	All	Not required	a, d, g, j, k
SAW	TC-U8a-S	U	U	R = 0	α = 45°	f = 1/4 max.	r = 3/8	F	—	d, g, j, k

Figure 5.1 (Continued)—Prequalified CJP Groove Welded Joint Details (See 5.4.1) (Dimensions in Inches)

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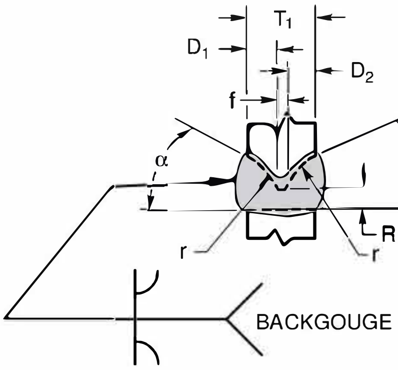
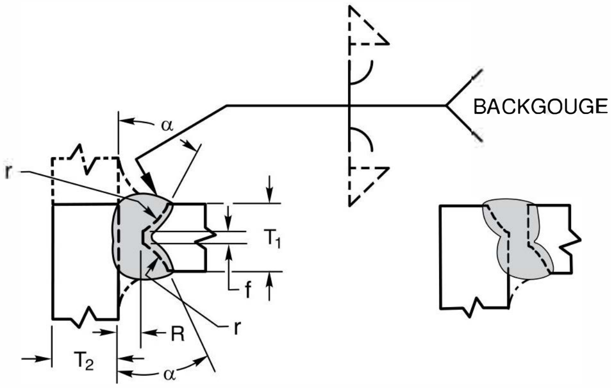
Double-J-groove weld (9)
Butt joint (B)



Tolerances	
As Detailed (see 5.4.1.1)	As Fit-Up (see 5.4.1.8)
R = +1/16, –0	+1/16, –1/8
α = +10°, –0°	+10°, –5°
f = +1/16, –0	Not Limited
r = 1/8, –0	±1/16

Welding Process	Joint Designation	Base Metal Thickness (U = unlimited) T_1	T_2	Groove Preparation: Root Opening	Groove Angle	Root Face	Bevel Radius	Allowed Welding Positions	Gas Shielding for FCAW	Notes
SMAW	B-U9	U	—	R = 0 to 1/8	α = 45°	f = 1/8	r = 3/8	All	—	c, d, e, h, j
GMAW FCAW	B-U9-GF	U	—	R = 0 to 1/8	α = 30°	f = 1/8	r = 3/8	All	Not required	a, c, d, h, j

Double-J-gnoove weld (9)
T-joint (T)
Corner joint (C)



Tolerances	
As Detailed (see 5.4.1.1)	As Fit-Up (see 5.4.1.8)
R = +1/16, –0	+1/16, –1/8
α = +10°, –0°	+10°, –5°
f = +1/16, –0	Not Limited
r = 1/8, –0	±1/16

Welding Process	Joint Designation	Base Metal Thickness (U = unlimited) T_1	T_2	Groove Preparation: Root Opening	Groove Angle	Root Face	Bevel Radius	Allowed Welding Positions	Gas Shielding for FCAW	Notes
SMAW	TC-U9a	U	U	R = 0 to 1/8	α = 45°	f = 1/8	r = 3/8	All	—	d, e, g, h, j, k
				R = 0 to 1/8	α = 30°	f = 1/8	r = 3/8	F, OH	—	d, e, g, h, k
GMAW FCAW	TC-U9a-GF	U	U	R = 0 to 1/8	α = 30°	f = 1/8	r = 3/8	All	Not required	a, d, g, h, j, k

Figure 5.1 (Continued)—Prequalified CJP Groove Welded Joint Details (See 5.4.1) (Dimensions in Inches)

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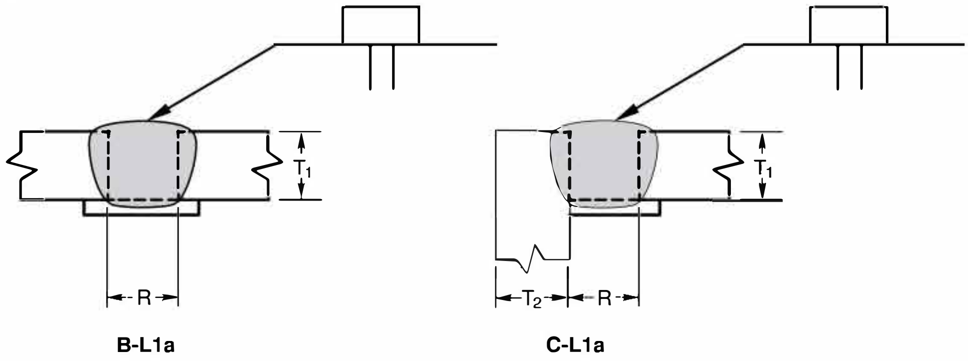
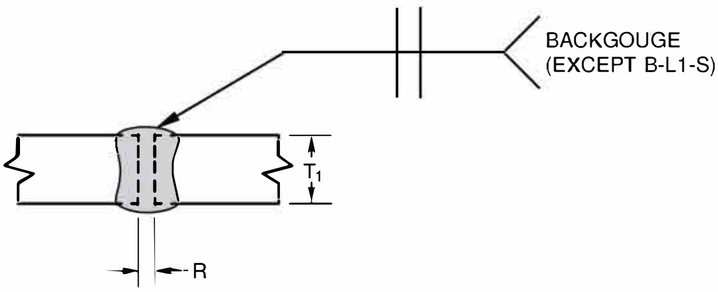
Square-groove weld (1)
Butt joint (B)
Corner joint (C)



Welding Process	Joint Designation	Base Metal Thickness (U = unlimited) T1	T2	Groove Preparation Root Opening	Tolerances As Detailed (see 5.4.1.1)	As Fit-Up (see 5.4.1.8)	Allowed Welding Positions	Gas Shielding for FCAW	Notes
SMAW	B-L1a	6 max.	—	$R = T_1$	+2, –0	+6, –2	All	—	e, j
	C-L1a	6 max.	U	$R = T_1$	+2, –0	+6, –2	All	—	e, j
FCAW GMAW	B-L1a-GF	10 max.	—	$R = T_1$	+2, –0	+6, –2	All	Not required	a, j

Square-groove weld (1)
Butt joint (B)



Welding Process	Joint Designation	Base Metal Thickness (U = unlimited) T1	T2	Groove Preparation Root Opening	Tolerances As Detailed (see 5.4.1.1)	As Fit-Up (see 5.4.1.8)	Allowed Welding Positions	Gas Shielding for FCAW	Notes
SMAW	B-L1b	6 max.	—	$R = \frac{T_1}{2}$	+2, –0	+2, –3	All	—	d, e, j
GMAW FCAW	B-L1b-GF	10 max.	—	R = 0 to 3	+2, –0	+2, –3	All	Not required	a, d, j
SAW	B-L1-S	10 max.	—	R = 0	±0	+2, –0	F	—	j
SAW	B-L1a-S	16 max.	—	R = 0	±0	+2, –0	F	—	d, j

Figure 5.1 (Continued)—Prequalified CJP Groove Welded Joint Details (See 5.4.1) (Dimensions in Millimeters)

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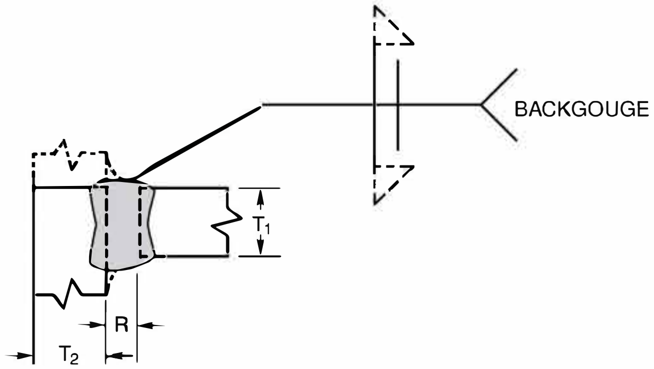
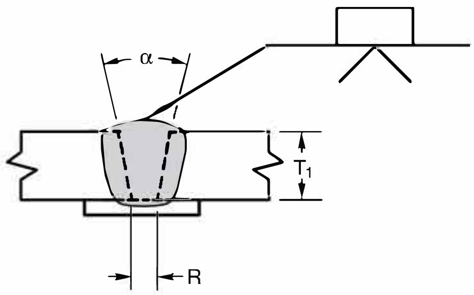
Square-groove weld (1)
T-joint (T)
Corner joint (C)



Welding Process	Joint Designation	Base Metal Thickness (U = unlimited)		Groove Preparation			Allowed Welding Positions	Gas Shielding for FCAW	Notes
					Tolerances				
		T_1	T_2	Root Opening	As Detailed (see 5.4.1.1)	As Fit-Up (see 5.4.1.8)			
SMAW	TC-L1b	6 max.	U	$R = \frac{T_1}{2}$	+2, –0	+2, –3	All	—	d, e, g
GMAW FCAW	TC-L1-GF	10 max.	U	R = 0 to 3	+2, –0	+2, –3	All	Not required	a, d, g
SAW	TC-L1-S	10 max.	U	R = 0	±0	+2, –0	F	—	d, g

Single-V-groove weld (2)
Butt joint (B)



Tolerances	
As Detailed (see 5.4.1.1)	As Fit-Up (see 5.4.1.8)
R = +2, –0	+6, –2
α = +10°, –0°	+10°, –5°

Welding Process	Joint Designation	Base Metal Thickness (U = unlimited)		Groove Preparation		Allowed Welding Positions	Gas Shielding for FCAW	Notes
		T_1	T_2	Root Opening	Groove Angle			
SMAW	B-U2a	U	—	R = 6	α = 45°	All	—	e, j
				R = 10	α = 30°	F, V, OH	—	e, j
				R = 12	α = 20°	F, V, OH	—	e, j
GMAW FCAW	B-U2a-GF	U	—	R = 5	α = 30°	F, V, OH	Required	a, j
				R = 10	α = 30°	F, V, OH	Not req.	a, j
				R = 6	α = 45°	F, V, OH	Not req.	a, j
SAW	B-L2a-S	50 max.	—	R = 6	α = 30°	F	—	j
SAW	B-U2-S	U	—	R = 16	α = 20°	F	—	j

Figure 5.1 (Continued)—Prequalified CJP Groove Welded Joint Details (See 5.4.1)
(Dimensions in Millimeters)

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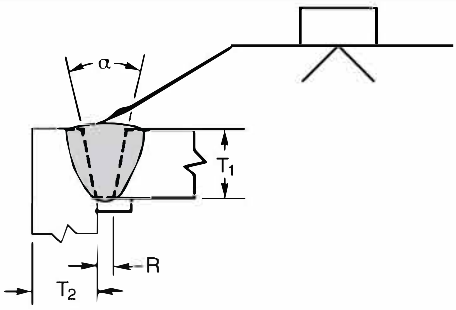
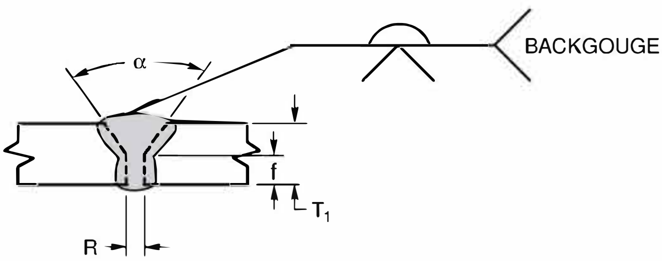
Single-V-groove weld (2)
Corner joint (C)



Tolerances	
As Detailed (see 5.4.1.1)	As Fit-Up (see 5.4.1.8)
R = +2, –0	+6, –2
α = +10°, –0°	+10°, –5°

Welding Process	Joint Designation	Base Metal Thickness (U = unlimited)		Groove Preparation		Allowed Welding Positions	Gas Shielding for FCAW	Notes
		T_1	T_2	Root Opening	Groove Angle			
SMAW	C-U2a	U	U	R = 6	α = 45°	All	—	e, o
				R = 10	α = 30°	F, V, OH	—	e, o
				R = 12	α = 20°	F, V, OH	—	e, o
GMAW FCAW	C-U2a-GF	U	U	R = 5	α = 30°	F, V, OH	Required	a
				R = 10	α = 30°	F, V, OH	Not req.	a, o
				R = 6	α = 45°	F, V, OH	Not req.	a, o
SAW	C-L2a-S	50 max.	U	R = 6	α = 30°	F	—	o
SAW	C-U2-S	U	U	R = 16	α = 20°	F	—	o

Single-V-groove weld (2)
Butt joint (B)



Welding Process	Joint Designation	Base Metal Thickness (U = unlimited)		Groove Preparation			Allowed Welding Positions	Gas Shielding for FCAW	Notes
				Root Opening Root Face Groove Angle	Tolerances				
		T_1	T_2		As Detailed (see 5.4.1.1)	As Fit-Up (see 5.4.1.8)			
SMAW	B-U2	U	—	R = 0 to 3 f = 0 to 3 α = 60°	+2, –0 +2, –0 +10°, –0°	+2, –3 Not limited +10°, –5°	All	—	d, e, j
GMAW FCAW	B-U2-GF	U	—	R = 0 to 3 f = 0 to 3 α = 60°	+2, –0 +2, –0 +10°, –0°	+2, –3 Not limited +10°, –5°	All	Not required	a, d, j
SAW	B-L2c-S	Over 12 to 25	—	R = 0 f = 6 max. α = 60°	R = ±0 f = +0, –f α = +10°, –0°	+2, –0 ±2 +10°, –5°	F	—	d, j
		Over 25 to 38	—	R = 0 f = 12 max. α = 60°					
		Over 38 to 50	—	R = 0 f = 16 max. α = 60°					

Figure 5.1 (Continued)—Prequalified CJP Groove Welded Joint Details (See 5.4.1) (Dimensions in Millimeters)

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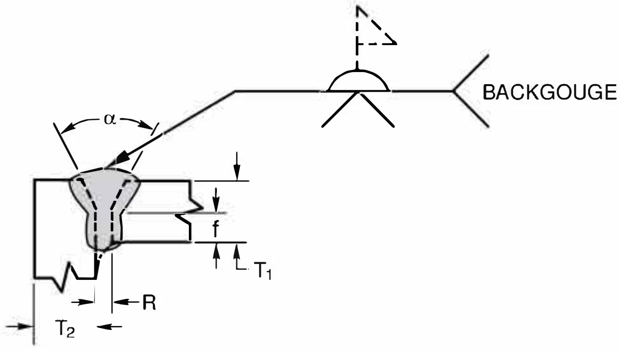
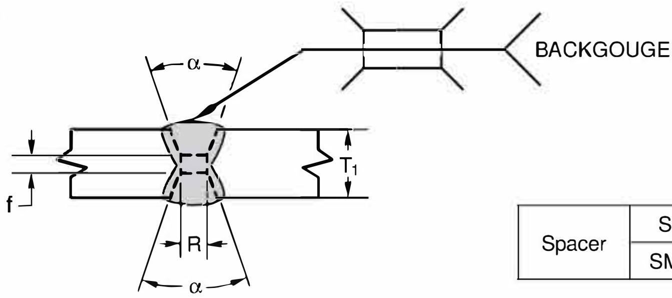
Single-V-groove weld (2)
Corner Joint (C)



Welding Process	Joint Designation	Base Metal Thickness (U – unlimited) T_1	T_2	Groove Preparation: Root Opening / Root Face / Groove Angle	Tolerances: As Detailed (see 5.4.1.1)	As Fit-Up (see 5.4.1.8)	Allowed Welding Positions	Gas Shielding for FCAW	Notes
SMAW	C-U2	U	U	R = 0 to 3 f = 0 to 3 α = 60°	+2, –0 +2, –0 +10°, –0°	+2, –3 Not limited +10°, –5°	All	—	d, e, g, j
GMAW FCAW	C-U2-GF	U	U	R = 0 to 3 f = 0 to 3 α = 60°	+2, –0 +2, –0 +10°, –0°	+2, –3 Not limited +10°, –5°	All	Not required	a, d, g, j
SAW	C-U2b-S	U	U	R = 0 to 3 f = 6 max. α = 60°	±0 +0, –6 +10°, –0°	+2, –0 ±2 +10°, –5°	F	—	d, g, j

Double-V-groove weld (3)
Butt joint (B)



		Tolerances: As Detailed (see 5.4.1.1)	As Fit-Up (see 5.4.1.8)
		R = ±0	+6, –0
		f = ±0	+2, –0
		α = +10°, –0°	+10°, –5°
Spacer	SAW	±0	+2, –0
	SMAW	±0	+3, –0

Welding Process	Joint Designation	Base Metal Thickness (U – unlimited) T_1	T_2	Groove Preparation: Root Opening	Root Face	Groove Angle	Allowed Welding Positions	Gas Shielding for FCAW	Notes
SMAW	B-U3a	U Spacer = 1/8 × R	—	R= 6	f = 0 to 3	α = 45°	All	—	d, e, h, j
				R = 10	f = 0 to 3	α = 30°	F, V, OH	—	
				R = 12	f = 0 to 3	α = 20°	F, V, OH	—	
SAW	B-U3a-S	U Spacer = 1/4 × R	—	R = 16	f = 0 to 6	α = 20°	F	—	d, h, j

Figure 5.1 (Continued)—Prequalified CJP Groove Welded Joint Details (See 5.4.1) (Dimensions in Millimeters)

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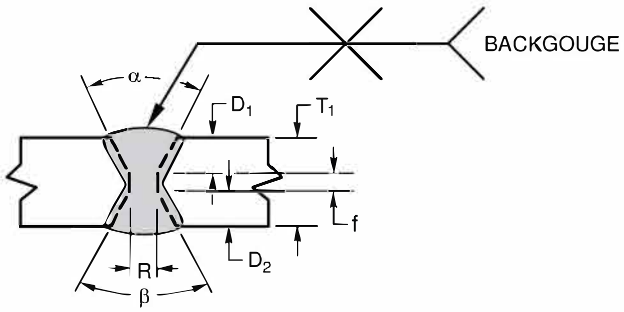
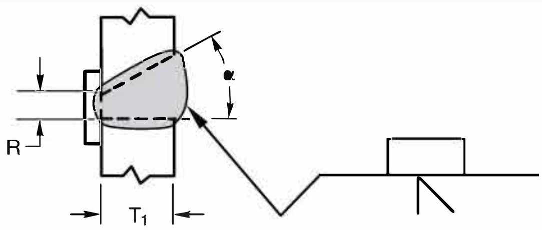
Double-V-groove weld (3)
Butt joint (B)



For B-U3c-S only		
T_1		D_1
Over	to	
50	60	35
60	80	45
80	90	55
90	100	60
100	120	70
120	140	80
140	160	95
For T_1 > 160 or $T_1 \leq 50$ $D_1 = 2/3(T_1 - 6)$		

Welding Process	Joint Designation	Base Metal Thickness (U – unlimited) T_1	T_2	Groove Preparation: Root Opening Root Face Groove Angle	Tolerances: As Detailed (see 5.4.1.1)	As Fit-Up (see 5.4.1.8)	Allowed Welding Positions	Gas Shielding for FCAW	Notes
SMAW	B-U3b	U	—	R = 0 to 3 f = 0 to 3 α = β = 60°	+2, –0 +2, –0 +10°, –0°	+2, –3 Not limited +10°, –5°	All	—	d, e, h, j
GMAW FCAW	B-U3-GF						All	Not required	a, d, h, j
SAW	B-U3c-S	U	—	R = 0 f = 6 min. α = β = 60°	+2, –0 +6, –0 +10°, –0°	+2, –0 +6, –0 +10°, –5°	F	—	d, h, j
				To find D_1, see table above: $D_2 = T_1 - (D_1 + f)$					

Single-bevel-groove weld (4)
Butt joint (B)



Tolerances	
As Detailed (see 5.4.1.1)	As Fit-Up (see 5.4.1.8)
R = +2, –0	+6, –2
α = +10°, –0°	+10°, –5°

Welding Process	Joint Designation	Base Metal Thickness (U = unlimited) T_1	T_2	Groove Preparation: Root Opening	Groove Angle	Allowed Welding Positions	Gas Shielding for FCAW	Notes
SMAW	B-U4a	U	—	R = 6	α = 45°	All	—	c, e, j
				R = 10	α = 30°	All	—	c, e, j
GMAW FCAW	B-U4a-GF	U	—	R – 5	α = 30°	All	Required	a, c, j
				R = 6	α = 45°	All	Not req.	a, c, j
				R = 10	α = 30°	F, H	Not req.	a, c, j
SAW	B-U4a-S	U	—	R = 10	α = 30°	F	—	c, j
				R = 6	α = 45°			

Figure 5.1 (Continued)—Prequalified CJP Groove Welded Joint Details (See 5.4.1) (Dimensions in Millimeters)

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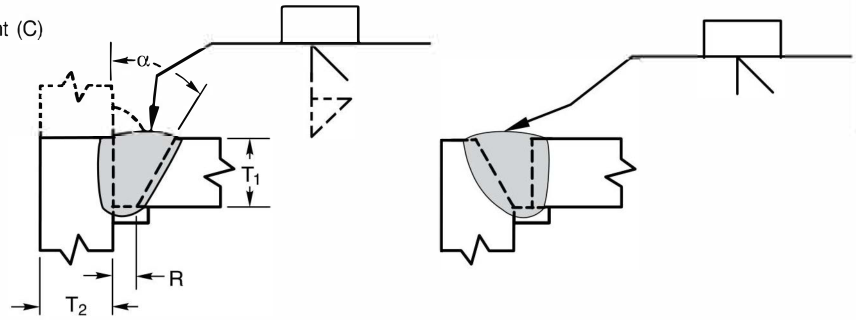
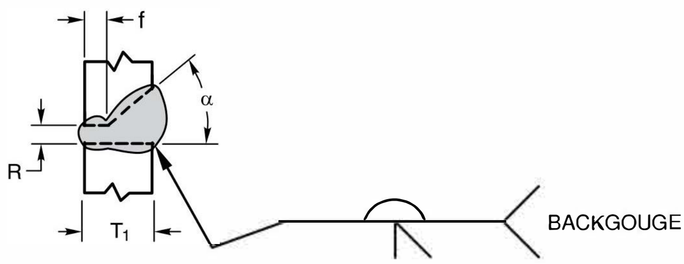
Single-bevel-groove weld (4)
T-joint (T)
Corner joint (C)



Tolerances	
As Detailed (see 5.4.1.1)	As Fit-Up (see 5.4.1.8)
R = +2, –0	+6, –2
α = +10°, –0°	+10°, –5°

Welding Process	Joint Designation	Base Metal Thickness (U – unlimited)		Groove Preparation		Allowed Welding Positions	Gas Shielding for FCAW	Notes
		T_1	T_2	Root Opening	Groove Angle			
SMAW	TC-U4a	U	U	R = 6	α = 45°	All	—	e, g, k, o
				R = 10	α = 30°	F, V, OH	—	e, g, k, o
GMAW FCAW	TC-U4a-GF	U	U	R = 5	α = 30°	All	Required	a, g, k, o
				R = 10	α = 30°	F	Not req.	a, g, k, o
				R = 6	α = 45°	All	Not req.	a, g, k, o
SAW	TC-U4a-S	U	U	R = 10	α = 30°	F	—	g, k, o
				R = 6	α = 45°			

Single-bevel-groove weld (4)
Butt joint (B)



Welding Process	Joint Designation	Base Metal Thickness (U – unlimited)		Groove Preparation			Allowed Welding Positions	Gas Shielding for FCAW	Notes
				Root Opening	Tolerances				
		T_1	T_2		As Detailed (see 5.4.1.1)	As Fit-Up (see 5.4.1.8)			
SMAW	B-U4b	U	—	R = 0 to 3 f = 0 to 3 α = 45°	+2, –0 +2, –0 +10°, –0°	+2, –3 Not limited 10°, –5°	All	—	c, d, e, j
GMAW FCAW	B-U4b-GF	U	—				All	Not required	a, c, d, j
SAW	B-U4b-S	U	—	R = 0 f = 6 max. α = 60°	±0 +0, –3 +10°, –0°	+6, –0 ±2 10°, –5°	F	—	c, d, j

Figure 5.1 (Continued)—Prequalified CJP Groove Welded Joint Details (See 5.4.1) (Dimensions in Millimeters)

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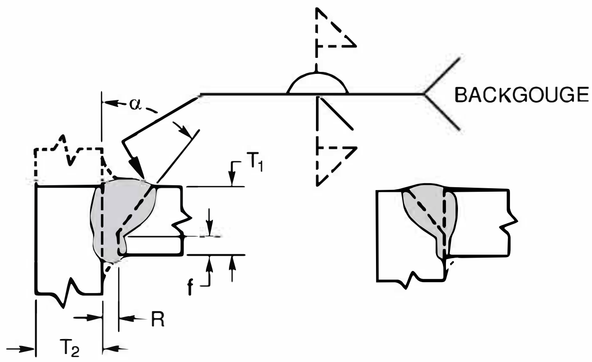
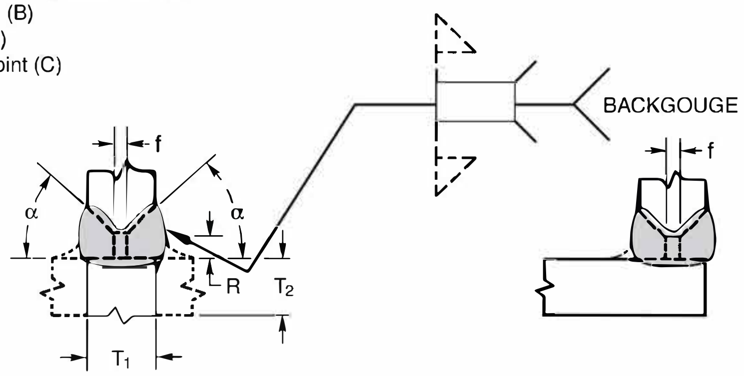
Single-bevel-groove weld (4)
T-joint (T)
Corner joint (C)



Welding Process	Joint Designation	Base Metal Thickness (U = unlimited)		Groove Preparation			Allowed Welding Positions	Gas Shielding for FCAW	Notes
				Root Opening Root Face Groove Angle	Tolerances				
		T_1	T_2		As Detailed (see 5.4.1.1)	As Fit-Up (see 5.4.1.8)			
SMAW	TC-U4b	U	U	R = 0 to 3 f = 0 to 3 α = 45°	+2, –0 +2, –0 +10°, –0°	+2, –3 Not limited +10°, –5°	All	—	d, e, g, j, k
GMAW FCAW	TC-U4b-GF	U	U				All	Not required	a, d, g, j, k
SAW	TC-U4b-S	U	U	R = 0 f = 6 max. α = 60°	±0 +0, –3 +10°, –0°	+6, –0 ±2 +10°, –5°	F	—	d, g, j, k

Double-bevel-groove weld (5)
Butt joint (B)
T-joint (T)
Corner joint (C)



	Tolerances	
	As Detailed (see 5.4.1.1)	As Fit-Up (see 5.4.1.8)
	R = ±0	+6, –0
	f = +2, –0	±2
	α = +10°, –0°	+10°, –5°
Spacer	+2, –0	+3, –0

Welding Process	Joint Designation	Base Metal Thickness (U = unlimited)		Groove Preparation			Allowed Welding Positions	Gas Shielding for FCAW	Notes
		T_1	T_2	Root Opening	Root Face	Groove Angle			
SMAW	B-U5b	U Spacer = 1/8 × R	—	R = 6	f = 0 to 3	α = 45°	All	—	c, d, e, h, j
	TC-U5a	U Spacer = 1/4 × R	U	R = 6	f = 0 to 3	α = 45°	All	—	d, e, g, h, j, k
				R = 10	f = 0 to 3	α = 30°	F, OH	—	d, e, g, h, j, k

Figure 5.1 (Continued)—Prequalified CJP Groove Welded Joint Details (See 5.4.1) (Dimensions in Millimeters)

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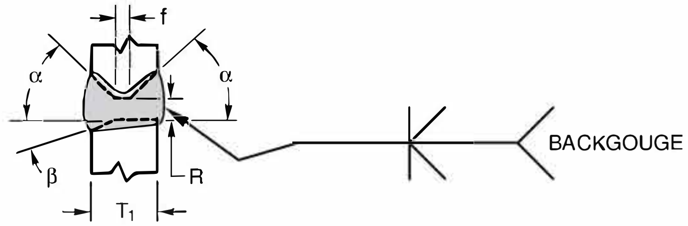
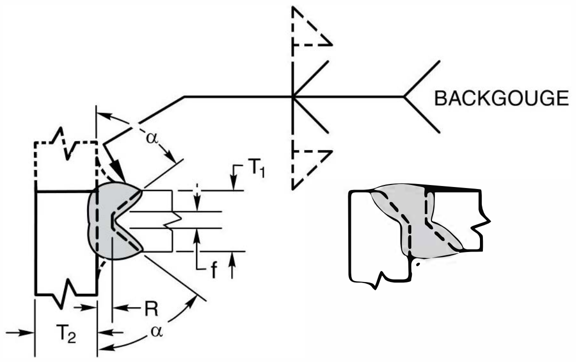
Double-bevel-groove weld (5)
Butt joint (B)



Welding Process	Joint Designation	Base Metal Thickness (U = unlimited) T_1	T_2	Groove Preparation: Root Opening Root Face Groove Angle	Tolerances: As Detailed (see 5.4.1.1)	As Fit-Up (see 5.4.1.8)	Allowed Welding Positions	Gas Shielding for FCAW	Notes
SMAW	B-U5a	U	—	R = 0 to 3 f = 0 to 3 α = 45° β = 0° to 15°	+2, –0 +2, –0 α + β = +10°, –0°	+2, –3 Not limited α + β = +10°, –5°	All	—	c, d, e, h, j
GMAW FCAW	B-U5-GF	U	—	R = 0 to 3 f = 0 to 3 α = 45° β = 0° to 15°	+2, –0 +2, –0 α + β = +10°, –0°	+2, –3 Not limited α + β = +10°, –5°	All	Not required	a, c, d, h, j

Double-bevel-groove weld (5)
T-joint (T)
Corner joint (C)



Welding Process	Joint Designation	Base Metal Thickness (U = unlimited) T_1	T_2	Groove Preparation: Root Opening Root Face Groove Angle	Tolerances: As Detailed (see 5.4.1.1)	As Fit-Up (see 5.4.1.8)	Allowed Welding Positions	Gas Shielding for FCAW	Notes
SMAW	TC-U5b	U	U	R = 0 to 3 f = 0 to 3 α = 45°	+2, –0 +2, –0 +10°, –0°	+2, –3 Not limited +10°, –5°	All	—	d, e, g, h, j, k
GMAW FCAW	TC-U5-GF	U	U				All	Not required	a, d, g, h, j, k
SAW	TC-U5-S	U	U	R = 0 f = 6 max. α = 60°	±0 +0, –5 +10°, –0°	+2, –0 ±2 +10°, –5°	F	—	d, g, h, j, k

Figure 5.1 (Continued)—Prequalified CJP Groove Welded Joint Details (See 5.4.1)
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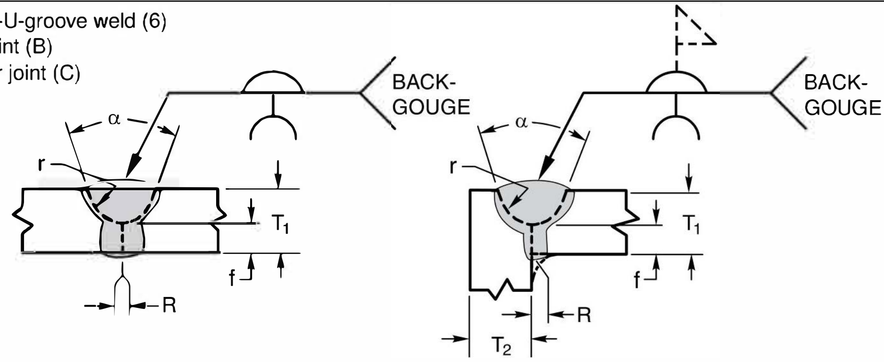
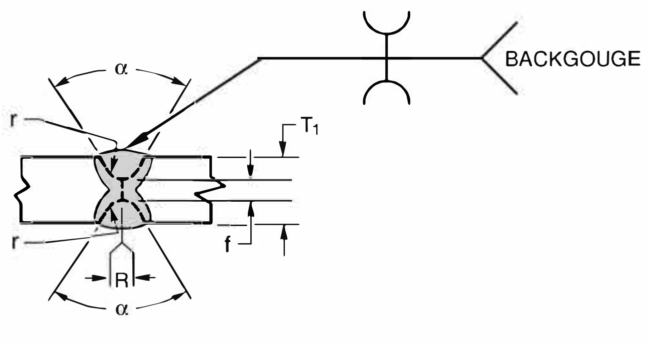
Single-U-groove weld (6)
Butt joint (B)
Corner joint (C)



Tolerances	
As Detailed (see 5.4.1.1)	As Fit-Up (see 5.4.1.8)
R = +2, −0	+2, −3
α = +10°, −0°	+10°, −5°
f = ±2	Not Limited
r = +3, −0	+3, −0

Welding Process	Joint Designation	Base Metal Thickness (U = unlimited)		Groove Preparation				Allowed Welding Positions	Gas Shielding for FCAW	Notes
		T_1	T_2	Root Opening	Groove Angle	Root Face	Bevel Radius			
SMAW	B-U6	U	—	R = 0 to 3	α = 45°	f = 3	r = 6	All	—	d, e, j
				R = 0 to 3	α = 20°	f = 3	r = 6	F, OH	—	d, e, j
	C-U6	U	U	R = 0 to 3	α = 45°	f = 3	r = 6	All	—	d, e, g, j
				R = 0 to 3	α = 20°	f = 3	r = 6	F, OH	—	d, e, g, j
GMAW FCAW	B-U6-GF	U	—	R = 0 to 3	α = 20°	f = 3	r = 6	All	Not req.	a, d, j
	C-U6-GF	U	U	R = 0 to 3	α = 20°	f = 3	r = 6	All	Not req.	a, d, g, j

Double-U-groove weld (7)
Butt joint (B)



Tolerances	
As Detailed (see 5.4.1.1)	As Fit-Up (see 5.4.1.8)
For B-U7 and B-U7-GF	
R = +2, −0	+2, −3
α = +10°, −0°	+10°, −5°
f = ±2, −0	Not Limited
r = +6, −0	±2
For B-U7-S	
R = +0	+2, −0
α = +10°, −0°	+10°, −5°
f = +0, −6	±2
r = +6, −0	±2

Welding Process	Joint Designation	Base Metal Thickness (U = unlimited)		Groove Preparation				Allowed Welding Positions	Gas Shielding for FCAW	Notes
		T_1	T_2	Root Opening	Groove Angle	Root Face	Bevel Radius			
SMAW	B-U7	U	—	R = 0 to 3	α = 45°	f = 3	r = 6	All	—	d, e, h, j
				R = 0 to 3	α = 20°	f = 3	r = 6	F, OH	—	d, e, h, j
GMAW FCAW	B-U7-GF	U	—	R = 0 to 3	α = 20°	f = 3	r = 6	All	Not required	a, d, j, h
SAW	B-U7-S	U	—	R = 0	α = 20°	f = 6 max.	r = 6	F	—	d, h, j

Figure 5.1 (Continued)—Prequalified CJP Groove Welded Joint Details (See 5.4.1)
(Dimensions in Millimeters)

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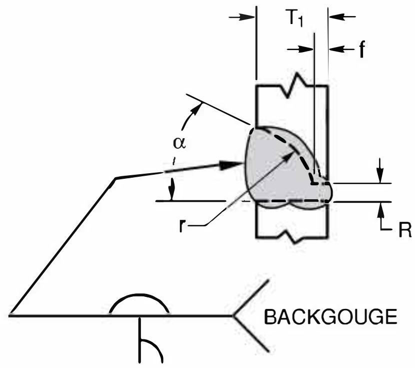
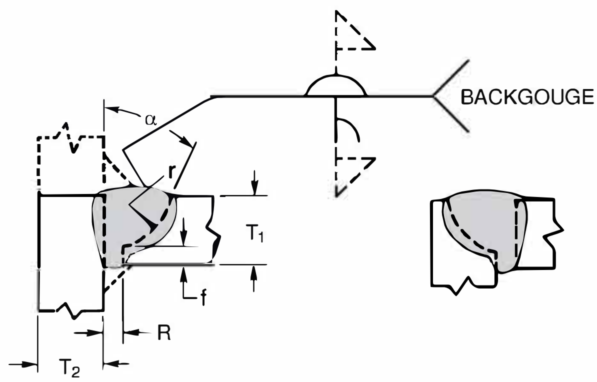
Single-J-groove weld (8)
Butt joint (B)



Tolerances	
As Detailed (see 5.4.1.1)	As Fit-Up (see 5.4.1.8)
B-U8 and B-U8-GF	
R = +2, −0	+2, −3
α = +10°, −0°	+10°, −5°
f = +3, −0	Not Limited
r = +6, −0	±1/16
B-U8-S	
R = ±0	+3, −0
α = +10°, −0°	+10°, −5°
f = +0, −3	±2
r = +6, −0	±2

Welding Process	Joint Designation	Base Metal Thickness (U = unlimited)		Groove Preparation				Allowed Welding Positions	Gas Shielding for FCAW	Notes
		T_1	T_2	Root Opening	Groove Angle	Root Face	Bevel Radius			
SMAW	B-U8	U	—	R = 0 to 3	α = 45°	f = 3	r = 10	All	—	c, d, e, j
GMAW FCAW	B-U8-GF	U	—	R = 0 to 3	α = 30°	f = 3	r = 10	All	Not req.	a, c, d, j
SAW	B-U8-S	U	—	R = 0	α = 45°	f = 6 max.	r = 10	F	—	c, d, j

Single-J-groove weld (8)
T-joint (T)
Corner joint (C)



Tolerances	
As Detailed (see 5.4.1.1)	As Fit-Up (see 5.4.1.8)
TC-U8a and TC-U8a-GF	
R = +2, −0	+2, −3
α = +10°, −0°	+10°, −5°
f = +2, −0	Not Limited
r = +6, −0	±1/16
TC-U8a-S	
R = ±0	+6, −0
α = +10°, −0°	+10°, −5°
f = +0, −3	±2
r = +6, −0	±2

Welding Process	Joint Designation	Base Metal Thickness (U = unlimited)		Groove Preparation				Allowed Welding Positions	Gas Shielding for FCAW	Notes
		T_1	T_2	Root Opening	Groove Angle	Root Face	Bevel Radius			
SMAW	TC-U8a	U	U	R = 0 to 3	α = 45°	f = 3	r = 10	All	—	d, e, g, j, k
				R = 0 to 3	α = 45°	f = 3	r = 10	F, OH	—	d, e, g, j, k
GMAW FCAW	TC-U8a-GF	U	U	R = 0 to 3	α = 45°	f = 3	r = 10	All	Not required	a, d, g, j, k
SAW	TC-U8a-S	U	U	R = 0	α = 45°	f = 6 max.	r = 10	F	—	d, g, j, k

Figure 5.1 (Continued)—Prequalified CJP Groove Welded Joint Details (See 5.4.1) (Dimensions in Millimeters)

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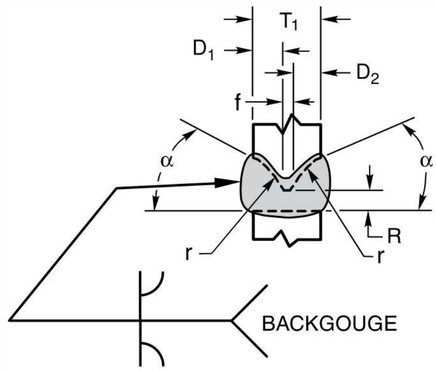
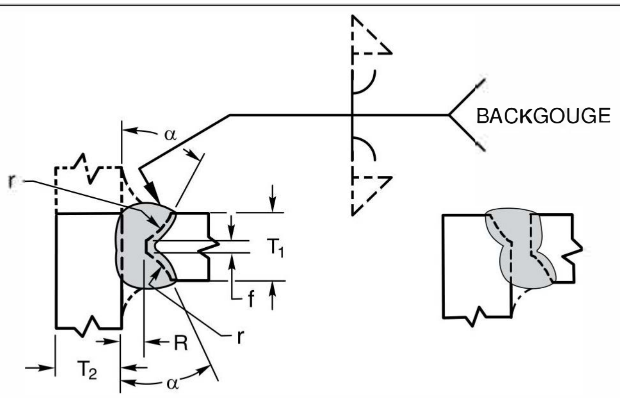
Double-J-groove weld (9)
Butt joint (B)



Tolerances	
As Detailed (see 5.4.1.1)	As Fit-Up (see 5.4.1.8)
R = +2, –0	+2, –3
α = +10°, –0°	+10°, –5°
f = +2, –0	Not Limited
r = +3, –0	±2

Welding Process	Joint Designation	Base Metal Thickness (U = unlimited)		Groove Preparation				Allowed Welding Positions	Gas Shielding for FCAW	Notes
		T_1	T_2	Root Opening	Groove Angle	Root Face	Bevel Radius			
SMAW	B-U9	U	—	R = 0 to 3	α = 45°	f = 3	r = 10	All	—	c, d, e, h, j
GMAW FCAW	B-U9-GF	U	—	R = 0 to 3	α = 30°	f = 3	r = 10	All	Not required	a, c, d, h, j

Double-J-groove weld (9)
T-joint (T)
Corner joint (C)



Tolerances	
As Detailed (see 5.4.1.1)	As Fit-Up (see 5.4.1.8)
R = +2, –0	+2, –3
α = +10°, –0°	+10°, –5°
f = +2, –0	Not Limited
r = 3, –0	±2

Welding Process	Joint Designation	Base Metal Thickness (U = unlimited)		Groove Preparation				Allowed Welding Positions	Gas Shielding for FCAW	Notes
		T_1	T_2	Root Opening	Groove Angle	Root Face	Bevel Radius			
SMAW	TC-U9a	U	U	R = 0 to 3	α = 45°	f = 3	r = 10	All	—	d, e, g, h, j, k
				R = 0 to 3	α = 30°	f = 3	r = 10	F, OH	—	d, e, g, h, j, k
GMAW FCAW	TC-U9a-GF	U	U	R = 0 to 3	α = 30°	f = 3	r = 10	All	Not required	a, d, g, h, j, k

Figure 5.1 (Continued)—Prequalified CJP Groove Welded Joint Details (See 5.4.1) (Dimensions in Millimeters)

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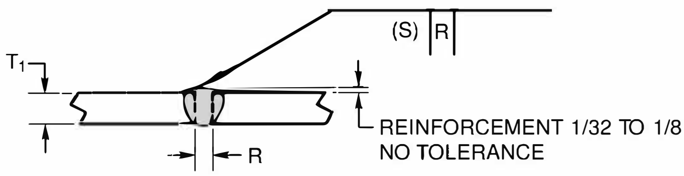
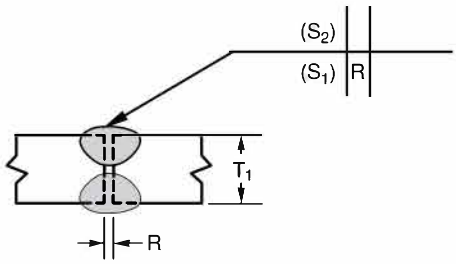
Square-groove weld (1)
Butt joint (B)



Welding Process	Joint Designation	Base Metal Thickness (U = unlimited)		Groove Preparation			Allowed Welding Positions	Weld Size (S)	Notes
					Tolerances				
		T_1	T_2	Root Opening	As Detailed (see 5.4.2.2)	As Fit-Up (see 5.4.2.7)			
SMAW	B-P1a	1/8	—	R = 0 to 1/16	+1/16, –0	±1/16	All	T_1 – 1/32	b
SMAW	B-P1c	1/4 max.	—	$R = \frac{T_1}{2}$ min.	+1/16, –0	±1/16	All	$\frac{T_1}{2}$	b
GMAW FCAW	B-P1a-GF	1/8	—	R = 0 to 1/16	+1/16, –0	±1/16	All	T_1 –1/32	b, e
GMAW FCAW	B-P1c-GF	1/4 max.	—	$R = \frac{T_1}{2}$ min.	+1/16, –0	±1/16	All	$\frac{T_1}{2}$	b, e

Square-groove weld (1)
Butt joint (B)



$S_1 + S_2$ MUST NOT EXCEED $\frac{3T_1}{4}$

Welding Process	Joint Designation	Base Metal Thickness (U = unlimited)		Groove Preparation			Allowed Welding Positions	Total Weld Size ($S_1 + S_2$)	Notes
					Tolerances				
		T_1	T_2	Root Opening	As Detailed (see 5.4.2.2)	As Fit-Up (see 5.4.2.7)			
SMAW	B-P1b	1/4 max.	—	$R = \frac{T_1}{2}$	+1/16, –0	±1/16	All	$\frac{T_1}{2}$	
GMAW FCAW	B-P1b-GF	1/4 max.	—	$R = \frac{T_1}{2}$	+1/16, –0	±1/16	All	$\frac{T_1}{2}$	e

Figure 5.2—Prequalified PJP Groove Weld Joint Details (see 5.4.2) (Dimensions in Inches)

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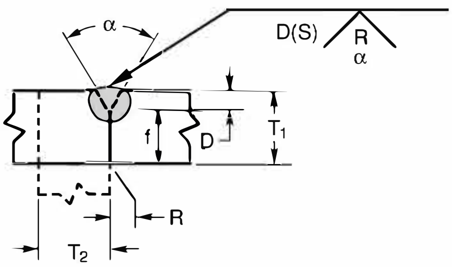
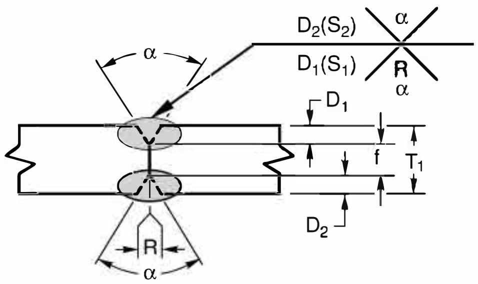
Single-V-groove weld (2)
Butt joint (B)
Corner joint (C)



Welding Process	Joint Designation	Base Metal Thickness (U = unlimited) T1	T2	Groove Preparation: Root Opening Root Face Groove Angle	Tolerances: As Detailed (see 5.4.2.2)	As Fit-Up (see 5.4.2.7)	Allowed Welding Positions	Weld Size (S)	Notes
SMAW	BC-P2	1/4 min.	U	R = 0 f = 1/32 min. α = 60°	+1/16, –0 +U, –0 +10°, –0°	+1/8, –1/16 ±1/16 +10°, –5°	All	D	b, e, f, j
GMAW FCAW	BC-P2-GF	1/4 min.	U	R = 0 f = 1/8 min. α = 60°	+1/16, –0 +U, –0 +10°, –0°	+1/8, –1/16 ±1/16 +10°, –5°	All	D	a, b, f, j
SAW	BC-P2-S	7/16 min.	U	R = 0 f = 1/4 min. α = 60°	±0 +U, –0 +10°, –0°	+1/16, –0 ±1/16 +10°, –5°	F	D	b, f, j

Double-V-groove weld (3)
Butt joint (B)



Welding Process	Joint Designation	Base Metal Thickness (U = unlimited) T1	T2	Groove Preparation: Root Opening Root Face Groove Angle	Tolerances: As Detailed (see 5.4.2.2)	As Fit-Up (see 5.4.2.7)	Allowed Welding Positions	Total Weld Size ($S_1 + S_2$)	Notes
SMAW	B-P3	1/2 min.	—	R = 0 f = 1/8 min. α = 60°	+1/16, –0 +U, –0 +10°, –0°	+1/8, –1/16 ±1/16 +10°, –5°	All	$D_1 + D_2$	e, f, i, j
GMAW FCAW	B-P3-GF	1/2 min.	—	R = 0 f = 1/8 min. α = 60°	+1/16, –0 +U, –0 +10°, –0°	+1/8, –1/16 ±1/16 +10°, –5°	All	$D_1 + D_2$	a, f, i, j
SAW	B-P3-S	3/4 min.	—	R = 0 f = 1/4 min. α = 60°	±0 +U, –0 +10°, –0°	+1/16, –0 ±1/16 +10°, –5°	F	$D_1 + D_2$	f, i, j

Figure 5.2 (Continued)—Prequalified PJP Groove Welded Joint Details (see 5.4.2) (Dimensions in Inches)

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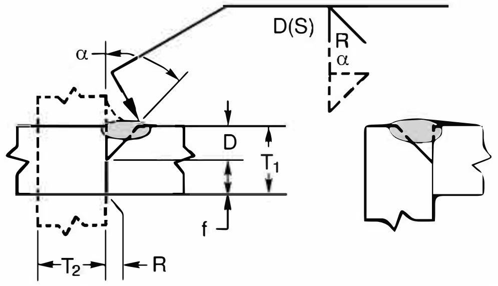
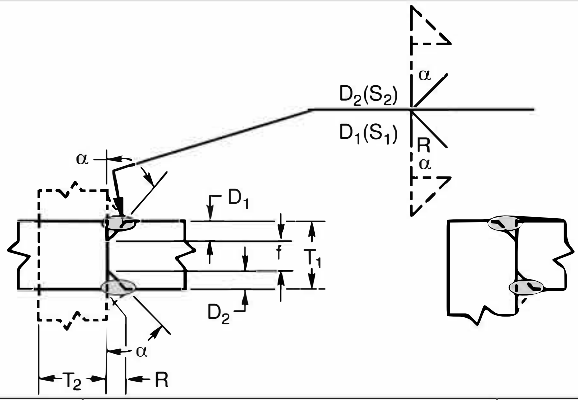
Single-bevel-groove weld (4)
Butt joint (B)
T-joint (T)
Corner joint (C)



Welding Process	Joint Designation	Base Metal Thickness (U = unlimited) T_1	T_2	Groove Preparation: Root Opening Root Face Groove Angle	Tolerances: As Detailed (see 5.4.2.2)	As Fit-Up (see 5.4.2.7)	Allowed Welding Positions	Weld Size (S)	Notes
SMAW	BTC-P4	U	U	R = 0 f = 1/8 min. α = 45°	+1/16, –0 +U –0 +10°, –0°	+1/8, –1/16 ±1/16 +10°, –5°	All	D –1/8	b, e, f, g, j, k
GMAW FCAW	BTC-P4-GF	1/4 min.	U	R = 0 f = 1/8 min. α = 45°	+1/16, –0 +U –0 +10°, –0°	+1/8, –1/16 ±1/16 +10°, –5°	F, H	D	a, b, f, g, j, k
							V, OH	D –1/8	
SAW	TC-P4-S	7/16 min.	U	R = 0 f = 1/4 min. α = 60°	±0 +U, –0 +10°, –0°	+1/16, –0 ±1/16 +10°, –5°	F	D	b, f, g, j, k

Double-bevel-groove weld (5)
Butt joint (B)
T-joint (T)
Corner joint (C)



Welding Process	Joint Designation	Base Metal Thickness (U = unlimited) T_1	T_2	Groove Preparation: Root Opening Root Face Groove Angle	Tolerances: As Detailed (see 5.4.2.2)	As Fit-Up (see 5.4.2.7)	Allowed Welding Positions	Total Weld Size (S_1 + S_2)	Notes
SMAW	BTC-P5	5/16 min.	U	R = 0 f = 1/8 min. α = 45°	+1/16, –0 +U –0 +10°, –0°	+1/8, –1/16 ±1/16 +10°, –5°	All	D_1 + D_2 –1/4	e, f, g, i, j, k
GMAW FCAW	BTC-P5-GF	1/2 min.	U	R = 0 f = 1/8 min. α = 45°	+1/16, –0 +U –0 +10°, –0°	+1/8, –1/16 ±1/16 +10°, –5°	F, H	D_1 + D_2	a, f, g, i, j, k
							V, OH	D_1 + D_2 –1/4	
SAW	TC-P5-S	3/4 min.	U	R = 0 f = 1/4 min. α = 60°	±0 +U, –0 +10°, –0°	+1/16, –0 ±1/16 +10°, –5°	F	D_1 + D_2	f, g, i, j, k

Figure 5.2 (Continued)—Prequalified PJP Groove Welded Joint Details (see 5.4.2) (Dimensions in Inches)

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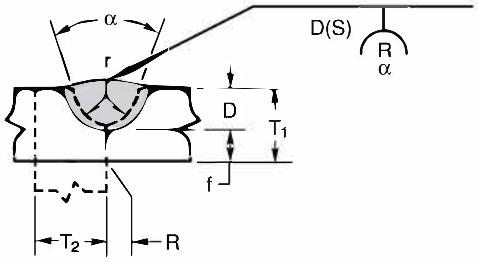
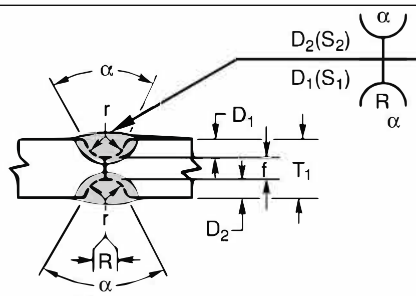
Single-U-groove weld (6)
Butt-joint (B)
Corner joint (C)



Welding Process	Joint Designation	Base Metal Thickness (U = unlimited) T_1	T_2	Groove Preparation: Root Opening Root Face Bevel Radius Groove Angle	Tolerances: As Detailed (see 5.4.2.2)	As Fit-Up (see 5.4.2.7)	Allowed Welding Positions	Weld Size (S)	Notes
SMAW	BC-P6	1/4 min.	U	R = 0 f = 1/32 min. r = 1/4 α = 45°	+1/16, –0 +U, –0 +1/4, –0 +10°, –0°	+1/8, –1/16 ±1/16 ±1/16 +10°, –5°	All	D	b, e, f, j
GMAW FCAW	BC-P6-GF	1/4 min.	U	R = 0 f = 1/8 min. r = 1/4 α = 20°	+1/16, –0 +U, –0 +1/4, –0 +10°, –0°	+1/8, –1/16 ±1/16 ±1/16 +10°, –5°	All	D	a, b, f, j
SAW	BC-P6-S	7/16 min.	U	R = 0 f = 1/4 min. r = 1/4 α = 20°	±0 +U, –0 +1/4, –0 +10°, –0°	+1/16, –0 ±1/16 ±1/16 +10°, –5°	F	D	b, f, j

Double-U-groove weld (7)
Butt joint (B)



Welding Process	Joint Designation	Base Metal Thickness (U = unlimited) T_1	T_2	Groove Preparation: Root Opening Root Face Bevel Radius Groove Angle	Tolerances: As Detailed (see 5.4.2.2)	As Fit-Up (see 5.4.2.7)	Allowed Welding Positions	Total Weld Size (S_1 + S_2)	Notes
SMAW	B-P7	1/2 min.	—	R = 0 f = 1/8 min. r = 1/4 α = 45°	+1/16, –0 +U, –0 +1/4, –0 +10°, –0°	+1/8, –1/16 ±1/16 ±1/16 +10°, –5°	All	D_1+D_2	e, f, i, j
GMAW FCAW	B-P7-GF	1/2 min.	—	R = 0 f = 1/8 min. r = 1/4 α = 20°	+1/16, –0 +U, –0 +1/4, –0 +10°, –0°	+1/8, –1/16 ±1/16 ±1/16 +10°, –5°	All	D_1+D_2	a, f, i, j
SAW	B-P7-S	3/4 min.	—	R = 0 f = 1/4 min. r = 1/4 α = 20°	±0 +U, –0 +1/4, –0 +10°, –0°	+1/16, –0 ±1/16 ±1/16 +10°, –5°	F	D_1+D_2	f, i, j

Figure 5.2 (Continued)—Prequalified PJP Groove Welded Joint Details (see 5.4.2) (Dimensions in Inches)

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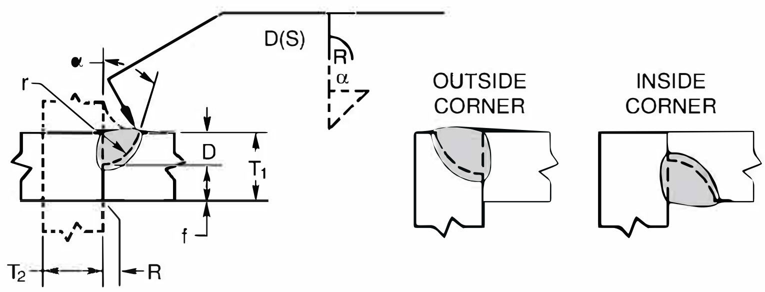
Single-J-groove weld (8)
Butt joint (B)
T-joint (T)
Corner joint (C)



Welding Process	Joint Designation	Base Metal Thickness (U = unlimited) T_1	T_2	Groove Preparation: Root Opening Root Face Bevel Radius Groove Angle	Tolerances: As Detailed (see 5.4.2.2)	As Fit-Up (see 5.4.2.7)	Allowed Welding Positions	Weld Size (S)	Notes
SMAW	B-P8	1/4 min.	—	R = 0 f = 1/8 min. r = 3/8 α = 30°	+1/16, –0 +U, –0 +1/4, –0 +10°, –0°	+1/8, –1/16 ±1/16 ±1/16 +10°, –5°	All	D	e, f, g, j, k
	TC-P8	1/4 min.	U	R = 0 f = 1/8 min. r = 3/8 $α_{oc}$ = 30°* $α_{ic}$ = 45°**	+1/16, –0 +U, –0 +1/4, –0 +10°, –0° +10°, –0°	+1/8, –1/16 ±1/16 ±1/16 +10°, –5° +10°, –5°	All	D	e, f, g, j, k
GMAW FCAW	B-P8-GF	1/4 min.	—	R = 0 f = 1/8 min. r = 3/8 α = 30°	+1/16, –0 +U, –0 +1/4, –0 +10°, –0°	+1/8, –1/16 ±1/16 ±1/16 +10°, –5°	All	D	a, f, g, j, k
	TC-P8-GF	1/4 min.	U	R = 0 f = 1/8 min. r = 3/8 $α_{oc}$ = 30°* $α_{ic}$ = 45°**	+1/16, –0 +U, –0 +1/4, –0 +10°, –0° +10°, –0°	+1/8, –1/16 ±1/16 ±1/16 +10°, –5° +10°, –5°	All	D	a, f, g, j, k
SAW	B-P8-S	7/16 min.	—	R = 0 f = 1/4 min. r = 1/2 α = 20°	±0 +U, –0 +1/4, –0 +10°, –0°	+1/16, –0 ±1/16 ±1/16 +10°, –5°	F	D	f, g, j, k
	TC-P8-S	7/16 min.	U	R = 0 f = 1/4 min. r = 1/2 $α_{oc}$ = 20°* $α_{ic}$ = 45°**	±0 +U, –0 +1/4, –0 +10°, –0° +10°, –0°	+1/16, –0 ±1/16 ±1/16 +10°, –5° +10°, –5°	F	D	f, g, j, k

*$α_{oc}$ = Outside corner groove angle.
**$α_{ic}$ = Inside corner groove angle.

Figure 5.2 (Continued)—Prequalified PJP Groove Welded Joint Details (see 5.4.2) (Dimensions in Inches)

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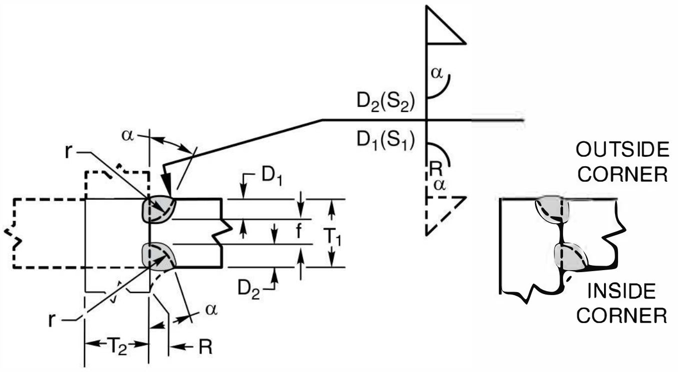
Double-J-groove weld (9)
Butt joint (B)
T-joint (T)
Corner joint (C)



Welding Process	Joint Designation	Base Metal Thickness (U = unlimited)		Groove Preparation			Allowed Welding Positions	Total Weld Size (S_1 + S_2)	Notes
		T_1	T_2	Root Opening Root Face Bevel Radius Groove Angle	Tolerances: As Detailed (see 5.4.2.2)	Tolerances: As Fit-Up (see 5.4.2.7)			
SMAW	B-P9	1/2 min.	—	R = 0 f = 1/8 min. r = 3/8 α = 30°	+1/16, –0 +U, –0 +1/4, –0 +10°, –0°	+1/8, –1/16 ±1/16 ±1/16 +10°, –5°	All	D_1 + D_2	e, f, g, i, j, k
SMAW	TC-P9	1/2 min.	U	R = 0 f = 1/8 min. r = 3/8 α_{oc} = 30°* α_{ic} = 45°**	+1/16, –0 +U, –0 +1/4, –0 +10°, –0° +10°, –0°	+1/8, –1/16 ±1/16 ±1/16 +10°, –5° +10°, –5°	All	D_1 + D_2	e, f, g, i, j, k
GMAW FCAW	B-P9-GF	1/2 min.	—	R = 0 f = 1/8 min. r = 3/8 α = 30°	+1/16, –0 +U, –0 +1/4, –0 +10°, –0°	+1/8, –1/16 ±1/16 ±1/16 +10°, –5°	All	D_1 + D_2	a, f, g, i, j, k
GMAW FCAW	TC-P9-GF	1/2 min.	U	R = 0 f = 1/8 min. r = 3/8 α_{oc} = 30°* α_{ic} = 45°**	±0 +U, –0 +1/4, –0 +10°, –0° +10°, –0°	+1/16, –0 ±1/16 ±1/16 +10°, –5° +10°, –5°	All	D_1 + D_2	a, f, g, i, j, k
SAW	B-P9-S	3/4 min.	—	R = 0 f = 1/4 min. r = 1/2 α = 20°	±0 +U, –0 +1/4, –0 +10°, –0°	+1/16, –0 ±1/16 ±1/16 +10°, –5°	F	D_1 + D_2	f, g, i, j, k
SAW	TC-P9-S	3/4 min.	U	R = 0 f = 1/4 min. r = 1/2 α_{oc} = 20°* α_{ic} = 45°**	±0 +U, –0 +1/4, –0 +10°, –0° +10°, –0°	+1/16, –0 ±1/16 ±1/16 +10°, –5° +10°, –5°	F	D_1 + D_2	f, g, i, j, k

*α_{oc} = Outside corner groove angle.
**α_{ic} = Inside corner groove angle.

Figure 5.2 (Continued)—Prequalified PJP Groove Welded Joint Details (see 5.4.2) (Dimensions in Inches)

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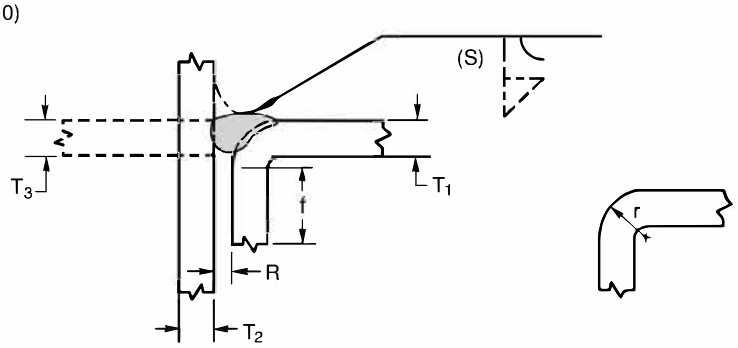
Flare-bevel-groove weld (10)
Butt joint (B)
T-joint (T)
Corner joint (C)



Welding Process	Joint Designation	Base Metal Thickness (U = unlimited)			Groove Preparation			Allowed Welding Positions	Weld Size (S)	Notes
						Tolerances				
		T_1	T_2	T_3	Root Opening Root Face Bend Radius	As Detailed (see 5.4.2.2)	As Fit-Up (see 5.4.2.7)			
SMAW FCAW-S	BTC-P10	3/16 min.	U	T_1 min.	R = 0 f = 3/16 min. $r = \frac{3T_1}{2}$ min.	+1/16, −0 +U, −0 +U, −0	+1/8, −1/16 +U, −1/16 +U, −0	All	5/16 r	e, g, j, l
GMAW FCAW-G	BTC-P10-GF	3/16 min.	U	T_1 min.	R = 0 f = 3/16 min. $r = \frac{3T_1}{2}$ min.	+1/16, −0 +U, −0 +U, −0	+1/8, −1/16 +U, −1/16 +U, −0	All	5/8 r	a, g, j, l, m
SAW	B-P10-S	1/2 min.	N/A	1/2 min.	R = 0 f = 1/2 min. $r = \frac{3T_1}{2}$ min.	±0 +U, −0 +U, −0	+1/16, −0 +U, −1/16 +U, −0	F	5/16 r	g, j, l, m

Figure 5.2 (Continued)—Prequalified PJP Groove Welded Joint Details (see 5.4.2) (Dimensions in Inches)

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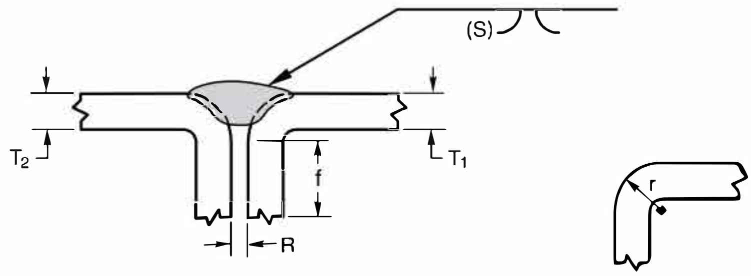
Flare-V-groove weld (11)
Butt joint (B)



		Base Metal Thickness (U = unlimited)		Groove Preparation					
					Tolerances				
Welding Process	Joint Designation	T_1	T_2	Root Opening Root Face Bend Radius	As Detailed (see 5.4.2.2)	As Fit-Up (see 5.4.2.7)	Allowed Welding Positions	Weld Size (S)	Notes
SMAW FCAW-S	B-P11	3/16 min.	T_1 min.	R = 0 f = 3/16 min. $r = \frac{3T_1}{2}$ min.	+1/16, –0 +U, –0 +U, –0	+1/8, –1/16 +U, –1/16 +U, –0	All	5/8 r	e, j, l, m, n
GMAW FCAW-G	B-P11-GF	3/16 min.	T_1 min.	R = 0 f = 3/16 min. $r = \frac{3T_1}{2}$ min.	+1/16, –0 +U, –0 +U, –0	+1/8, –1/16 +U, –1/16 +U, –0	All	3/4 r	a, j, l, m, n
SAW	B-P11-S	1/2 min.	T_1 min.	R = 0 f = 1/2 min. $r = \frac{3T_1}{2}$ min.	±0 +U, –0 +U, –0	+1/16, –0 +U, –1/16 +U, –0	F	1/2 r	j, l, m, n

Figure 5.2 (Continued)—Prequalified PJP Groove Welded Joint Details (see 5.4.2) (Dimensions in Inches)

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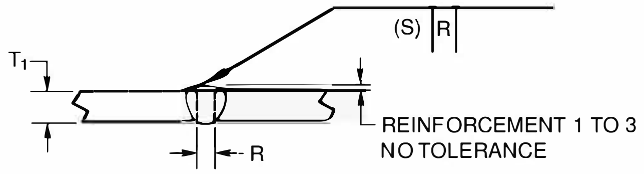
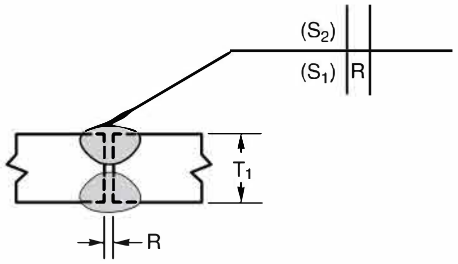
Square-groove weld (1)
Butt joint (B)



Welding Process	Joint Designation	Base Metal Thickness (U = unlimited)		Groove Preparation			Allowed Welding Positions	Weld Size (S)	Notes
					Tolerances				
		T_1	T_2	Root Opening	As Detailed (see 5.4.2.2)	As Fit-Up (see 5.4.2.7)			
SMAW	B-P1a	3	—	R = 0 to 2	+2, –0	±2	All	$T_1 - 1$	b
	B-P1c	6 max.	—	$R = \frac{T_1}{2}$ min.	+2, –0	±2	All	$\frac{T_1}{2}$	b
GMAW FCAW	B-P1a-GF	3	—	R = 0 to 2	+2, –0	±2	All	$T_1 - 1$	b, e
	B-P1c-GF	6 max.	—	$R = \frac{T_1}{2}$ min.	+2, –0	±2	All	$\frac{T_1}{2}$	b, e

Square-groove weld (1)
Butt joint (B)



$(S_1)+(S_2)$ MUST NOT EXCEED $\frac{3T_1}{4}$

Welding Process	Joint Designation	Base Metal Thickness (U = unlimited)		Groove Preparation			Allowed Welding Positions	Total Weld Size ($S_1 + S_2$)	Notes
					Tolerances				
		T_1	T_2	Root Opening	As Detailed (see 5.4.2.2)	As Fit-Up (see 5.4.2.7)			
SMAW	B-P1b	6 max.	—	$R = \frac{T_1}{2}$	+2, –0	±2	All	$\frac{3T_1}{4}$	
GMAW FCAW	B-P1b-GF	6 max.	—	$R = \frac{T_1}{2}$	+2, –0	±2	All	$\frac{3T_1}{4}$	e

Figure 5.2 (Continued)—Prequalified PJP Groove Welded Joint Details (See 5.4.2) (Dimensions in Millimeters)

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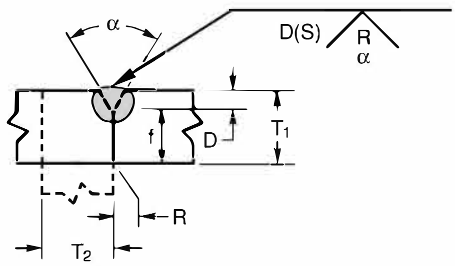
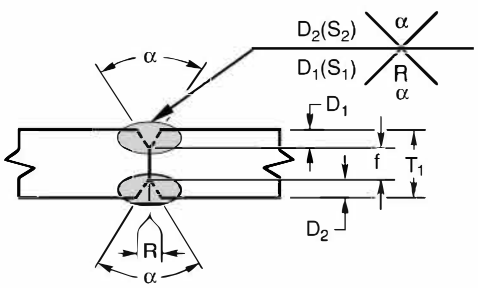
Single-V-groove weld (2)
Butt joint (B)
Corner joint (C)



Welding Process	Joint Designation	Base Metal Thickness (U = unlimited) T_1	T_2	Groove Preparation: Root Opening Root Face Groove Angle	Tolerances As Detailed (see 5.4.2.2)	Tolerances As Fit-Up (see 5.4.2.7)	Allowed Welding Positions	Weld Size (S)	Notes
SMAW	BC-P2	6 min.	U	R = 0 f = 1 min. α = 60°	+2, −0 +U, −0 +10°, −0°	+3, −2 ±2 +10°, −5°	All	D	b, e, f, j
GMAW FCAW	BC-P2-GF	6 min.	U	R = 0 f = 3 min. α = 60°	+2, −0 +U, −0 +10°, −0°	+3, −2 ±2 +10°, −5°	All	D	a, b, f, j
SAW	BC-P2-S	11 min.	U	R = 0 f = 6 min. α = 60°	±0 +U, −0 +10°, −0°	+2, −0 ±2 +10°, −5°	F	D	b, f, j

Double-V-groove weld (3)
Butt joint (B)



Welding Process	Joint Designation	Base Metal Thickness (U = unlimited) T_1	T_2	Groove Preparation: Root Opening Root Face Groove Angle	Tolerances As Detailed (see 5.4.2.2)	Tolerances As Fit-Up (see 5.4.2.7)	Allowed Welding Positions	Total Weld Size ($S_1 + S_2$)	Notes
SMAW	B-P3	12 min.	—	R = 0 f = 3 min. α = 60°	+2, −0 +U, −0 +10°, −0°	+3, −2 ±2 +10°, −5°	All	$D_1 + D_2$	e, f, i, j
GMAW FCAW	B-P3-GF	12 min.	—	R = 0 f = 3 min. α = 60°	+2, −0 +U, −0 +10°, −0°	+3, −2 ±2 +10°, −5°	All	$D_1 + D_2$	a, f, i, j
SAW	B-P3-S	20 min.	—	R = 0 f = 6 min. α = 60°	±0 +U, −0 +10°, −0°	+2, −0 ±2 +10°, −5°	F	$D_1 + D_2$	f, i, j

Figure 5.2 (Continued)—Prequalified PJP Groove Welded Joint Details (See 5.4.2) (Dimensions in Millimeters)

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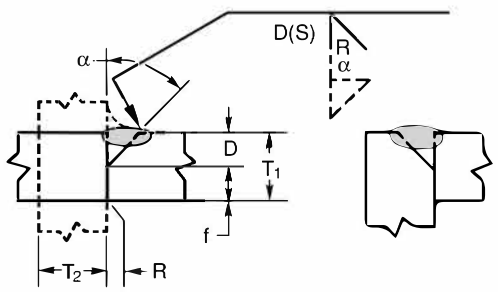
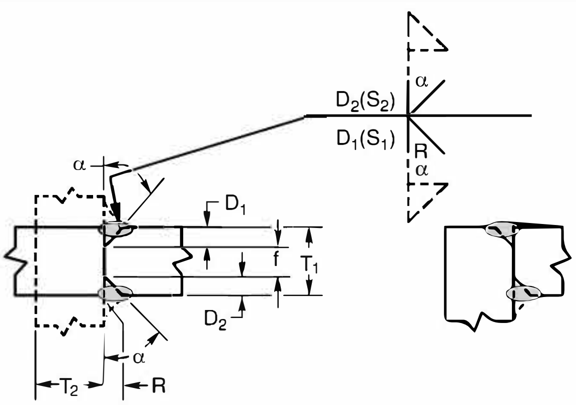
Single-bevel-groove weld (4)
Butt joint (B)
T-joint (T)
Corner joint (C)



Welding Process	Joint Designation	Base Metal Thickness (U = unlimited) T_1	T_2	Groove Preparation: Root Opening, Root Face, Groove Angle	Tolerances: As Detailed (see 5.4.2.2)	Tolerances: As Fit-Up (see 5.4.2.7)	Allowed Welding Positions	Weld Size (S)	Notes
SMAW	BTC-P4	U	U	R = 0 f = 3 min. α = 45°	+2, –0 +U –0 +10°, –0°	+3, –2 ±2 +10°, –5°	All	D –3	b, e, f, g, j, k
GMAW FCAW	BTC-P4-GF	6 min.	U	R = 0 f = 3 min. α = 45°	+2, –0 +U –0 +10°, –0°	+3, –2 ±2 +10°, –5°	F, H V, OH	D D –3	a, b, f, g, j, k
SAW	TC-P4-S	11 min.	U	R = 0 f = 6 min. α = 60°	±0 +U, –0 +10°, –0°	+2, –0 ±2 +10°, –5°	F	D	b, f, g, j, k

Double-bevel-groove weld (5)
Butt joint (B)
T-joint (T)
Corner joint (C)



Welding Process	Joint Designation	Base Metal Thickness (U = unlimited) T_1	T_2	Groove Preparation: Root Opening, Root Face, Groove Angle	Tolerances: As Detailed (see 5.4.2.2)	Tolerances: As Fit-Up (see 5.4.2.7)	Allowed Welding Positions	Total Weld Size (S_1 + S_2)	Notes
SMAW	BTC-P5	8 min.	U	R = 0 f = 3 min. α = 45°	+2, –0 +U –0 +10°, –0°	+3, –2 ±2 +10°, –5°	All	D_1 + D_2 –6	e, f, g, i, j, k
GMAW FCAW	BTC-P5-GF	12 min.	U	R = 0 f = 3 min. α = 45°	+2, –0 +U –0 +10°, –0°	+3, –2 ±2 +10°, –5°	F, H V, OH	D_1 + D_2 D_1 + D_2 –6	a, f, g, i, j, k
SAW	TC-P5-S	20 min.	U	R = 0 f = 6 min. α = 60°	±0 +U, –0 +10°, –0°	+2, –0 ±2 +10°, –5°	F	D_1 + D_2	f, g, i, j, k

Figure 5.2 (Continued)—Prequalified PJP Groove Welded Joint Details (See 5.4.2) (Dimensions in Millimeters)

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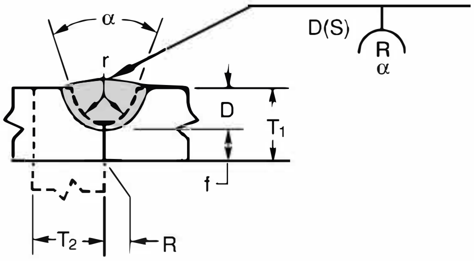
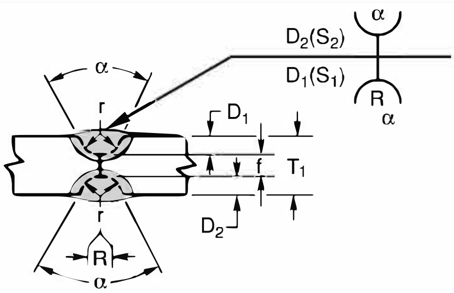
Single-U-groove weld (6)
Butt joint (B)
Corner joint (C)



Welding Process	Joint Designation	Base Metal Thickness (U = unlimited) T_1	T_2	Groove Preparation: Root Opening Root Face Bevel Radius Groove Angle	Tolerances: As Detailed (see 5.4.2.2)	As Fit-Up (see 5.4.2.7)	Allowed Welding Positions	Weld Size (S)	Notes
SMAW	BC-P6	6 min.	U	R = 0 f = 1 min. r = 6 α = 45°	+2, –0 +U, –0 +6, –0 +10°, –0°	+3, –2 ±2 ±2 +10°, –5°	All	D	b, e, f, j
GMAW FCAW	BC-P6-GF	6 min.	U	R = 0 f = 3 min. r = 6 α = 20°	+2, –0 +U, –0 +6, –0 +10°, –0°	+3, –2 ±2 ±2 +10°, –5°	All	D	a, b, f, j
SAW	BC-P6-S	11 min.	U	R = 0 f = 6 min. r = 6 α = 20°	±0 +U, –0 +6, –0 +10°, –0°	+2, –0 ±2 ±2 +10°, –5°	F	D	b, f, j

Double-U-groove weld (7)
Butt joint (B)



Welding Process	Joint Designation	Base Metal Thickness (U = unlimited) T_1	T_2	Groove Preparation: Root Opening Root Face Bevel Radius Groove Angle	Tolerances: As Detailed (see 5.4.2.2)	As Fit-Up (see 5.4.2.7)	Allowed Welding Positions	Total Weld Size (S_1 + S_2)	Notes
SMAW	B-P7	12 min.	—	R = 0 f = 3 min. r = 6 α = 45°	+2, –0 +U, –0 +6, –0 +10°, –0°	+3, –2 ±2 ±2 +10°, –5°	All	D_1 + D_2	e, f, i, j
GMAW FCAW	B-P7-GF	12 min.	—	R = 0 f = 3 min. r = 6 α = 20°	+2, –0 +U, –0 +6, –0 +10°, –0°	+3, –2 ±2 ±2 +10°, –5°	All	D_1 + D_2	a, f, i, j
SAW	B-P7-S	20 min.	—	R = 0 f = 6 min. r = 6 α = 20°	±0 +U, –0 +6, –0 +10°, –0°	+2, –0 ±2 ±2 +10°, –5°	F	D_1 + D_2	f, i, j

Figure 5.2 (Continued)—Prequalified PJP Groove Welded Joint Details (See 5.4.2) (Dimensions in Millimeters)

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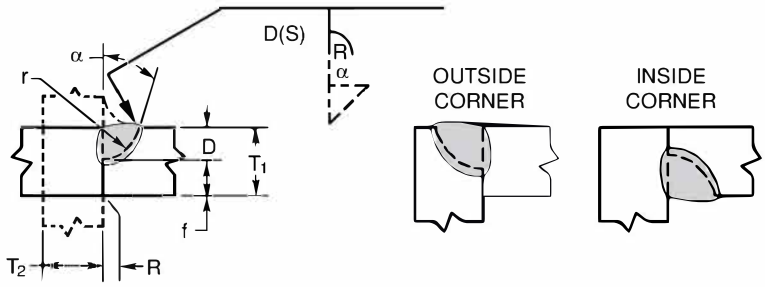
Single-J-groove weld (8)
Butt joint (B)
T-joint (T)
Corner joint (C)



Welding Process	Joint Designation	Base Metal Thickness (U = unlimited)		Groove Preparation			Allowed Welding Positions	Weld Size (S)	Notes
				Root Opening Root Face Bevel Radius Groove Angle	Tolerances				
		T_1	T_2		As Detailed (see 5.4.2.2)	As Fit-Up (see 5.4.2.7)			
SMAW	B-P8	6 min.	—	R = 0 f = 3 min. r = 10 α = 30°	+2, –0 +U, –0 +6, –0 +10°, –0°	+3, –2 ±2 ±2 +10°, –5°	All	D	e, f, g, j, k
SMAW	TC-P8	6 min.	U	R = 0 f = 3 min. r = 10 α_{oc} = 30°* α_{ic} = 45°**	+2, –0 +U, –0 +6, –0 +10°, –0° +10°, –0°	+3, –2 ±2 ±2 +10°, –5° +10°, –5°	All	D	e, f, g, j, k
GMAW FCAW	B-P8-GF	6 min.	—	R = 0 f = 3 min. r = 10 α = 30°	+2, –0 +U, –0 +6, –0 +10°, –0°	+3, –2 ±2 ±2 +10°, –5°	All	D	a, f, g, j, k
GMAW FCAW	TC-P8-GF	6 min.	U	R = 0 f = 3 min. r = 10 α_{oc} = 30°* α_{ic} = 45°**	+2, –0 +U, –0 +6, –0 +10°, –0° +10°, –0°	+3, –2 ±2 ±2 +10°, –5° +10°, –5°	All	D	a, f, g, j, k
SAW	B-P8-S	11 min.	—	R = 0 f = 6 min. r = 12 α = 20°	±0 +U, –0 +6, –0 +10°, –0°	+2, –0 ±2 ±2 +10°, –5°	F	D	f, g, j, k
SAW	TC-P8-S	11 min.	U	R = 0 f = 6 min. r = 12 α_{oc} = 20°* α_{ic} = 45°**	±0 +U, –0 +6, –0 +10°, –0° +10°, –0°	+2, –0 ±2 ±2 +10°, –5° +10°, –5°	F	D	f, g, j, k

*α_{oc} = Outside corner groove angle.
**α_{ic} = Inside corner groove angle.

Figure 5.2 (Continued)—Prequalified PJP Groove Welded Joint Details (See 5.4.2) (Dimensions in Millimeters)

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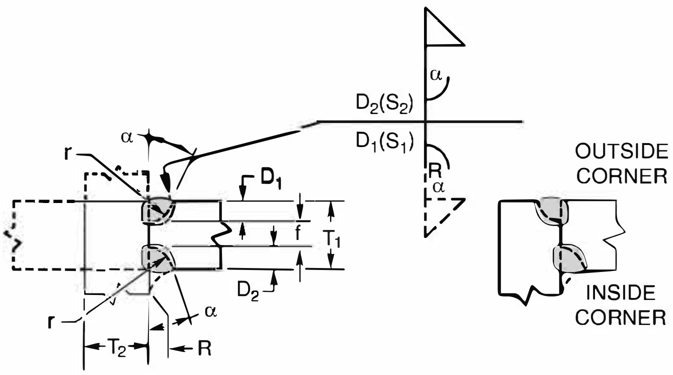
Double-J-groove weld (9)
Butt joint (B)
T-joint (T)
Corner joint (C)



Welding Process	Joint Designation	Base Metal Thickness (U = unlimited) T_1	T_2	Groove Preparation: Root Opening, Root Face, Bevel Radius, Groove Angle	Tolerances: As Detailed (see 5.4.2.2)	As Fit-Up (see 5.4.2.7)	Allowed Welding Positions	Total Weld Size ($S_1 + S_2$)	Notes
SMAW	B-P9	12 min.	—	R = 0 f = 3 min. r = 10 α = 30°	+2, –0 +U, –0 +6, –0 +10°, –0°	+3, –2 ±2 ±2 +10°, –5°	All	$D_1 + D_2$	e, f, g, i, j, k
SMAW	TC-P9	12 min.	U	R = 0 f = 3 min. r = 10 α_{oc} = 30°* α_{ic} = 45°**	+2, –0 +U, –0 +6, –0 +10°, –0° +10°, –0°	+3, –2 ±2 ±2 +10°, –5° +10°, –5°	All	$D_1 + D_2$	e, f, g, i, j, k
GMAW FCAW	B-P9-GF	6 min.	—	R = 0 f = 3 min. r = 10 α = 30°	+2, –0 +U, –0 +6, –0 +10°, –0°	+3, –2 ±2 ±2 +10°, –5°	All	$D_1 + D_2$	a, f, g, i, j, k
GMAW FCAW	TC-P9-GF	6 min.	U	R = 0 f = 3 min. r = 10 α_{oc} = 30°* α_{ic} = 45°**	+2, –0 +U, –0 +6, –0 +10°, –0° +10°, –0°	+3, –2 ±2 ±2 +10°, –5° +10°, –5°	All	$D_1 + D_2$	a, f, g, i, j, k
SAW	B-P9-S	20 min.	—	R = 0 f = 6 min. r = 12 α = 20°	±0 +U, –0 +6, –0 +10°, –0°	+2, –0 ±2 ±2 +10°, –5°	F	$D_1 + D_2$	f, g, i, j, k
SAW	TC-P9-S	20 min.	U	R = 0 f = 6 min. r = 12 α_{oc} = 20°* α_{ic} = 45°**	±0 +U, –0 +6, –0 +10°, –0° +10°, –0°	+2, –0 ±2 ±2 +10°, –5° +10°, –5°	F	$D_1 + D_2$	f, g, i, j, k

*α_{oc} = Outside corner groove angle.
**α_{ic} = Inside corner groove angle.

Figure 5.2 (Continued)—Prequalified PJP Groove Welded Joint Details (See 5.4.2) (Dimensions in Millimeters)

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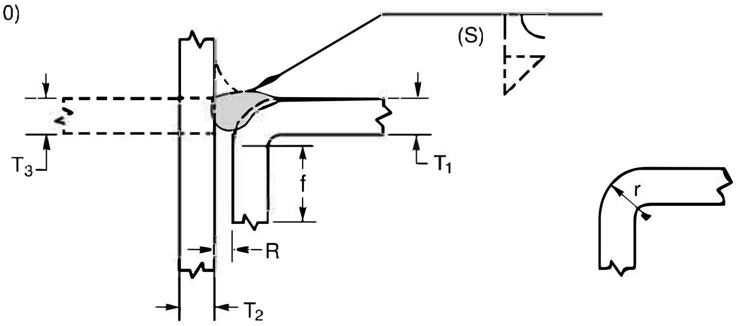
Flare-bevel-groove weld (10)
Butt joint (B)
T-joint (T)
Corner joint (C)



Welding Process	Joint Designation	Base Metal Thickness (U = unlimited) T_1	T_2	T_3	Groove Preparation: Root Opening Root Face Bend Radius	Tolerances: As Detailed (see 5.4.2.2)	As Fit-Up (see 5.4.2.7)	Allowed Welding Positions	Weld Size (S)	Notes
SMAW FCAW-S	BTC-P10	5 min.	U	T_1 min.	R = 0 f = 5 min. $r = \frac{3T_1}{4}$ min.	+2, –0 +U, –0 +U, –0	+3, –2 +U, –2 +U, –0	All	5/16 r	e, g, j, l
GMAW FCAW-G	BTC-P10-GF	5 min.	U	T_1 min.	R = 0 f = 5 min. $r = \frac{3T_1}{4}$ min.	+2, –0 +U, –0 +U, –0	+3, –2 +U, –2 +U, –0	All	5/8 r	a, g, j, l, m
SAW	B-P10-S	12 min.	12 min.	N/A	R = 0 f = 12 min. $r = \frac{3T_1}{4}$ min.	±0 +U, –0 +U, –0	+2, –0 +U, –2 +U, –0	F	5/16 r	g, j, l, m

Figure 5.2 (Continued)—Prequalified PJP Groove Welded Joint Details (See 5.4.2) (Dimensions in Millimeters)

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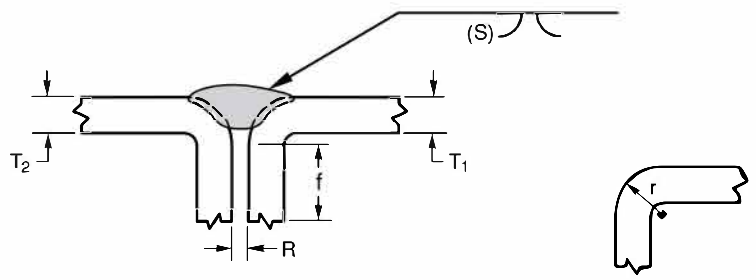
See Notes on Page 81

Flare-V-groove weld (11)
Butt joint (B)



Welding Process	Joint Designation	Base Metal Thickness (U = unlimited)		Groove Preparation			Allowed Welding Positions	Weld Size (S)	Notes
				Root Opening Root Face Bend Radius	Tolerances				
		T_1	T_2		As Detailed (see 5.4.2.2)	As Fit-Up (see 5.4.2.7)			
SMAW FCAW-S	B-P11	5 min.	T_1 min.	R = 0 f = 5 min. $r = \frac{3T_1}{2}$ min.	+2, –0 +U, –0 +U, –0	+3, –2 +U, –2 +U, –0	All	5/8 r	e, j, l, m, n
GMAW FCAW-G	B-P11-GF	5 min.	T_1 min.	R = 0 f = 5 min. $r = \frac{3T_1}{2}$ min.	+2, –0 +U, –0 +U, –0	+3, –2 +U, –2 +U, –0	All	3/4 r	a, j, l, m, n
SAW	B-P11-S	12 min.	T_1 min.	R = 0 f = 12 min. $r = \frac{3T_1}{2}$ min.	±0 +U, –0 +U, –0	+2, –0 +U, –2 +U, –0	F	1/2 r	j, l, m, n

Figure 5.2 (Continued)—Prequalified PJP Groove Welded Joint Details (See 5.4.2) (Dimensions in Millimeters)

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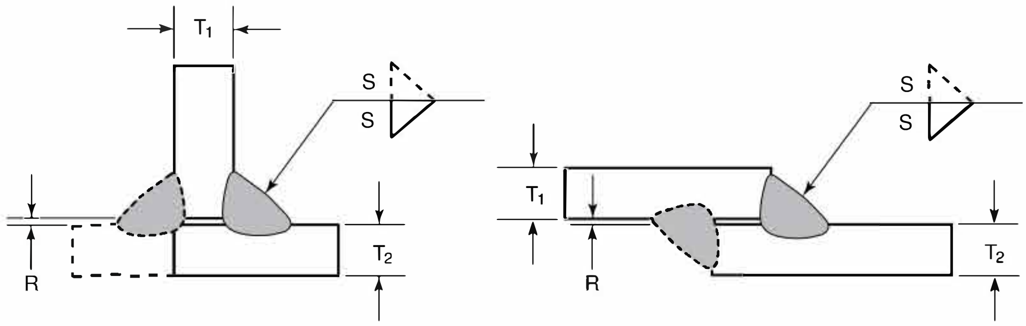
Fillet weld (12)
T-joint (T)
Corner joint (C)
Lap joint (L)



Welding Process	Joint Designation	Base Metal Thickness	Joint Design/Geometry			Allowed Welding Positions	Notes
				Tolerances			
		T_1 or T_2	Root Opening	As Detailed	As Fit-Up		
SMAW	TC-F12	< 3	R = 0	+1/16, –0	3/16 max.	All	a, b, d
	TC-F12a	≥ 3			5/16 max.		a, b, d
	L-F12	< 3			3/16 max.		a, b, c
	L-F12a	≥ 3			5/16 max.		a, b, c
GMAW FCAW	TC-F12-GF	< 3	R = 0	+1/16, --0	3/16 max.	All	a, b, d
	TC-F12a-GF	≥ 3			5/16 max.		a, b, d
	L-F12-GF	< 3			3/16 max.		a, b, c
	L-F12a-GF	≥ 3			5/16 max.		a, b, c
SAW	TC-F12-S	< 3	R = 0	+1/16, --0	3/16 max.	F, H	a, b, d
	TC-F12a-S	≥ 3			5/16 max.		a, b, d
	L-F12-S	< 3			3/16 max.		a, b, c
	L-F12a-S	≥ 3			5/16 max.		a, b, c

Notes for Figure 5.3
[a] Fillet weld size ("S"). See 4.4.2.8 and Clause 7.13 for minimum fillet weld sizes. See Table 5.1 for maximum single pass size.
[b] See 7.21.1 for additional fillet weld assembly requirements or exceptions.
[c] See 4.4.2.9 for maximum weld size in lap joints.
[d] Perpendicularity of the members shall be within ±10°.

Figure 5.3—Prequalified Fillet Weld Joint Details (Dimensions in Inches) (See 5.4.3)

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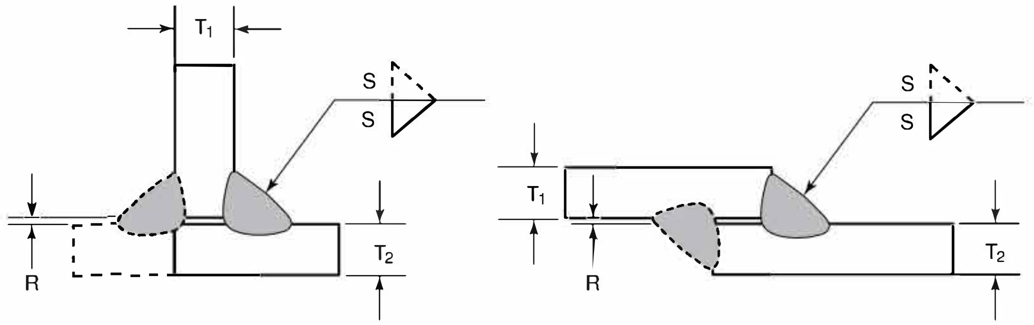
Fillet weld (12)
T-joint (T)
Corner joint (C)
Lap joint (L)



Welding Process	Joint Designation	Base Metal Thickness T_1 or T_2	Joint Design/Geometry: Root Opening	Tolerances: As Detailed	Tolerances: As Fit-Up	Allowed Welding Positions	Notes
SMAW	TC-F12	< 75	R = 0	+2, −0	5 max.	All	a, b, d
	TC-F12a	≥ 75			8 max.		a, b, d
	L-F12	< 75			5 max.		a, b, c
	L-F12a	≥ 75			8 max.		a, b, c
GMAW FCAW	TC-F12-GF	< 75	R = 0	+2, −0	5 max.	All	a, b, d
	TC-F12a-GF	≥ 75			8 max.		a, b, d
	L-F12-GF	< 75			5 max.		a, b, c
	L-F12a-GF	≥ 75			8 max.		a, b, c
SAW	TC-F12-S	< 75	R = 0	+2, −0	5 max.	F, H	a, b, d
	TC-F12a-S	≥ 75			8 max.		a, b, d
	L-F12-S	< 75			5 max.		a, b, c
	L-F12a-S	≥ 75			8 max.		a, b, c

Notes for Figure 5.3
[a] Fillet weld size ("S"). See 4.4.2.8 and Clause 7.13 for minimum fillet weld sizes. See Table 5.1 for maximum single pass size.
[b] See 7.21.1 for additional fillet weld assembly requirements or exceptions.
[c] See 4.4.2.9 for maximum weld size in lap joints.
[d] Perpendicularity of the members shall be within ±10°.

Figure 5.3 (Continued)—Prequalified Fillet Weld Joint Details (Dimensions in Millimeters) (See 5.4.3)

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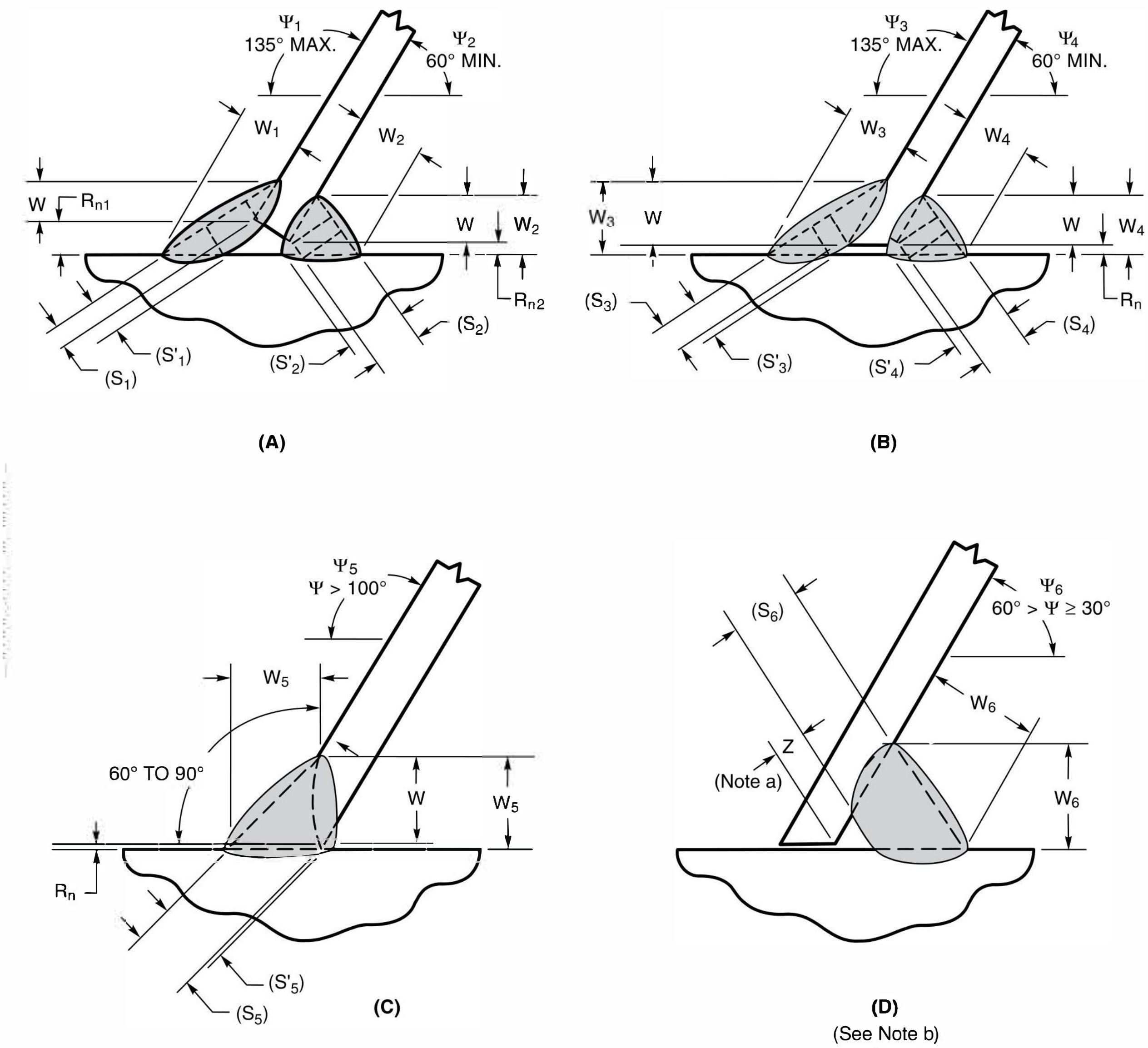

[a] Detail (D). Apply Z loss dimension of Table 4.2 to determine effective throat.

[b] Detail (D) shall not be prequalified for under 30°. For welder qualifications, see Table 6.10.

Notes:

1. (S_n), (S'_n) = Weld size dependent on magnitude of root opening (R_n) (see 7.21.1). (n) represents 1 through 5.
2. t = thickness of thinner part
3. Not prequalified for GMAW-S or GTAW.

Figure 5.4—Prequalified Skewed T-Joint Joint Details (Nontubular) (See 5.4.3.2)

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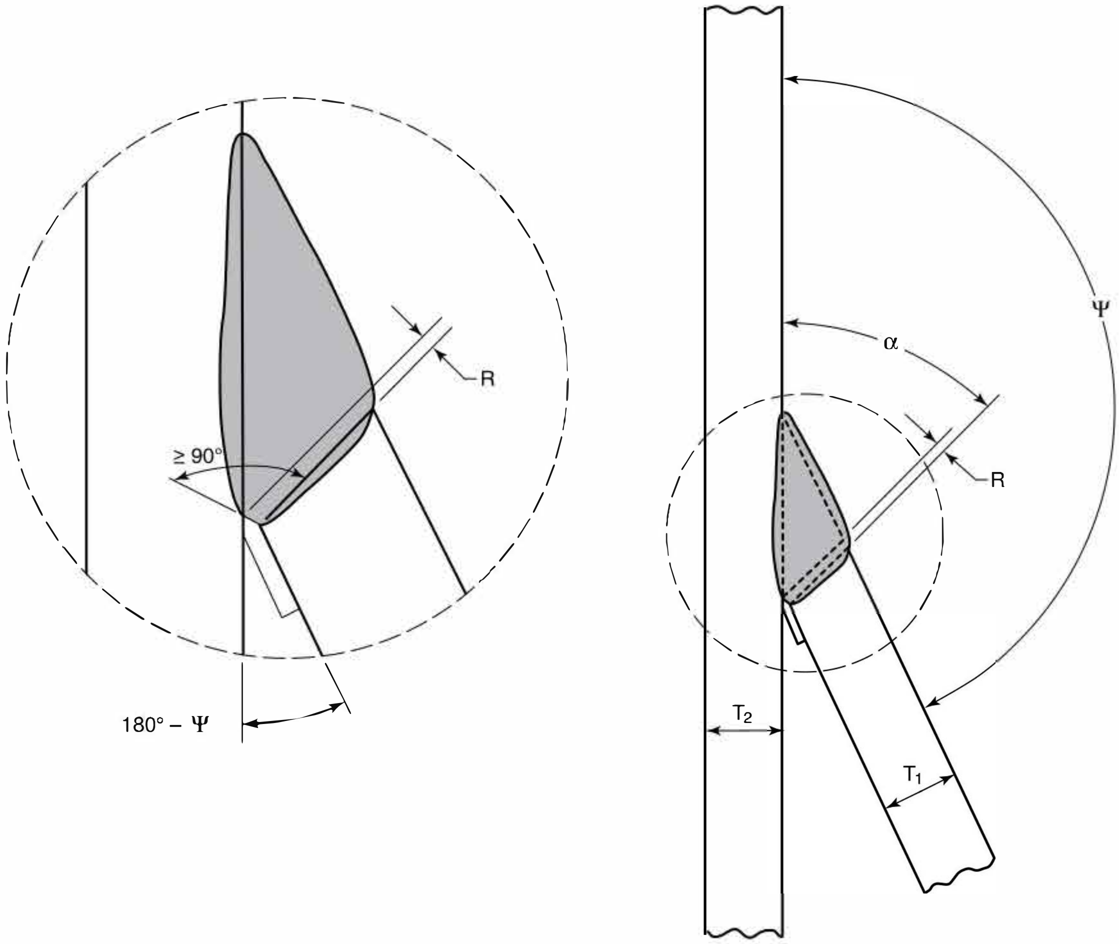

Note: 90° ≤ Ψ ≤ 170°.

Figure 5.5—Prequalified CJP Groove, T-, and Corner Joint (See Notes for Figures 5.1 and 5.2, Note o)

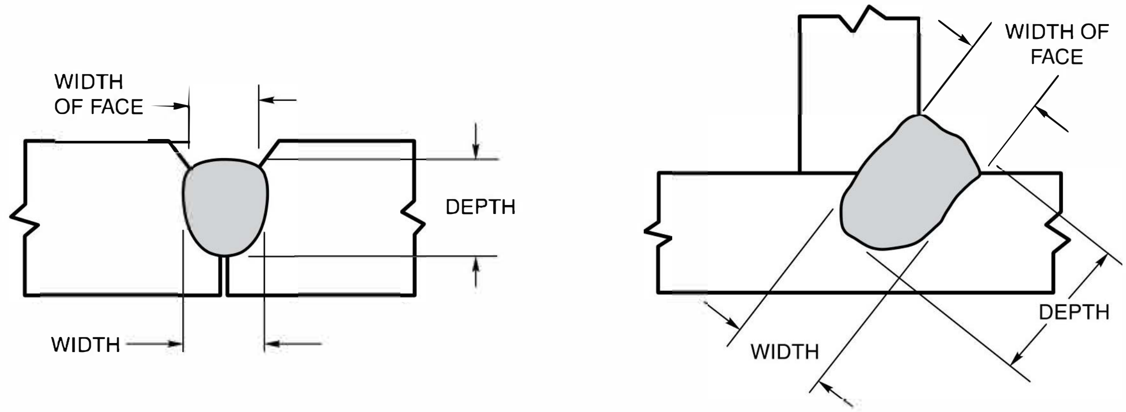

Figure 5.6—Weld Bead in which Depth and Width Exceed the Width of the Weld Face (see 5.8.2.1)

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6. Qualification

6.1 Scope

This clause contains the requirements for qualification testing of welding procedure specifications (WPSs) and welding personnel. It is divided into four parts as follows:

Part A—General Requirements. This part covers general requirements of both WPS and welding personnel performance requirements.

Part B—Welding Procedure Specification (WPS) Qualification. This part covers the qualification of a WPS that is not classified as prequalified in conformance with Clause 5.

Part C—Performance Qualification. This part covers the performance qualification tests required by the code to determine a welder's, welding operator's, or tack welder's ability to produce sound welds.

Part D—Requirements for CVN ToughnessTesting. This part covers general requirements and procedures for CVN testing when specified by the contract documents.

Part A
General Requirements

6.2 General

The requirements for qualification testing of WPSs and welding personnel (defined as welders, welding operators, and tack welders) are described in this section.

6.2.1 Welding Procedure Specification (WPS). Except for prequalified WPSs conforming to the requirements of Clause 5, a WPS for use in production welding shall be qualified in conformance with Clause 6, Part B. Properly documented evidence of previous WPS qualification may be used.

6.2.1.1 Qualification Responsibility. Each manufacturer or Contractor shall conduct the tests required by this code to qualify the WPS. Properly documented WPSs qualified under the provisions of this code by a company that later has a name change due to voluntary action or consolidation with a parent company may utilize the new name on its WPS documents while maintaining the supporting PQR qualification records with the old company name.

6.2.1.2 WPS Qualification to Other Standards. The acceptability of qualification to other standards is the Engineer's responsibility, to be exercised based upon either the specific structure or service conditions, or both. AWS B2.1-X-XXX Series on Standard Welding Procedure Specifications may, in this manner, be accepted for use in this code.

6.2.1.3 CVN Test Requirements. When required by contract documents, CVN tests shall be included in the WPS qualification. The CVN tests, requirements, and procedure shall be in conformance with the provisions of Part D of this section, or as specified in the contract documents.

6.2.2 Performance Qualification of Welding Personnel. Welders, welding operators and tack welders to be employed to weld under this code, and using the SMAW, SAW, GMAW, GTAW, FCAW, ESW, or EGW processes, shall have been qualified by the applicable tests as described in Part C of this clause.

6.2.2.1 Previous Performance Qualification. Previous performance qualification tests of welders, welding operators, and tack welders that are properly documented are acceptable with the approval of the Engineer. The acceptability of performance qualification to other standards is the Engineer's responsibility, to be exercised based upon either the specific structure or service conditions, or both.

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6.2.2.2 Qualification Responsibility. Each manufacturer or Contractor shall be responsible for the qualification of welders, welding operators and tack welders, whether the qualification is conducted by the manufacturer, Contractor, or an independent testing agency.

6.2.3 Period of Effectiveness

6.2.3.1 Welders and Welding Operators. The welder's or welding operator's qualification as specified in this code shall be considered as remaining in effect indefinitely unless:

(1) the welder is not engaged in a given process of welding for which the welder or welding operator is qualified for a period exceeding six months, or

(2) there is some specific reason to question a welder's or welding operator's ability (see 6.25.1).

6.2.3.2 Tack Welders. A tack welder who passes the test described in Part C or those tests required for welder qualification shall be considered eligible to perform tack welding indefinitely in the positions and with the process for which the tack welder is qualified unless there is some specific reason to question the tack welder's ability (see 6.25.2).

6.3 Common Requirements for WPS and Welding Personnel Performance Qualification

6.3.1 Qualification to Earlier Editions. Qualifications performed to and having met the requirements of earlier editions of AWS D1.1 or AWS D1.0 or AWS D2.0 while those editions were in effect are valid and may be used. The use of earlier editions shall be prohibited for new qualifications in lieu of the current editions, unless the specific early edition is specified in the contract documents.

6.3.2 Aging. When allowed by the filler metal specification applicable to weld metal being tested, fully welded qualification test specimens may be aged at 200°F to 220°F [95°C to 105°C] for 48 ± 2 hours.

6.3.3 Records. Records of the test results shall be kept by the manufacturer or Contractor and shall be made available to those authorized to examine them.

6.3.4 Positions of Welds. All welds shall be classified as flat (F), horizontal (H), vertical (V), or overhead (OH), in conformance with the definitions shown in Figure 6.1, Figure 6.2, and 10.11.1.

Test assembly positions are shown in:

(1) Figure 6.3 (groove welds in plate)

(2) Figure 6.4 (fillet welds on plate)

Part B
Welding Procedure Specification (WPS) Qualification

6.4 Production Welding Positions Qualified

The production welding positions qualified by a plate test shall conform to the requirements of Clause 6 and Table 6.1. The production welding positions qualified by a tubular test shall conform to the requirements of Clause 10 and Table 10.8.

6.5 Type of Qualification Tests

The type and number of qualification tests required to qualify a WPS for a given thickness, diameter, or both, shall conform to Table 6.2 (CJP), Table 6.3 (PJP) or Table 6.4 (fillet). Details on the individual NDT and mechanical test requirements are found in the following subclauses:

(1) Visual Inspection (see 6.10.1)

(2) NDT (see 6.10.2)

(3) Face, root and side bend (see 6.10.3.1)

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(4) Reduced Section Tension (see 6.10.3.4)

(5) All-Weld-Metal Tension (see 6.10.3.6)

(6) Macroetch (see 6.10.4)

6.6 Weld Types for WPS Qualification

For the purpose of WPS qualification, weld types shall be classified as follows:

(1) CJP Groove Welds for Nontubular Connections (see 6.11)

(2) PJP Groove Welds for Nontubular Connections (see 6.12)

(3) Fillet Welds (see 6.13)

(4) CJP Groove Welds for Tubular Connections (see 10.14)

(5) PJP Groove Welds for Tubular T-, Y-, and K-connections and Butt Joints (see 10.15)

(6) Plug and Slot Welds (see 6.14)

6.7 Preparation of WPS

The manufacturer or Contractor shall prepare a written WPS that specifies all of the applicable essential variables referenced in 6.8. The specific values for these WPS variables shall be obtained from the procedure qualification record (PQR), which shall serve as written confirmation of a successful WPS qualification.

6.8 Essential Variables

6.8.1 SMAW, SAW, GMAW, GTAW, and FCAW. Changes beyond the limitations of PQR essential variables for the SMAW, SAW, GMAW, GTAW, and FCAW processes shown in Table 6.5 and Table 6.7 (when CVN testing is specified) shall require requalification of the WPS (see 6.2.1.3).

6.8.2 ESW and EGW. See Table 6.6 for the PQR essential variable changes requiring WPS requalification for the EGW and ESW processes. Supplementary essential variables (when CVN testing is specified) are shown in Table 6.7.

6.8.3 Base Metal Qualification. Procedure qualification tests using base metals listed in Table 5.3 shall also qualify WPSs using base metals from other groups as specified in Table 6.8. WPSs for base metals not listed in Table 5.3 or Table 6.9 shall be qualified in conformance with Clause 6.

WPSs with steels listed in Table 6.9 shall also qualify Table 5.3 or Table 6.9, steels in conformance with Table 6.8. Table 6.9 also contains recommendations for matching strength filler metal and minimum preheat and interpass temperatures for the materials in the table.

6.8.4 Preheat and Interpass Temperature. The minimum preheat and interpass temperature should be established on the basis of steel composition as shown in Table 5.8. Alternatively, recognized methods of prediction or guidelines such as those provided in Annex B, or other methods may be used. Preheat and interpass temperatures lower than required per Table 5.8 or calculated per Annex B may be used provided they are approved by the Engineer and qualified by WPS testing.

The methods of Annex B are based on laboratory cracking tests and may predict preheat temperatures higher than the minimum temperature shown in Table 5.8. Annex B may be of value in identifying situations where the risk of cracking is increased due to composition, restraint, hydrogen level, or lower welding heat input where higher preheat may be warranted. Alternatively, Annex B may assist in defining conditions under which hydrogen cracking is unlikely and where the minimum requirements of Table 5.8 may be safely relaxed.

6.8.5 Heat Input. When CVN testing is required by the contract documents, heat input shall be calculated as follows:

(1) When non-waveform-controlled welding is to be used, heat input shall be calculated by any one of the methods shown in 6.8.5.1 equations (1) through (3).

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(2) When waveform-controlled welding is to be used, heat input shall be calculated by either of the methods shown in 6.8.5.1 equation (2) or (3).

6.8.5.1 Heat Input Calculation Methods. The following equations shall be applicable to the calculation of heat input. Selection of an equation will depend on the measurement capacity of the welding equipment and whether waveform controlled welding is being used.

$$\text{Heat input (Joules/in [Joules/mm])} = \frac{A \times Volts \times 60}{TS\left(\frac{in}{min}\right)\left[\frac{mm}{min}\right]} \quad (1)$$

where:

A = Current, amps
Volts = Voltage
TS = Travel Speed, in/min [mm/min]

$$\text{Heat input (J/in [J/mm])} = \frac{TIE}{L} \quad (2)$$

where:

TIE = Total Instantaneous Energy, J (measured by the power source)

L = Weld bead length, in [mm]

$$\text{Heat input (J/in [J/mm])} = \frac{(\text{AIP} \times \text{T})}{\text{L}} \quad (3)$$

where:

AIP = Average Instantaneous Power, W(J/s) (measured at the power source)

T= arc time, s
L = weld bead length, in [mm]

6.8.5.2 Maximum Heat Input for Multi-Position WPSs. The maximum heat input for a multiple position WPS shall be established by the PQR with the highest heat input.

6.8.5.3 Measurement of Total Instantaneous Energy or Power. Welding systems, comprised of interconnected power sources and wire feed controllers, shall display total instantaneous energy or average instantaneous power using one of the following:

(1) meters or displays incorporated in the power source/wire feed controller,

(2) external meters with high frequency sampling capable of determining and displaying total instantaneous energy or average instantaneous power, or

(3) upgrades or modifications to the welding equipment to facilitate determination and display total instantaneous energy or average instantaneous power.

6.9 WPS Requirements for Production Welding Using Existing Non-Waveform or Waveform WPSs

6.9.1 WPSs Qualified with Non-Waveform-Controlled Power Sources. WPSs qualified using non-waveform-controlled welding and heat input determined by 6.8.5.1 equation (1) shall remain qualified for use in production welding using waveform-controlled welding equipment, provided the WPS is revised to require heat input determination for production welds using the heat input calculation methods of either 6.8.5.1 equation (2) or (3).

6.9.2 Production Welds Made with Non-Waveform Equipment Using WPSs Qualified with Waveform Equipment. The heat input of production welds determined by 6.8.5.1 equation (1) shall not exceed the heat input limits of the WPS as determined from 6.8.5.1 equation (2) or (3).

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6.10 Methods of Testing and Acceptance Criteria for WPS Qualification

The welded test assemblies conforming to 6.10.2 shall have test specimens prepared by cutting the test plate as shown in Figures 6.5 through 6.7, whichever is applicable. The test specimens shall be prepared for testing in conformance with Figures 6.8, 6.9, 6.10, and 6.14, as applicable.

6.10.1 Visual Inspection of Welds. The visual acceptance criteria for qualification of groove and fillet welds (excluding weld tabs) shall conform to the following requirements, as applicable:

6.10.1.1 Visual Inspection of Groove Welds. Groove welds shall meet the following requirements:

(1) Any crack shall be unacceptable, regardless of size.

(2) All craters shall be filled to the full cross section of the weld.

(3) Weld reinforcement shall not exceed 1/8 in [3 mm]. The weld profile shall conform to Figure 7.4 and shall have complete fusion.

(4) Undercut shall not exceed 1/32 in [1 mm].

(5) The weld root for CJP grooves shall be inspected, and shall not have any cracks, incomplete fusion, or inadequate joint penetration.

(6) For CJP grooves welded from one side without backing, root concavity or melt-through shall conform to the following:

(a) The maximum root concavity shall be 1/16 in [2 mm], provided the total weld thickness is equal to or greater than that of the base metal.

(b) The maximum melt-through shall be 1/8 in [3 mm].

6.10.1.2 Visual Inspection of Fillet Welds. Fillet welds shall meet the following requirements:

(1) Any crack shall be unacceptable, regardless of size.

(2) All craters shall be filled to the full cross section of the weld.

(3) The fillet weld leg sizes shall not be less than the required leg sizes.

(4) The weld profile shall meet the requirements of Figure 7.4.

(5) Base metal undercut shall not exceed 1/32 in [1 mm].

6.10.2 NDT. Before preparing mechanical test specimens, the qualification test plate, pipe, or tubing shall be nondestructively tested for soundness as follows:

6.10.2.1 RT or UT. Either RT or UT shall be used. The entire length of the weld in test plates, except the discard lengths at each end, shall be examined in conformance with Clause 8, Part E or F, and Clause 10, Part F for tubulars.

6.10.2.2 RT or UT Acceptance Criteria. For acceptable qualification, the weld, as revealed by RT or UT, shall conform to the requirements of Clause 8, Part C or Clause 10, Part F for tubulars.

6.10.3 Mechanical Testing. Mechanical testing shall be as follows:

6.10.3.1 Root, Face, and Side Bend Specimens (see Figure 6.8 for root and face bends, Figure 6.9 for side bends). Each specimen shall be bent in a bend test jig that meets the requirements shown in Figures 6.11 through 6.13 or is substantially in conformance with those figures, provided the maximum bend radius is not exceeded. Any convenient means may be used to move the plunger member with relation to the die member.

The specimen shall be placed on the die member of the jig with the weld at mid-span. Face bend specimens shall be placed with the face of the weld directed toward the gap. Root bend and fillet weld soundness specimens shall be placed with the root of the weld directed toward the gap. Side bend specimens shall be placed with that side showing the greater discontinuity, if any, directed toward the gap.

The plunger shall force the specimen into the die until the specimen becomes U-shaped. The weld and HAZs shall be centered and completely within the bent portion of the specimen after testing. When using the wraparound jig, the

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specimen shall be firmly clamped on one end so that there is no sliding of the specimen during the bending operation. The weld and HAZs shall be completely in the bent portion of the specimen after testing. Test specimens shall be removed from the jig when the outer roll has been moved 180° from the starting point.

6.10.3.2 Longitudinal Bend Specimens. When material combinations differ markedly in mechanical bending properties, as between two base materials or between the weld metal and the base metal, longitudinal bend tests (face and root) may be used in lieu of the transverse face and root bend tests. The welded test assemblies conforming to 6.10.2 shall have test specimens prepared by cutting the test plate as shown in Figure 6.6 or 6.7, whichever is applicable. The test specimens for the longitudinal bend test shall be prepared for testing as shown in Figure 6.8.

6.10.3.3 Acceptance Criteria for Bend Tests. The convex surface of the bend test specimen shall be visually examined for surface discontinuities. For acceptance, the surface shall contain no discontinuities exceeding the following dimensions:

(1) 1/8 in [3 mm] measured in any direction on the surface

(2) 3/8 in [10 mm]—the sum of the greatest dimensions of all discontinuities exceeding 1/32 in [1 mm], but less than or equal to 1/8 in [3 mm]

(3) 1/4 in [6 mm]—the maximum corner crack, except when that corner crack results from visible slag inclusion or other fusion type discontinuity, then the 1/8 in [3 mm] maximum shall apply.

Specimens with corner cracks exceeding 1/4 in [6 mm] with no evidence of slag inclusions or other fusion type discontinuity shall be disregarded, and a replacement test specimen from the original weldment shall be tested.

6.10.3.4 Reduced-Section Tension Specimens (see Figure 6.10). Before testing, the least width and corresponding thickness of the reduced section shall be measured. The specimen shall be ruptured under tensile load, and the maximum load shall be determined. The cross-sectional area shall be obtained by multiplying the width by the thickness. The tensile strength shall be obtained by dividing the maximum load by the cross-sectional area.

6.10.3.5 Acceptance Criteria for Reduced-Section Tension Test. The tensile strength shall be no less than the minimum of the specified tensile range of the base metal used.

6.10.3.6 All-Weld-Metal Tension Specimen (see Figure 6.14). The test specimen shall be tested in conformance with ASTM A370, *Mechanical Testing of Steel Products*.

6.10.4 Macroetch Test. The weld test specimens shall be prepared with a finish suitable for macroetch examination. A suitable solution shall be used for etching to give a clear definition of the weld.

6.10.4.1 Acceptance Criteria for Macroetch Test. For acceptable qualification, the test specimen, when inspected visually, shall conform to the following requirements:

(1) PJP groove welds; the actual weld size shall be equal to or greater than the specified weld size, (S).

(2) Fillet welds shall have fusion to the root of the joint, but not necessarily beyond.

(3) Minimum leg size shall meet the specified fillet weld size.

(4) The PJP groove welds and fillet welds shall have the following:

(a) no cracks

(b) thorough fusion between adjacent layers of weld metal and between weld metal and base metal

(c) weld profiles conforming to specified detail, but with none of the variations prohibited in 7.23

(d) no undercut exceeding 1/32 in [1 mm]

6.10.5 Retest. If any one test specimen, of all those tested, fails to meet the test requirements of Clause 6.10 the test coupon shall be considered as failed. Retests may be performed on two additional test specimens according to one of the following alternatives. The results of both test specimens shall meet the test requirements.

(1) If adequate material from the original welded test coupon exists, the additional test specimens shall be removed as close as practicable to the original test specimen location.

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(2) If adequate material from the original welded test coupon does not exist, a new test coupon shall be prepared following the original PQR as closely as practicable. The new welded test coupon need only be of sufficient length to provide the required two test specimens. If the new test specimens pass, the essential and supplementary essential variables shall be documented on the PQR.

For material over 1-1/2 in [38 mm] thick when multiple test specimens are required to represent the complete thickness, failure of a test specimen representing a portion of the thickness shall require testing of all test specimens representing the complete thickness from two additional locations in the test coupon.

6.11 CJP Groove Welds

See Table 6.2(1) for the requirements for qualifying a WPS of a CJP weld on nontubular connections. See Figures 6.5–6.7 for the appropriate test plate.

6.11.1.1 Corner or T-Joints. Test specimens for groove welds in corner or T-joints shall be butt joints having the same groove configuration as the corner or T-joint to be used on construction, except the depth of groove need not exceed 1 in [25 mm].

6.12 PJP Groove Welds

Qualification of a PJP groove weld WPS shall be by one of the following methods:

(1) Use of a CJP WPS qualified by testing to support the qualification of a PJP WPS using any Figure 5.2 joint detail (see 6.12.1)

(2) Use of a CJP WPS qualified by testing to support the qualification of a PJP WPS using a joint detail not shown in Figure 5.2 (see 6.12.2)

(3) Qualification of a PJP WPS not supported by a CJP WPS (see 6.12.3)

(4) Qualifying flare-groove welds (see 6.12.4)

Any PJP qualification shall also qualify any fillet weld size on any thickness.

6.12.1 PJP WPS Qualification: Method 1. Qualification of a CJP WPS in accordance with Clause 6 shall qualify PJP groove welds conforming to Figure 5.2 provided the essential variables for the qualified CJP WPS are within the limits listed in Tables 6.5 and 6.6 (when applicable).

6.12.2 PJP WPS Qualification: Method 2. When a CJP WPS has been qualified and is used to support a PJP groove weld detail not shown in Figure 5.2, the qualified PJP weld size shall be determined as shown below:

6.12.2.1 A test plate shall be welded using the minimum root opening and the minimum groove angle to be listed on the WPS. The test plate shall conform to Figure 6.29 (Detail A). Any steel base metal may be used.

6.12.2.2 Three macroetch cross section test specimens shall be prepared and visually examined to demonstrate that the specified weld size is met or exceeded.

6.12.2.3 The maximum weld size of the qualified joint shall be the minimum value of the three macroetch specimens.

6.12.2.4 The qualified WPS shall be prepared, to specify the maximum designed PJP weld size in relation to the depth of groove determined in 6.12.2.3 and the minimum root opening, minimum groove angle, and groove depth qualified.

6.12.3 PJP WPS Qualification: Method 3. Alternately, a PJP WPS shall be qualified and tested as required in Table 6.3. If a PJP bevel- or J- groove weld is to be used for T-joints or inside corner joints, the test joint shall have a temporary restrictive plate in the plane of the square face to simulate the restricted joint configuration. This restrictive plate shall be removed prior to cutting mechanical test specimens.

6.12.4 Qualification of a PJP Flare-Groove Weld WPS. The effective weld size qualified shall be determined by the following:

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6.12.4.1 A test plate shall be welded in conformance with Figure 6.29 Details B or C, as applicable. Weld parameters must be within those specified on the CJP WPS. Any steel base metal chemical composition may be used.

6.12.4.2 A minimum of three macroetch cross section test specimens, cut normal to the weld axis, shall be prepared and visually examined to verify that the specified weld size is met or exceeded. The sections shall be taken from the midlength and near the ends of the weld as shown in Figure 6.29 Details B or C.

6.12.4.3 The maximum weld size qualified is the minimum weld size of the three cross sections from 6.12.4.2 above. The minimum radius qualified is that tested.

6.13 Fillet Welds

6.13.1 Type and Number of Specimens. Except as permitted elsewhere in Clause 6, the type and number of specimens that shall be tested to qualify a single-pass fillet weld and/or multiple-pass fillet weld WPS are shown in Table 6.4. Qualification testing may be for either a single-pass fillet weld or multiple-pass fillet weld or both.

6.13.2 Fillet Weld Test. A fillet welded T-joint, as shown in Figure 6.15 for plate or Figure 10.16 for pipe (Detail A or Detail B), shall be made for each WPS and position to be used in construction. Testing is required for the maximum size single-pass fillet weld and the minimum size multiple-pass fillet weld used in construction. These two fillet weld tests may be combined in a single test weldment or assembly or individually qualified as standalone qualifications. Each weldment shall be cut perpendicular to the direction of welding at locations shown in Figure 6.15 or Figure 10.16 as applicable. Specimens representing one face of each cut shall constitute a macroetch test specimen and shall be tested in conformance with 6.10.4.

6.13.3 Consumables Verification Test

6.13.3.1 When a Test is Required. A consumables verification test is required when:

(1) The welding consumable does not conform to the prequalified provisions of Clause 5, and

(2) The WPS using the proposed consumable has not been qualified in accordance with 6.11 or 6.12.

6.13.3.2 Test Plate Weld. The test plate shall be welded as follows:

(1) The test plate shall have the groove configuration shown in Figure 6.16 (Figure 6.17 for SAW), with steel backing.

(2) The plate shall be welded in the 1G (flat) position.

(3) The plate length shall be adequate to provide the test specimens required and oriented as shown in Figure 6.18.

(4) The welding test conditions of current, voltage, travel speed, and gas flow shall approximate those to be used in making production fillet welds as closely as practical.

These conditions establish the WPS from which, when production fillet welds are made, changes in essential variables will be measured in conformance with 6.8.

6.13.3.3 Test Requirements. The test plate shall be tested as follows:

(1) Two side bend (Figure 6.9) specimens and one all-weld-metal tension (Figure 6.14) test specimen shall be removed from the test plate, as shown in Figure 6.18.

(2) The bend test specimens shall be tested in conformance with 6.10.3.1. Those test results shall conform to the requirements of 6.10.3.3.

(3) The tension test specimen shall be tested in conformance with 6.10.3.6. The test result shall determine the strength level for the welding consumable, which shall conform to the requirements of Table 4.3 or the base metal strength level being welded.

6.14 Plug and Slot Welds

When plug and slot welds are specified, WPS qualification shall be in conformance with 6.22.3.

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6.15 Welding Processes Requiring Qualification

6.15.1 GTAW, GMAW-S, ESW, and EGW. GTAW, GMAW-S, ESW, and EGW may be used, provided the WPSs are qualified in conformance with the requirements of Clause 6.

6.15.1.1 WPS Requirement (GMAW-S). Prior to use, the Contractor shall prepare a WPS(s) and qualify each WPS in accordance with the requirements of Clause 6. The essential variable limitations in Table 6.5 for GMAW shall also apply to GMAW-S.

6.15.1.2 WPS Requirement (GTAW). Prior to use, the Contractor shall prepare a WPS(s) and qualify each WPS in conformance with the requirements of Clause 6.

6.15.1.3 WPS Requirements (ESW/EGW).

(1) Prior to use, the Contractor shall prepare and qualify each ESW or EGW WPS to be used according to the requirements in Clause 6. The WPS shall include the joint details, filler metal type and diameter, amperage, voltage (type and polarity), speed of vertical travel if not an automatic function of arc length or deposition rate, oscillation (traverse speed, length, and dwell time), type of shielding including flow rate and dew point of gas or type of flux, type of molding shoe, PWHT if used, and other pertinent information.

(2) **All-Weld-Metal Tension Test Requirements.** Prior to use, the Contractor shall demonstrate by the test described in Clause 6, that each combination of shielding and filler metal will produce weld metal having the mechanical properties specified in the latest edition of AWS A5.25, *Specification for Carbon and Low Alloy Steel Electrodes and Fluxes for Electroslag Welding*, or the latest edition of AWS A5.26, *Specification for Carbon and Low Alloy Steel Electrodes for Electrogas Welding*, as applicable, when welded in conformance with the WPS.

(3) **Previous Qualification.** WPSs that have been previously qualified may be used, providing there is proper documentation, and the WPS is approved by the Engineer.

6.15.2 Other Welding Processes. Other welding processes not listed in 5.5.1 or 6.15.1 may be used, provided the WPSs are qualified by testing. The limitation of essential variables applicable to each welding process shall be established by the Contractor developing the WPS and approved by the Engineer. Essential variable ranges shall be based on documented evidence of experience with the process, or a series of tests shall be conducted to establish essential variable limits. Any change in essential variables outside the range so established shall require requalification.

Part C
Performance Qualification

6.16 General

The performance qualification tests required by this code are specifically devised tests to determine a welder's, welding operators, or tack welder's ability to produce sound welds. The qualification tests are not intended to be used as guides for welding or tack welding during actual construction. The latter shall be performed in conformance with a WPS.

6.16.1 Production Welding Positions Qualified

6.16.1.1 Welders and Welding Operators. The qualified production welding positions qualified by a plate test for welders and welding operators shall be in conformance with Table 6.10. The qualified production welding positions qualified by a tubular test for welders and welding operators shall be in conformance with Clause 10 and Table 10.12.

6.16.1.2 Tack Welders. A tack welder shall be qualified by one test plate in each position in which the tack welding is to be performed.

6.16.2 Production Thicknesses and Diameters Qualified

6.16.2.1 Welders or Welding Operators. The range of qualified production welding thicknesses and diameters for which a welder or welding operator is qualified for shall be in conformance with Table 6.11.

6.16.2.2 Tack Welders. Tack welder qualification shall qualify for thicknesses greater than or equal to 1/8 in [3 mm].

6.16.3 Welder and Welding Operator Qualification Through WPS Qualification. A welder or welding operator may also be qualified by welding a satisfactory WPS qualification test plate, pipe or tubing that meets the requirements of 6.10. The welder or welding operator is thereby qualified in conformance with 6.16.1 and 6.16.2.

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6.17 Type of Qualification Tests Required

6.17.1 Welders and Welding Operators. The type and number of qualification tests required for welders or welding operators shall conform to Table 6.11. Details on the individual NDT and mechanical test requirements are found in the following subclauses:

(1) Visual Inspection (see 6.10.1) (use WPS requirements)

(2) Face, root, and side bend (see 6.10.3.1) (use WPS requirements)

(3) Macroetch (see 6.23.2)

(4) Fillet Weld Break (see 6.23.4)

6.17.1.1 Substitution of RT for Guided Bend Tests. Except for joints welded by GMAW-S, radiographic examination of a welder or welding operator qualification test plate or test pipe may be made in lieu of bend tests described in 6.17.1(2) (see 6.23.3 for RT requirements).

In lieu of mechanical testing or RT of the qualification test assemblies, a welding operator may be qualified by RT of the initial 15 in [380 mm] of a production groove weld. The material thickness range qualified shall be that shown in Table 6.11.

6.17.1.2 Guided Bend Tests. Mechanical test specimens shall be prepared by cutting the test plate, pipe, or tubing as shown in Figures 6.16, 6.19, 6.20, 6.21, 6.22, and 10.23 for welder qualification or Figure 6.17, 6.22, or 6.24 for welding operator qualification, whichever is applicable. These specimens shall be approximately rectangular in cross section, and be prepared for testing in conformance with Figure 6.8, 6.9, 6.10, or 6.14, whichever is applicable.

6.17.2 Tack Welders. The tack welder shall make a 1/4 in [6 mm] maximum size tack weld approximately 2 in [50 mm] long on the fillet-weld-break specimen as shown in Figure 6.27.

6.17.2.1 Extent of Qualification. A tack welder who passes the fillet weld break test shall be qualified to tack weld all types of joints (except CJP groove welds, welded from one side without backing; e.g., butt joints and T-, Y-, and K-connections) for the process and in the position in which the tack welder is qualified. Tack welds in the foregoing exception shall be performed by welders fully qualified for the process and in the position in which the welding is to be done.

6.18 Weld Types for Welder and Welding Operator Performance Qualification

For the purpose of welder and welding operator qualification, weld types shall be classified as follows:

(1) CJP Groove Welds for Nontubular Connections (see 6.21)

(2) PJP Groove Welds for Nontubular Connections (see 6.22.1)

(3) Fillet Welds for Nontubular Connections (see 6.22.2)

(4) CJP Groove Welds for Tubular Connections (see 10.18)

(5) PJP Groove Welds for Tubular Connections (see 10.19)

(6) Fillet Welds for Tubular Connections (see 10.20)

(7) Plug and Slot Welds for Tubular and Nontubular Connections (see 6.22.3)

6.19 Preparation of Performance Qualification Forms

The welding personnel shall follow a WPS applicable to the qualification test required. All of the WPS essential variable limitations of 6.8 shall apply, in addition to the performance essential variables of 6.20. The Welding Performance Qualification Record (WPQR) shall serve as written verification and shall list all of the applicable essential variables of Table 6.12. Suggested forms are found in Annex J.

6.20 Essential Variables

Changes beyond the limitation of essential variables for welders, welding operators, or tack welders shown in Table 6.12 shall require requalification.

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6.21 CJP Groove Welds for Nontubular Connections

See Table 6.10 for the position requirements for welder or welding operator qualification on nontubular connections. Note that qualification on joints with backing qualifies for welding production joints that are backgouged and welded from the second side.

6.21.1 Welder Qualification Plates. The following figure numbers apply to the position and thickness requirements for welders.

(1) Figure 6.16—All Positions—Unlimited Thickness

(2) Figure 6.19—Horizontal Position—Unlimited Thickness

(3) Figure 6.20—All Positions—Limited Thickness

(4) Figure 6.21—Horizontal Position—Limited Thickness

6.21.2 Welding Operator Qualification Test Plates

6.21.2.1 For Other than EGW, ESW, and Plug Welds. The qualification test plate for a welding operator not using EGW or ESW or plug welding shall conform to Figure 6.17. This shall qualify a welding operator for groove and fillet welding in material of unlimited thickness for the process and position tested.

6.21.2.2 For ESW and EGW. The qualification test plate for an ESW or EGW welding operator shall consist of welding a joint of the maximum thickness of material to be used in construction, but the thickness of the material of the test weld need not exceed 1-1/2 in [38 mm] (see Figure 6.24). If a 1-1/2 in [38 mm] thick test weld is made, no test need be made for a lesser thickness. The test shall qualify the welding operator for groove and fillet welds in material of unlimited thickness for this process and test position.

6.22 Extent of Qualification

6.22.1 PJP Groove Welds for Nontubular Connections. Qualification for CJP groove welds shall qualify for all PJP groove welds.

6.22.2 Fillet Welds for Nontubular Connections. Qualification of CJP groove welds shall qualify for fillet welds. However, where only fillet weld qualification is required, see Table 6.11.

6.22.3 Plug and Slot Welds. Qualification for CJP groove welds on tubular or nontubular connections shall qualify for all plug and slot welds. See Table 6.10 for plug and slot weld qualification only. The joint shall consist of a 3/4 in [20 mm] diameter hole in a 3/8 in [10 mm] thick plate with a 3/8 in [10 mm] minimum thickness backing plate (see Figure 6.26).

6.23 Methods of Testing and Acceptance Criteria for Welder and Welding Operator Qualification

6.23.1 Visual Inspection. See 6.10.1 for acceptance criteria.

6.23.2 Macroetch Test. The test specimens shall be prepared with a finish suitable for macroetch examination. A suitable solution shall be used for etching to give a clear definition of the weld.

6.23.2.1 Plug and Fillet Weld Macroetch Tests.

The face of the macroetch shall be smooth for etching.

(1) The plug weld macroetch tests shall be cut from the test joints per:

(a) Welder Qualification—Figure 6.26

(b) Welding Operator Qualification—Figure 6.26

(2) The fillet weld macroetch tests shall be cut from the test joints per:

(a) Welder Qualification—Figure 6.25

(b) Welding Operator Qualification—Figure 6.25

6.23.2.2 Macroetch Test Acceptance Criteria. For acceptable qualification, the test specimen, when inspected visually, shall conform to the following requirements:

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(1) Fillet welds shall have fusion to the root of the joint but not necessarily beyond.

(2) Minimum leg size shall meet the specified fillet weld size.

(3) Plug welds shall have:

(a) No cracks

(b) Thorough fusion to backing and to sides of the hole

(c) No visible slag in excess of 1/4 in [6 mm] total accumulated length

6.23.3 RT. If RT is used in lieu of the prescribed bend tests, the weld reinforcement need not to be ground or otherwise smoothed for inspection unless its surface irregularities or juncture with the base metal would cause objectionable weld discontinuities to be obscured in the radiograph. If the backing is removed for RT, the root shall be ground flush (see 7.23.3.1) with the base metal.

6.23.3.1 RT Test Procedure and Technique. The RT procedure and technique shall be in conformance with the requirements of Clause 8, Part E and Clause 10, Part F for tubulars. For welder qualification, exclude 1-1/4 in [32 mm] at each end of the weld from evaluation in the plate test; for welding operator qualification exclude 3 in [75 mm] at each end of the test plate length.

6.23.3.2 RT Acceptance Criteria. For acceptable qualification, the weld, as revealed by the radiograph, shall conform to the requirements of 8.12.2, except that 8.12.2.2 shall not apply.

6.23.4 Fillet Weld Break Test. The entire length of the fillet weld shall be examined visually, and then a 6 in [150 mm] long specimen (see Figure 6.25) or a quarter-section of the pipe fillet weld assembly shall be loaded in such a way that the root of the weld is in tension. At least one welding start and stop shall be located within the test specimen. The load shall be increased or repeated until the specimen fractures or bends flat upon itself.

6.23.4.1 Acceptance Criteria for Fillet Weld Break Test. To pass the visual examination prior to the break test, the weld shall present a reasonably uniform appearance and shall be free of overlap, cracks, and undercut in excess of the requirements of 8.9. There shall be no porosity visible on the weld surface.

The broken specimen shall pass if:

(1) The specimen bends flat upon itself, or

(2) The fillet weld, if fractured, has a fracture surface showing complete fusion to the root of the joint with no inclusion or porosity larger than 3/32 in [2.5 mm] in greatest dimension, and

(3) The sum of the greatest dimensions of all inclusions and porosity shall not exceed 3/8 in [10 mm] in the 6 in [150 mm] long specimen.

6.23.5 Root, Face, and Side Bend Specimens. See. 6.10.3.3 for acceptance criteria.

6.24 Method of Testing and Acceptance Criteria for Tack Welder Qualification

A force shall be applied to the specimen as shown in Figure 6.23 until rupture occurs. The force may be applied by any convenient means. The surface of the weld and of the fracture shall be examined visually for defects.

6.24.1 Visual Acceptance Criteria. The tack weld shall present a reasonably uniform appearance and shall be free of overlap, cracks, and undercut exceeding 1/32 in [1 mm]. There shall be no porosity visible on the surface of the tack weld.

6.24.2 Destructive Testing Acceptance Criteria. The fractured surface of the tack weld shall show fusion to the root, but not necessarily beyond, and shall exhibit no incomplete fusion to the base metals or any inclusion or porosity larger than 3/32 in [2.5 mm] in greatest dimension.

6.25 Retest

When a welder, welding operator or tack welder either fails a qualification test, or if there is specific reason to question their welding abilities or period of effectiveness has lapsed, the following shall apply:

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6.25.1 Welder and Welding Operator Retest Requirements

6.25.1.1 Immediate Retest. An immediate retest may be made consisting of two welds of each type and position that the welder or welding operator failed. All retest specimens shall meet all of the specified requirements.

6.25.1.2 Retest After Further Training or Practice. A retest may be made, provided there is evidence that the welder or welding operator has had further training or practice. A complete retest of the types and positions failed or in question shall be made.

6.25.1.3 Retest After Lapse of Qualification Period of Effectiveness. When a welder's or welding operator's qualification period of effectiveness has lapsed, a requalification test shall be required. Welders have the option of using a test thickness of 3/8 in [10 mm] to qualify any production welding thickness greater than or equal to 1/8 in [3 mm].

6.25.1.4 Exception—Failure of a Requalification Retest. No immediate retest shall be allowed after failure of a requalification retest. A retest shall be allowed only after further training and practice per 6.25.1.2.

6.25.2 Tack Welder Retest Requirements

6.25.2.1 Retest without Additional Training. In case of failure to pass the test requirements, the tack welder may make one retest without additional training.

6.25.2.2 Retest After Further Training or Practice. A retest may be made, provided the tack welder has had further training or practice. A complete retest shall be required.

Part D
Requirements for CVN Toughness Testing

6.26 General: CVN Testing

6.26.1 Application. The CVN test requirements and test procedures in this section shall apply when CVN testing is specified in contract documents or required by this code [see 6.2.1.3 and 7.25.5(3)(d)].

6.26.1.1 Combination of WPSs. Except as required by 6.26.1.2, multiple WPSs, each of which have been qualified with CVN testing, are permitted to be used in a single joint without further qualification testing. WPSs that have been qualified without CVN tests are permitted to have CVN tests conducted on a test coupon welded using the WPS essential variables and then be used with WPSs qualified with CVN testing to deposit weld metal in a single joint.

6.26.1.2 FCAW-S. When welding processes other than FCAW-S are used to deposit weld metal over FCAW-S in a single joint, an additional set of CVN tests shall be conducted in compliance with 6.28.

6.26.2 Test Standards. The CVN test specimens shall be machined and tested in conformance with ASTM E23, *Standard Methods for Notched Bar Impact Testing of Metallic Materials*, for Type A Charpy (simple beam) Impact Specimen, ASTM A370, *Standard Test Method and Definitions for Mechanical Testing of Steel Products*, or AWS B4.0, *Standard Methods for Mechanical Testing of Welds*.

6.26.3 Test Requirements. When WPSs are required to be supported by PQRs with CVN testing, the following shall be required:

(1) A WPS shall be qualified with testing that includes CVN tests, or

(2) If a WPS qualified in accordance with the requirements of Clause 6 exists except that the supporting PQR does not list CVN test results, a test coupon shall be prepared with the WPS parameters such that the heat input does not exceed the heat input of the existing WPS and CVN test specimens can be extracted from the test plate and tested.

If option (1) is used, a new WPS shall be written using the PQR within the limits of Tables 6.1, 6.2, and 6.5, plus those PQR supplementary essential variables applicable to CVN testing (Table 6.7). CVN test specimens shall be removed from the test coupon as shown in one of the test coupon figures (Figures 6.5, 6.6 and 6.7 for plate, Figures 10.14 and 10.15 for tubulars).

If option (2) is used, the existing WPS parameters shall be used to weld the test coupon and the heat input of the existing WPS shall not be exceeded. The coupon shall meet the requirements for WPS qualification (Part B) except mechanical

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tensile and bend specimen testing shall not be required. The original WPS shall be revised to accommodate the PQR supplementary essential variables applicable to CVN testing (Table 6.7) and the PQR essential variables (Table 6.5).

Option (2) shall not apply to prequalified WPSs.

6.27 CVN Tests

6.27.1 Test Locations. Test specimen locations for CVN testing shall be at the weld metal centerline and in the HAZ when specified.

Unless the alternative locations are specified, the specimen locations within the zone being tested and the joint detail used shall comply with Figure 6.28.

6.27.2 Number of Specimens. Three CVN specimens shall be removed from each test coupon. Alternatively, five CVN specimens may be removed from each test coupon and the specimens with the highest and lowest CVN values shall be discarded prior to determining acceptance.

6.27.3 Specimen Size. Full Size (10 mm x 10 mm) specimens shall be used when test coupon material is 7/16 in [11 mm] or thicker and when the overall test coupon geometry permits. When test coupon is less than 7/16 in [11 mm] or when the coupon geometry prevents full size specimens, sub-sized specimens shall be used. When sub-sized specimens are used for CVN qualification, they shall be made to one of the standard sizes shown in Table 6.14.

The largest possible standard sub-size specimen size shall be machined from the test coupon.

6.27.4 Procedure for Locating the Notch. The CVN test specimens shall conform to the following:

(1) The specimens shall be machined from the test coupon at the appropriate depth as shown in Figure 6.28. The specimens should be made slightly over length to allow for exact positioning of the notch.

(2) The CVN test specimen bars shall be etched with a mild etchant such as 5% nital to reveal the location of the weld fusion line and HAZs.

(3) The longitudinal centerline of the specimens shall be transverse to the weld axis. The CVN notch shall be perpendicular (normal) to the surface of the test coupon.

(4) The centerline of the notch shall be located in the specimens, as shown in Figure 6.28 for the weld joint type being qualified.

Testing may be required at alternative locations to those shown in Figure 6.28 when required as described in 6.26.1.2.

6.27.5 CVN Test Temperature. CVN test specimen testing temperature shall be as specified in contract documents except that for sub-sized specimens, the testing temperature shall be modified in accordance with 6.27.6.

6.27.6 Use of Sub-size CVN Specimens

6.27.6.1 Test Coupon Thickness 7/16 in [11 mm] or greater. When sub-sized specimens are required due to geometry and when the width of the specimens across the notch is less than 80% of the base metal thickness, the test temperature shall be reduced in conformance with Table 6.14. No temperature reduction is required if the width of the specimen across the notch is 80% or more of the base metal thickness. (See C-6.27.6.1 for example calculation.)

6.27.6.2 Test Coupon Thickness less than 7/16 in [11 mm]. When sub-sized specimens are required due to the thickness of the test coupon and the width of the specimen across the notch is less than 80% of the test coupon thickness, the test temperature shall be reduced by an amount equal to the difference (referring to Table 6.14) between the temperature reduction corresponding to the test coupon thickness and the temperature reduction corresponding to the CVN specimen width actually tested. No temperature reduction is required if the width of the specimen across the notch is 80% or more of the base metal thickness. (See C-6.27.6.2 for example calculations.)

6.27.7 Acceptance Criteria. The average energy and minimum single-specimen energy shall be specified by the engineer per 4.3.2 and 1.5.1(5).

The reduction in the minimum acceptance energy values for sub-sized specimens shall be determined in conformance with Table 6.15.

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6.27.8 Retests. When the requirements of 6.27.7 are not met, one retest may be performed. The retest shall consist of an additional three (3) CVN specimens removed from the same test coupon as the failed test specimens. The energy value of each CVN specimen shall meet the minimum specified average acceptance criteria [see 6.27.7].

If there is insufficient coupon material remaining to remove the three retest CVN specimens, a complete test coupon shall be prepared and all NDT, mechanical, and CVN tests required by Part B of this clause shall be performed.

6.28 Combining FCAW-S with Other Welding Processes in a Single Joint

This subclause provides testing procedures used to determine the suitability of combining FCAW-S with other welding processes in a single joint.

6.28.1 Filler Metal Variables. Filler metal essential variables for the intermix CVN testing shall be as summarized in Table 6.16. Changes in these essential variables shall require an additional test.

6.28.2 Test Plate Details. A single test plate of ASTM A36, A572 Grade 50, or A992 shall be used to evaluate E70 [E49] filler metal combinations, and ASTM A572 Grade 65 or A913 Grade 65 shall be used to evaluate E80 [E55] filler metal combinations. ASTM A913 Grade 70 shall be used to evaluate E90 [E62] filler metal combinations. The test plate shall be 3/4 in [20 mm] thick, with either a 5/8 in [16 mm] root opening with a 20° included groove angle, or a 1/2 in [12 mm] root opening with a 45° included groove angle. The test plate and specimens shall be as shown in Figure 6.30.

Alternatively, a PQR test plate may be used wherein CVN test specimens have been taken from the intermixed zone

Regardless of the testing method used, the testing shall demonstrate that the acceptance criteria of 6.28 are met.

6.28.3 Welding of Test Plate. The sequence of placement of weld metals shall be the same as that to be employed in production. The first material shall be known as the substrate/root material, and the subsequent material shall be known as the fill material. Approximately one-third the thickness of the test joint shall be welded with the substrate/root material. The balance of the joint shall be welded with the fill material.

6.28.4 Test Specimens Required. Five or ten CVN test specimens shall be made from the test plate, depending on the required number of tests. CVN specimens shall be prepared in accordance with AWS B4.0, *Standard Methods for Mechanical Testing of Welds*.

6.28.5. CVN Specimen Location. The CVN impact bar shall be located as follows:

(1) Transverse specimens from which CVN bars are to be machined shall be etched to reveal the cross section of the weld.

(2) A line shall be scribed on the etched cross section, at the interface of the two welding process deposits (see Figure 6.31).

(3) The CVN specimen shall be taken from primarily material deposited by the second process. The interface location shall be included in the specimen, with the edge of the specimen within 1/16 in [1.5 mm] of the interface location (see Figure 6.32).

6.28.6. Acceptance Criteria. The lowest and highest values obtained from the five test specimens shall be disregarded. Two of the remaining three values shall equal or exceed the specified minimum average absorbed energy at the testing temperature. One of the three may be lower, but not lower than 5 ft·lbf [7 J] below the required absorbed energy. The average of the three shall not be less than the minimum required absorbed energy.

6.29 Reporting

All CVN test results required by this code or contract documents, including all test results from either three-piece or five-piece sets and all retest specimens, shall be reported on the PQR. If CVN testing is performed to obtain results for an existing WPS qualified in accordance with Part B of this clause, the original PQR shall be amended to show the CVN test values.

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Table 6.1
WPS Qualification—Production Welding Positions Qualified by Plate, Pipe, and Box Tube Tests (see 6.4)

Qualification Test			Production Plate Welding Qualified			Production Pipe Welding Qualified					Production Box Tube Welding Qualified				
						Butt Joint[a]		T-, Y-, K-Connections			Butt Joint		T-, Y-, K-Connections		
	Weld Type	Test Positions	Groove CJP	Groove PJP	Fillet[b]	CJP	PJP	CJP	PJP	Fillet[b]	CJP	PJP	CJP	PJP	Fillet[b]
PLATE	CJP Groove[c]	1G 2G 3G 4G	F F, H V OH	F F, H V OH	F F, H V OH	F F, H V OH	F F, H V OH			F F, H V OH	F F, H V OH	F F, H V OH			F F, H V OH
PLATE	Fillet[a,c]	1F 2F 3F 4F			F F, H V OH					F F, H V OH					F F, H V OH
PLATE	Plug/ Slot	Qualifies Plug/Slot Welding for Only the Positions Tested													

CJP—Complete Joint Penetration PJP—Partial Joint Penetration

[a] Qualifies for circumferential welds in pipes equal to or greater than 24 in [600 mm] nominal outer diameter.
[b] Fillet welds in production T-, Y-, or K-connections shall conform to Figure 10.5. WPS qualification shall conform to 6.13
[c] Qualifies for a welding axis with an essentially straight line, including welding along a line parallel to the axis of circular pipe.

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Table 6.2
WPS Qualification—CJP Groove Welds: Number and Type of Test Specimens and Range of Thickness Qualified (see 6.5)

1. Tests on Plate[a]

Nominal Plate Thickness (T) Tested, in [mm]	Number of Specimens: Reduced Section Tension (see Fig. 6.10)	Root Bend (see Fig. 6.8)	Face Bend (see Fig. 6.8)	Side Bend (see Fig. 6.9)	Nominal Base Metal Thickness Qualified, in [mm]: Min.	Max.[b]
1/8 ≤ T ≤ 3/8 [3 ≤ T ≤ 10]	2	2	2	(Footnote d)	1/8	2T
3/8 < T < 1 [10 < T < 25]	2	—	—	4	1/8	2T
1 and over [25 and over]	2	—	—	4	1/8	Unlimited

2. Tests on ESW and EGW[c]

Nominal Plate Thickness Tested	Number of Specimens: Reduced Section Tension (see Fig. 6.10)	All-Weld-Metal Tension (see Fig. 6.14)	Side Bend (see Fig. 6.9)	Nominal Base Metal Thickness Qualified: Min.	Max.
T	2	1	4	0.5T	1.1T

[a] See Figures 6.6 and 6.7 for test plate requirements.
[b] For square groove welds that are qualified without backgouging, the maximum thickness qualified is limited to the test thickness.
[c] See Figure 6.5 for test plate requirements.
[d] For 3/8 in [10 mm] plate thickness, a side-bend test may be substituted for each of the required face- and root-bend tests.

Table 6.3
WPS Qualification—PJP Groove Welds: Number and Type of Test Specimens and Range of Thickness Qualified (see 6.12.3)

Test Groove Depth, D in [mm]	Number of Specimens: Macroetch for Weld Size (S) 6.12.3	Reduced-Section Tension (see Fig. 6.10)	Root Bend (see Fig. 6.8)	Face Bend (see Fig. 6.8)	Side Bend (see Fig. 6.9)	Qualification Ranges: Max Groove Depth	Nominal Plate Thickness, in [mm]: Min.	Max.
1/8 ≤ D ≤ 3/8 [3 ≤ D ≤ 10]	3	2	2	2	—	D	1/8 [3]	2T[a]
3/8 < D ≤ 1 [10 < D ≤ 25]	3	2	—	—	4	D	1/8 [3]	Unlimited

[a] T is the thickness of the plate used in the test assembly

Notes:
1. Remove macroetch test specimens to determine weld size prior to removing material to prepare mechanical test specimens.
2. Remove excess material thickness from root side of test plate to the thickness of the weld size determined by the macroetch testing before preparing mechanical bend and tensile specimens.

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Table 6.4
WPS Qualification—Fillet Welds: Number and Type of Test Specimens and Range of Thickness Qualified (see 6.13)

			Test Specimens Required[a]			Size Qualified	
Test Specimen	Fillet Size	Number of Welds per WPS	Macroetch 6.13.1 6.10.4	All-Weld-Metal Tension (see Figure 6.14)	Side Bend (see Figure 6.9)	Plate/Pipe Thickness[b]	Fillet Size
Plate T-test (Figure 6.15)	Single pass, max. size to be used in construction	1 in each position to be used	3 faces	—	—	Unlimited	Max. tested single pass and smaller
	Multiple pass, min. size to be used in construction	1 in each position to be used	3 faces	—	—	Unlimited	Min. tested multiple pass and larger
Consumables Verification Test (Figure 6.18)	—	1 in 1G position	—	1	2	Qualifies welding consumables to be used in T-test above	

[a] All welded test plates shall be visually inspected per 6.10.1.
[b] The minimum thickness qualified shall be 1/8 in [3 mm].

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Table 6.5
PQR Essential Variable Changes Requiring WPS Requalification for SMAW, SAW, GMAW, FCAW, and GTAW (see 6.8.1)

Essential Variable Changes to PQR Requiring Requalification	Process				
	SMAW	SAW	GMAW	FCAW	GTAW
Filler Metal					
(1) Increase in filler metal classification strength	X		X	X	
(2) Change from low-hydrogen to nonlow-hydrogen SMAW electrode	X				
(3) Change from one electrode or flux-electrode classification to any other electrode or flux-electrode classification[a]		X		X	X
(4) Change to an electrode or flux-electrode classification[b] not covered in:	AWS A5.1 or A5.5	AWS A5.17 or A5.23	AWS A5.18, A5.28, or A5.36	AWS A5.20, A5.29, or A5.36	AWS A5.18 or A5.28
(5) Addition or deletion of filler metal					X
(6) Change from cold wire feed to hot wire feed or vice versa					X
(7) Addition or deletion of supplemental powdered or granular filler metal or cut wire		X			
(8) Increase in the amount of supplemental powdered or granular filler metal or wire		X			
(9) If the alloy content of the weld metal is largely dependent on supplemental powdered filler metal, any WPS change that results in a weld deposit with the important alloying elements not meeting the WPS chemical composition requirements		X			
(10) Change in nominal filler metal diameter by:	> 1/32 in [0.8 mm] increase	Any increase[c]	Any increase or decrease	Any increase	> 1/16 in [1.6 mm] increase or decrease
(11) Change in number of electrodes		X	X	X	X
Process Parameters					
(12) A change in the amperage for each diameter used by:	To a value not recommended by manufacturer	> 10% increase or decrease	> 10% increase or decrease	> 10% increase or decrease	> 25% increase or decrease
(13) A change in type of current (ac or dc) or polarity (electrode positive or negative for dc current)	X	X	X	X	X
(14) A change in the mode of transfer			X		
(15) A change from CV to CC output			X	X	
(16) A change in the voltage for each diameter used by:		> 7% increase or decrease	> 7% increase or decrease	> 7% increase or decrease	
(17) An increase or decrease in the wire feed speed for each electrode diameter (if not amperage controlled) by:		> 10%	> 10%	> 10%	

(Continued)

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Table 6.5 (Continued)
PQR Essential Variable Changes Requiring WPS Requalification for SMAW, SAW, GMAW, FCAW, and GTAW (see 6.8.1)

Essential Variable Changes to PQR Requiring Requalification	Process				
	SMAW	SAW	GMAW	FCAW	GTAW
Process Parameters (Cont'd)					
(18) A change in the travel speed[d] by:		> 15% increase or decrease	> 25% increase or decrease	> 25% increase or decrease	> 50% increase or decrease
Shielding Gas					
(19) A change in shielding gas from a single gas to any other single gas or mixture of gas, or in the specified nominal percentage composition of a gas mixture, or to no gas			X	X	X
(20) A change in total gas flow rate by:			Increase > 50% Decrease > 20%	Increase > 50% Decrease > 20%	Increase > 50% Decrease > 20%
(21) A change from the actual classification shielding gas not covered in:			AWS A5.18, A5.28, or A5.36. For A5.36 fixed and open classifications, variations in the shielding gas classification range shall be limited to the specific shielding gas tested or the designator used for the electrode classification.	AWS A5.20, A5.29, or A5.36. For A5.36 fixed and open classifications, variations in the shielding gas classification range shall be limited to the specific shielding gas tested or the designator used for the electrode classification.	
SAW Parameters					
(22) A change of > 10%, or 1/8 in [3 mm], whichever is greater, in the longitudinal spacing of the arcs		X			
(23) A change of > 10%, or 1/8 in [3 mm], whichever is greater, in the lateral spacing of the arcs		X			
(24) An increase or decrease of more than 10° in the angular orientation of any parallel electrode		X			
(25) For mechanized or automatic SAW; an increase or decrease of more than 3° in the angle of the electrode		X			
(26) For mechanized or automatic SAW, an increase or decrease of more than 5° normal to the direction of travel		X			

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Table 6.5 (Continued)
PQR Essential Variable Changes Requiring WPS Requalification for SMAW, SAW, GMAW, FCAW, and GTAW (see 6.8.1)

Essential Variable Changes to PQR Requiring Requalification	Process				
	SMAW	SAW	GMAW	FCAW	GTAW
General					
(27) A change in position not qualified by Table 6.1 or 6.10	X	X	X	X	X
(28) A change in diameter, or thickness, or both, not qualified by Table 6.2 or 10.9	X	X	X	X	X
(29) A change in base metal or combination of base metals not listed in on the PQR or qualified by Table 6.8	X	X	X	X	X
(30) Vertical Welding: For any pass from uphill to downhill or vice versa	X		X	X	X
(31) A change in groove type (e.g., single-V to double-V), except qualification of any CJP groove weld qualifies for any groove detail conforming with the requirements of 5.4.1, 5.4.2, 10.9, or 10.10	X	X	X	X	X
(32) A change in the type of groove to a square groove and vice versa	X	X	X	X	X
(33) A change exceeding the tolerances of 5.4.1, 5.4.2, 7.22.4.1 or 10.9, 10.10, and 10.23.2.1 involving: a) A decrease in the groove angle b) A decrease in the root opening c) An increase in the root face for CJP groove welds	X	X	X	X	X
(34) The omission, but not inclusion, of backing or backgouging	X	X	X	X	X
(35) Decrease from preheat temperature[e] by:	> 25°F [15°C]	> 25°F [15°C]	> 25°F [15°C]	> 25°F [15°C]	> 100°F [55°C]
(36) Decrease from interpass temperature[e] by:	> 25°F [15°C]	> 25°F [15°C]	> 25°F [15°C]	> 25°F [15°C]	> 100°F [55°C]
(37) Addition or deletion of PWHT	X	X	X	X	X

[a] The filler metal strength may be decreased without WPS requalification.
[b] AWS A5M (SI Units) electrodes of the same classification may be used in lieu of the AWS A5 (U.S. Customary Units) electrode classification.
[c] For WPSs using alloy flux, any increase or decrease in the electrode diameter shall require WPS requalification.
[d] Travel speed ranges for all sizes of fillet welds may be determined by the largest single pass fillet weld and the smallest multiple-pass fillet weld qualification tests.
[e] The production welding preheat or interpass temperature may be less than the PQR preheat or interpass temperature provided that the provisions of 7.6 are met, and the base metal temperature shall not be less than the WPS temperature at the time of subsequent welding.

Note: An "x" indicates applicability for the process; a shaded block indicates nonapplicability.

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Table 6.6
PQR Essential Variable Changes Requiring WPS Requalification for ESW or EGW (see 6.8.2)

Essential Variable Changes to PQR Requiring Requalification	Requalification by WPS Test	Requalification by RT or UT[a]
Filler Metal		
(1) A “significant” change in filler metal or consumable guide metal composition	X	
Molding Shoes (fixed or moveable)		
(2) A change from metallic to nonmetallic or vice versa		X
(3) A change from fusing to nonfusing or vice versa		X
(4) A reduction in any cross-sectional dimension or area of a solid nonfusing shoe > 25%		X
(5) A change in design from nonfusing solid to water cooled or vice versa	X	
Filler Metal Oscillation		
(6) A change in oscillation traverse speed > 10 ipm [4 mm/s]		X
(7) A change in oscillation traverse dwell time > 2 seconds (except as necessary to compensate for joint opening variations)		X
(8) A change in oscillation traverse length that affects by more than 1/8 in [3 mm], the proximity of filler metal to the molding shoes		X
Filler Metal Supplements		
(9) A change in consumable guide metal core cross-sectional area > 30%	X	
(10) A change in the flux system, i.e., cored, magnetic electrode, external, etc.	X	
(11) A change in flux composition including consumable guide coating	X	
(12) A change in flux burden > 30%		X
Electrode/Filler Metal Diameter		
(13) Increase or decrease in electrode diameter > 1/32 in [1 mm]		X
(14) A change in the number of electrodes used	X	
Electrode Amperage		
(15) An increase or decrease in the amperage > 20%	X	
(16) A change in type of current (ac or dc) or polarity		X
Electrode Arc Voltage		
(17) An increase or decrease in the voltage > 10%		X
Process Characteristics		
(18) A change to a combination with any other welding process	X	
(19) A change from single pass to multi-pass and vice versa	X	
(20) A change from constant current to constant voltage and vice versa		X
Wire Feed Speed		
(21) An increase or decrease in the wire feed speed > 40%	X	
Travel Speed		
(22) An increase or decrease in the travel speed (if not an automatic function of arc length or deposition rate) > 20% (except as necessary to compensate for variation in joint opening)		X

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Table 6.6 (Continued)
PQR Essential Variable Changes Requiring WPS Requalification for ESW or EGW (see 6.8.2)

Essential Variable Changes to PQR Requiring Requalification	Requalification by WPS Test	Requalification by RT or UT[a]
Electrode Shielding (EGW only)		
(23) A change in shielding gas composition of any one constituent > 5% of total flow	X	
(24) An increase or decrease in the total shielding flow rate > 25%		X
Welding Position		
(25) A change in vertical position by > 10°		X
Groove Type		
(26) An increase in cross-sectional area (for nonsquare grooves)	X	
(27) A decrease in cross-sectional area (for nonsquare grooves)		X
(28) A change in PQR joint thickness, T outside limits of 0.5T-1.1T	X	
(29) An increase or decrease > 1/4 in [6 mm] in square groove root opening		X
Postweld Heat Treatment		
(30) A change in PWHT	X	

[a] Testing shall be performed in conformance with Clause 8, Parts E or F, and Clause 10, Part F for tubulars, as applicable.

Note: An "x" indicates applicability for the requalification method; a shaded block indicates nonapplicability.

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Table 6.7
PQR Supplementary Essential Variable Changes for CVN Testing Applications Requiring WPS Requalification for SMAW, SAW, GMAW, FCAW, GTAW (see 6.8.1), and ESW/EGW (see 6.8.2)

Variable	SMAW	SAW	GMAW	FCAW	GTAW	ESW/EGW
Base Metal						
(1) A change in Group Number	X	X	X	X	X	X
(2)(a) Minimum thickness qualified is T or 5/8 in [16 mm] whichever is less, except if T is less than 1/4 in [6 mm], then the minimum thickness qualified is 1/8 in [3 mm]	X	X	X	X	X	
(2)(b) Minimum thickness qualified is 0.5T						X
Filler Metal						
(3) A change in the AWS A5.X Classification, or to a weld metal or filler metal classification not covered by A5.X specifications. Carbon and low-alloy steel FCAW and GMAW-Metal Cored electrodes previously classified under A5.18, A5.20, A5.28, or A5.29 and reclassified under A5.36 without change of manufacturer or brand name, and meeting all of the previous classification requirements used in PQR/WPS CVN qualification shall be acceptable without requalification.	X	X	X	X	X	X
(4) A change in the Flux/Wire classification		X				X[b]
(5) A change in either the electrode or flux trade name when not classified by an AWS specification		X				X
(6) A change from virgin flux to crushed slag flux		X				X[b]
(7) A change in the manufacturer or the manufacturer's brand name or type of electrode			X[a]	X		
Preheat/Interpass Temperature						
(8) An increase of more than 100°F [56°C] in the maximum preheat or interpass temperature qualified	X	X	X	X	X	X
Postweld Heat Treatment						
(9) A change in the PWHT temperature and/or time ranges. The PQR test shall be subject to 80% of the aggregate times at temperature(s). Total time(s) may be applied in signal or multiple heating cycle(s).	X	X	X	X	X	X
Electrical Characteristics						
(10) An increase in heat input over that qualified (see 6.8.5), except when a grain refining austenitizing heat treatment is applied after welding.	X	X	X	X	X	X
Other Variables						
(11) In the vertical position, a change from stringer to weave	X		X	X	X	
(12) A change from multipass per side to single pass per side	X	X	X	X	X	
(13) A change exceeding ±20% in the oscillation variables for mechanized or automatic welding		X	X	X	X	X

[a] Restriction shall only apply to metal cored electrodes listed in AWS A5.18/A5.18M, *Specification for Carbon Steel Electrodes and Rods for Gas Shielded Arc Welding,* AWS A5.28/A5.28M, *Specification for Low-Alloy Steel Electrodes and Rods for Gas Shielded Arc Welding, and* AWS A5.36/A5.36M:2012, *Specification for Carbon and Low-Alloy Steel Flux Cored Arc Welding and Metal Cored Electrodes for Gas Metal Arc Welding.*
[b] ESW only

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Table 6.8
Table 5.3, Table 6.9, and Unlisted Steels Qualified by PQR (see 6.8.3)

PQR Base Metal	WPS Base Metal Group Combinations Allowed by PQR
Any Group I Steel to Any Group I Steel	Any Group I Steel to Any Group I Steel
Any Group II Steel to Any Group II Steel	Any Group I Steel to Any Group I Steel Any Group II Steel to Any Group I Steel Any Group II Steel to Any Group II Steel
Any Specific Group III or Table 6.9 Steel to Any Group I Steel	The Specific PQR Group III or Table 6.9 Steel Tested to Any Group I Steel
Any Specific Group III or Table 6.9 Steel to Any Group II Steel	The Specific PQR Group III or Table 6.9 Steel Tested to Any Group I or Group II Steel
Any Group III Steel to the Same or Any Other Group III Steel or Any Group IV Steel to the Same or Any Other Group IV Steel or Any Table 6.9 Steel to the Same or Any Other Table 6.9 Steel	Steels shall be of the same material specification, grade/type and minimum yield strength as the Steels listed in the PQR
Any Combination of Group III, IV, and Table 6.9 Steels	Only the Specific Combination of Steels listed in the PQR
Any Unlisted Steel to Any Unlisted Steel or Any Steel Listed in Table 5.3 or Table 6.9	Only the Specific Combination of Steels listed in the PQR

Notes:
1. Groups I through IV are found in Table 5.3.
2. When allowed by the steel specification, the yield strength may be reduced with increased metal thickness.

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Table 6.9
Code-Approved Base Metals and Filler Metals Requiring Qualification per Clause 6 (see 6.8.3)

Base Metal					Matching Strength Filler Metal			Base Metal Thickness, T		Minimum Preheat and Interpass Temperature	
	Minimum Yield Point/Strength		Tensile Range								
Specification	ksi	MPa	ksi	MPa	Process	AWS Electrode Specification[a]	Electrode Classification	in	mm	°F	°C
ASTM A871 Grade 60 Grade 65	60 65	415 450	75 min. 80 min.	520 min. 550 min.	SMAW	A5.5	E8015-X E8016-X E8018-X				
					SAW	A5.23	F8XX-EXXX-XX F8XX-ECXXX-XX				
					GMAW	A5.28 A5.36	ER80S-XXX E80C-XXX E8XTX-XAX-XXX				
					FCAW	A5.29 A5.36	E8XTX-X E8XTX-XC E8XTX-XM E8XTX-AX-XXX E8XTX-XAX-XXX	Up to 3/4 Over 3/4 thru 1-1/2	Up to 20 Over 20 thru 38	50 125	10 50
ASTM A514 Over 2-1/2 in [65 mm]	90	620	100–130	690–895	SMAW	A5.5	E10015-X E10016-X E10018-X E10018M	Over 1-1/2 thru 2-1/2	Over 38 thru 65	175	80
ASTM A709 Grade HPS 100W [HPS 690W] Over 2-1/2 in to 4 in [65 mm to 100 mm]	90	620	100–130	690–895	SAW	A5.23	F10XX-EXXX-XX F10XX-ECXXX-XX				
					GMAW	A5.28 A5.36	ER100S-XXX E100C-XXX E10TX-XAX-XXX	Over 2-1/2	Over 65	225	110
ASTM A710 Grade A, Class 1 5/16 in [8 mm] and under Over 5/16 in to 3/4 in incl [8 mm to 20 mm incl]	85 80	585 550	90 min. 90 min.	620 min. 620 min.	FCAW	A5.29 A5.36	E10XTX-XC E10XTX-XM E10TX-XAX-XXX				
ASTM A710 Grade A, Class 3 1-1/4 in [30 mm] and under Over 1-1/4 in to 2 in incl [30 mm to 50 mm incl]	80 75	550 515	85 min. 85 min.	585 min. 585 min.							

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Table 6.9 (Continued)
Code-Approved Base Metals and Filler Metals Requiring Qualification per Clause 6 (see 6.8.3)

Base Metal					Matching Strength Filler Metal						
	Minimum Yield Point/Strength		Tensile Range					Base Metal Thickness, T		Minimum Preheat and Interpass Temperature	
Specification	ksi	MPa	ksi	MPa	Process	AWS Electrode Specification[a]	Electrode Classification	in	mm	°F	°C
ASTM A514 2-1/2 in [65 mm] and under	100	690	110–130	760–895	SMAW	A5.5	E11015-X E11016-X E11018-X E11018M				
ASTM A517 2-1/2 in [65 mm] and under Over 2-1/2 in [65 mm]	100 90	690 620	115–135 105–135	795–930 725–930	SAW	A5.23	F11XX-EXXX-XX F11XX-ECXXX-XX				
					GMAW	A5.28 A5.36	ER110S-XXX E110C-XXX E11TX-XAX-XXX	Up to 3/4	Up to 20	50	10
ASTM A709 Grade HPS 100W [HPS 690W] 2-1/2 in [65 mm] and under	100	690	110–130	760–895	FCAW	A5.29 A5.36	E11XTX-XC E11XTX-XM E11TX-XAX-XXX	Over 3/4 thru 1-1/2	Over 20 thru 38	125	50
ASTM A1043/A1043M Grade 36 Grade 50	36–52 50–65	250–360 345–450	58 min. 65 min.	400 min. 450 min.	SMAW	A5.1	E7015 E7016 E7018 E7028	Over 1-1/2 thru 2-1/2	Over 38 thru 65	175	80
						A5.5	E7015-X E7016-X E7018-X	Over 2-1/2	Over 65	225	110
					SAW	A5.17 A5.23	F7XX-EXXX F7XX-ECXXX F7XX-EXXX-XX F7XX-ECXXX-XX				

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Table 6.9 (Continued)
Code-Approved Base Metals and Filler Metals Requiring Qualification per Clause 6 (see 6.8.3)

Base Metal					Matching Strength Filler Metal					Minimum Preheat and Interpass Temperature	
	Minimum Yield Point/Strength		Tensile Range					Base Metal Thickness, T			
Specification	ksi	MPa	ksi	MPa	Process	AWS Electrode Specification[a]	Electrode Classification	in	mm	°F	°C
ASTM A1043/A1043M Grade 36 Grade 50 (Cont'd)	 36–52 50–65	 250–360 345–450	 58 min. 65 min.	 400 min. 450 min.		A5.18	ER70S-X E70C-XC E70C-XM (Electrodes with the -GS suffix shall be excluded) (Fixed Classification, carbon steel)				
					GMAW	A5.36	E70C-6M (Electrodes with the -GS suffix shall be excluded) (Open Classification, carbon steel)	Up to 3/4	Up to 20	50	10
						A5.36	E7XT15-XAX-CS1 E7XT15-XAX-CS2 E7XT16-XAX-CS1 E7XT16-XAX-CS2 (Electrodes with the -GS suffix shall be excluded)	Over 3/4 thru 1-1/2	Over 20 thru 38	125	50
						A5.28	ER70S-XXX E70C-XXX	Over 1-1/2 thru 2-1/2	Over 38 thru 65	175	80
						A5.36	(Open Classification, GMAW-Metal Cored low-alloy steel)				
					FCAW	A5.20	E7XT-X E7XT-XC E7XT-XM (Electrodes with the –2C, –2M, –3, –10, –13, –14, and -GS suffix shall be excluded, and electrodes with the –11 suffix shall be excluded for thicknesses greater than 1/2 in [12 mm])	Over 2-1/2	Over 65	225	110

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Table 6.9 (Continued)
Code-Approved Base Metals and Filler Metals Requiring Qualification per Clause 6 (see 6.8.3)

Base Metal					Matching Strength Filler Metal					Minimum Preheat and Interpass Temperature	
Specification	Minimum Yield Point/ Strength		Tensile Range		Process	AWS Electrode Specification[a]	Electrode Classification	Base Metal Thickness, T			
	ksi	MPa	ksi	MPa				in	mm	°F	°C
ASTM A1043/A1043M											
Grade 36	36–52	250–360	58 min.	400 min.	FCAW (Cont'd)	A5.36	(Fixed Classification, carbon steel)				
Grade 50	50–65	345–450	65 min.	450 min.			E7XT-1C	Up to 3/4	Up to 20	50	10
(Cont'd)							E7XT-1M				
							E7XT-5C				
							E7XT-5M				
							E7XT-9C	Over 3/4 thru 1-1/2	Over 20 thru 38	125	50
							E7XT-9M				
							E7XT-12C				
							E7XT-12M				
							E70T-4	Over 1-1/2 thru 2-1/2	Over 38 thru 65	175	80
							E7XT-6				
							E7XT-7				
							E7XT-8	Over 2-1/2	Over 65	225	110
							(Flux Cored Electrodes with the T1S, T3S, T10S, and -GS suffix shall be excluded and electrodes with the T11 suffix shall be excluded for thicknesses greater than 1/2 in [12 mm]				

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Table 6.9 (Continued)
Code-Approved Base Metals and Filler Metals Requiring Qualification per Clause 6 (see 6.8.3)

Base Metal					Matching Strength Filler Metal			Base Metal Thickness, T		Minimum Preheat and Interpass Temperature	
	Minimum Yield Point/Strength		Tensile Range								
Specification	ksi	MPa	ksi	MPa	Process	AWS Electrode Specification[a]	Electrode Classification	in	mm	°F	°C
ASTM A1043/A1043M	36–52 50–65	250–360 345–450	58 min. 65 min.	400 min. 450 min.		A5.36	(Open Classification, carbon steel) E7XTX-XAX-CS1 E7XTX-XAX-CS2 E7XTX-AX-CS3 *(Flux Cored Electrodes with the T1S, T3S, T10S, and -GS suffix shall be excluded and electrodes with the T11 suffix shall be excluded for thicknesses greater than 1/2 in [12 mm]*	Up to 3/4	Up to 20	50	10
								Over 3/4 thru 1-1/2	Over 20 thru 38	125	50
					FCAW (Cont'd)	A5.29	E7XTX-X E7XTX-XC E7XTX-XM	Over 1-1/2 thru 2-1/2	Over 38 thru 65	175	80
						A5.36	(Open Classification, FCAW, low-alloy steel) E6XTX-AX-XXX E6XTX-XAX-XXX E7XTX-AX-XXX E7XTX-XAX-XXX	Over 2-1/2	Over 65	225	110

[a] A5.36/A5.36M open classifications are listed in Annex M

Notes:
1. When welds are to be stress relieved, the deposited weld metal shall not exceed 0.05% vanadium (see 7.8).
2. When required by contract or job specifications, deposited weld metal shall have a minimum CVN energy of 20 ft·lbf [27.J] at 0°F [–20°C] as determined using CVN testing in conformance with Clause 6, Part D.
3. For ASTM A514, A517, and A709, Grade HPS 100W [HPS 690W], the maximum preheat and interpass temperature shall not exceed 400°F [200°C] for thicknesses up to 1-1/2 in [38 mm] inclusive, and 450°F [230°C] for greater thickness.
4. Filler metal properties have been moved to informative Annex L, except for AWS A5.36, see Annex M.
5. AWS A5M (SI Units) electrodes of the same classification may be used in lieu of the AWS A5 (U.S. Customary Units) electrode classification.

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Table 6.10
Welder and Welding Operator Qualification—Production Welding Positions Qualified by Plate Tests (see 6.16.1)[a]

Qualification Test			Production Plate Welding Qualified			Production Pipe Welding Qualified					Production Box Tube Welding Qualified				
	Weld Type	Test Positions[c]	Groove CJP	Groove PJP	Fillet[d]	Butt Joint[b] CJP	Butt Joint[b] PJP	T-, Y-, K-Connections CJP	T-, Y-, K-Connections PJP[b,e]	Fillet[d]	Butt Joint CJP[f]	Butt Joint PJP	T-, Y-, K-Connections CJP	T-, Y-, K-Connections PJP[e]	Fillet[d]
PLATE	Groove[g]	1G	F	F	F, H	F	F		F	F, H	F	F		F	F, H
		2G	F, H	F, H	F, H	F, H	F, H		F, H	F, H	F, H	F, H		F, H	F, H
		3G	F, H, V	F, H, V	F, H, V	F, H, V	F, H, V		F, H, V	F, H, V	F, H, V	F, H, V		F, H, V	F, H, V
		4G	F, OH	F, OH	F, H, OH	F, OH	F, OH		F, OH	F, H, OH	F, OH	F, OH		F, OH	F, H, OH
		3G + 4G	All	All	All	All	All		All	All	All	All		All	All
	Fillet	1F			F					F					F
		2F			F, H					F, H					F, H
		3F			F, H, V					F, H, V					F, H, V
		4F			F, H, OH					F, H, OH					F, H, OH
		3F + 4F			All					All					All
	Plug	Qualifies Plug and Slot Welding for Only the Positions Tested													

CJP—Complete Joint Penetration
PJP—Partial Joint Penetration

[a] The qualification of welding operators for electroslag welding (ESW) or electrogas welding (EGW) shall only apply for the position tested.
[b] Only qualified for pipe equal to or greater than 24 in [600 mm] in diameter with backing, backgouging, or both.
[c] See Figures 6.3 and 6.4.
[d] See 6.22 and 10.19 for dihedral angle restrictions for plate joints and tubular T-, Y-, K-connections.
[e] Not qualified for welds having groove angles less than 30° (see 10.14.4.2).
[f] Not qualified for joints welded from one side without backing, or welded from two sides without backgouging.
[g] Groove weld qualification shall also qualify plug and slot welds for the test positions indicated.

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Table 6.11
Welder and Welding Operator Qualification—Number and Type of Specimens and Range of Thickness and Diameter Qualified (Dimensions in Inches) (see 6.16.2.1)

(1) Test on Plate

Production Groove or Plug Welds		Number of Specimens[a]				Qualified Dimensions	
						Nominal Plate, Pipe or Tube Thickness Qualified, in	
Type of Test Weld (Applicable Figures)	Nominal Thickness of Test Plate (T) in	Face Bend[b] (Fig. 6.8)	Root Bend[b] (Fig. 6.8)	Side Bend[b] (Fig. 6.9)	Macro-etch	Min.	Max.
Groove (Fig. 6.20 or 6.21)	3/8	1	1	(Footnote c)	—	1/8	3/4 max.[d]
Groove (Fig. 6.16, 6.17, or 6.19)	3/8 < T < 1	—	—	2	—	1/8	2T max.[d]
Groove (Fig. 6.16, 6.17, or 6.19)	1 or over	—	—	2	—	1/8	Unlimited[d]
Plug (Fig. 6.26)	3/8	—	—	—	2	1/8	Unlimited

Production Fillet Welds (T-joint and Skewed)		Number of Specimens[a]					Qualified Dimensions			
							Nominal Plate Thickness Qualified, in		Dihedral Angles Qualified[e]	
Type of Test Weld (Applicable Figures)	Nominal Test Plate Thickness, T, in	Fillet Weld Break	Macro-etch	Side Bend[b]	Root Bend[b]	Face Bend[b]	Min.	Max.	Min.	Max.
Groove (Fig. 6.20 or 6.21)	3/8	—	—	(Footnote c)	1	1	1/8	Unlimited	30°	Unlimited
Groove (Fig. 6.20 or 6.21)	3/8 < T < 1	—	—	2	—	—	1/8	Unlimited	30°	Unlimited
Groove (Fig. 6.16, 6.17, or 6.19)	≥1	—	—	2	—	—	1/8	Unlimited	30°	Unlimited
Fillet Option 1 (Fig. 6.25)	1/2	1	1	—	—	—	1/8	Unlimited	60°	135°
Fillet Option 2 (Fig. 6.22)	3/8	—	—	—	2	—	1/8	Unlimited	60°	135°
Fillet Option 3 (Fig.10.16) [Any diam. pipe]	> 1/8	—	1	—	—	—	1/8	Unlimited	30°	Unlimited

(2) Tests on Electroslag and Electrogas Welding

Production Plate Groove Welds		Number of Specimens[a]	Nominal Plate Thickness Qualified, in	
Type of Test Weld	Nominal Plate Thickness Tested, T, in	Side Bend[b] (see Fig. 6.9)	Min.	Max.
Groove (Fig. 6.24)	< 1-1/2	2	1/8	T
	1-1/2	2	1/8	Unlimited

[a] All welds shall be visually inspected (see 6.23.1).
[b] Radiographic examination of the test plate may be made in lieu of the bend tests (see 6.17.1.1).
[c] For 3/8 in plate or wall thickness, a side-bend test may be substituted for each of the required face- and root-bend tests.
[d] Also qualifies for welding any fillet or PJP weld size on any thickness of plate, pipe or tubing.
[e] For dihedral angles < 30°, see 10.18.1; except 6GR test not required.

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Table 6.11 (Continued)
Welder and Welding Operator Qualification—Number and Type of Specimens and Range of Thickness and Diameter Qualified (Dimensions in Millimeters) (see 6.16.2.1)

(1) Test on Plate

Production Groove or Plug Welds		Number of Specimens[a]				Qualified Dimensions	
						Nominal Plate, Pipe or Tube Thickness Qualified, mm	
Type of Test Weld (Applicable Figures)	Nominal Thickness of Test Plate, T, mm	Face Bend[b] (Fig. 6.8)	Root Bend[b] (Fig. 6.8)	Side Bend[b] (Fig. 6.9)	Macro-etch	Min.	Max.
Groove (Fig. 6.20 or 6.21)	10	1	1	(Footnote c)	—	3	20 max[d]
Groove (Fig. 6.16, 6.17, or 6.19)	10 < T < 25	—	—	2	—	3	2T max[d]
Groove (Fig. 6.16, 6.17, or 6.19)	25 or over	—	—	2	—	3	Unlimited[d]
Plug (Fig. 6.26)	10	—	—	—	2	3	Unlimited

Production Fillet Welds (T-joint and Skewed)		Number of Specimens[a]					Qualified Dimensions			
							Nominal Plate Thickness Qualified, mm		Dihedral Angles Qualified[e]	
Type of Test Weld (Applicable Figures)	Nominal Test Plate Thickness, T, mm	Fillet Weld Break	Macro-etch	Side Bend[b]	Root Bend[b]	Face Bend[b]	Min.	Max.	Min.	Max.
Groove (Fig. 6.20 or 6.21)	10	—	—	(Footnote c)	1	1	3	Unlimited	30°	Unlimited
Groove (Fig. 6.20 or 6.21)	10 < T < 25	—	—	2	—	—	3	Unlimited	30°	Unlimited
Groove (Fig. 6.16, 6.17, or 6.19)	≥ 25	—	—	2	—	—	3	Unlimited	30°	Unlimited
Fillet Option 1 (Fig. 6.25)	12	1	1	—	—	—	3	Unlimited	60°	135°
Fillet Option 2 (Fig. 6.22)	10	—	—	—	2	—	3	Unlimited	60°	135°
Fillet Option 3 (Fig. 10.16) [Any diam. pipe]	> 3	—	1	—	—	—	3	Unlimited	30°	Unlimited

(2) Tests on Electroslag and Electrogas Welding

Production Plate Groove Welds		Number of Specimens[a]	Nominal Plate Thickness Qualified, mm	
Type of Test Weld	Nominal Plate Thickness Tested, T, mm	Side Bend[b] (see Fig. 6.9)	Min.	Max.
Groove (Fig. 6.24)	< 38	2	3	T
	38	2	3	Unlimited

[a] All welds shall be visually inspected (see 6.23.1).
[b] Radiographic examination of the test plate may be made in lieu of the bend tests (see 6.17.1.1).
[c] For 10 mm plate or wall thickness, a side-bend test may be substituted for each of the required face- and root-bend tests.
[d] Also qualifies for welding any fillet or PJP weld size on any thickness of plate, pipe or tubing.
[e] For dihedral angles < 30°, see 10.18.1; except 6GR test not required.

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Table 6.12
Welding Personnel Performance Essential Variable Changes Requiring Requalification (see 6.20)

Essential Variable Changes to WPQR Requiring Requalification	Welding Personnel		
	Welders[a]	Welding Operators[a, b]	Tack Welders
(1) To a process not qualified (GMAW-S is considered a separate process)	X	X	X
(2) To an SMAW electrode with an F-number (see Table 6.13) higher than the WPQR electrode F-number	X		X
(3) To a position not qualified	X	X	X
(4) To a diameter or thickness not qualified	X	X	
(5) To a vertical welding progression not qualified (uphill or downhill)	X		
(6) The omission of backing (if used in the WPQR test)	X	X	
(7) To multiple electrodes (if a single electrode was used in the WPQR test) but not vice versa		X[c]	

[a] Welders qualified for SAW, GMAW, FCAW, or GTAW shall be considered as qualified welding operators in the same process(es) and subject to the welder essential variable limitations.
[b] A groove weld qualifies a slot weld for the WPQR position and the thickness ranges as shown in Table 6.11.
[c] Not for ESW or EGW.

Notes:
1. An "x" indicates applicability for the welding personnel; a shaded area indicates nonapplicability.
2. WPQR = Welding Performance Qualification Record.

Table 6.13
Electrode Classification Groups (see Table 6.12)

Group Designation	AWS Electrode Classification
F4	EXX15, EXX16, EXX18, EXX48, EXX15-X, EXX16-X, EXX18-X
F3	EXX10, EXX11, EXX10-X, EXX11-X
F2	EXX12, EXX13, EXX14, EXX13-X
F1	EXX20, EXX24, EXX27, EXX28, EXX20-X, EXX27-X

Note: The letters "XX" used in the classification designation in this table stand for the various strength levels (60 [415], 70 [485], 80 [550], 90 [620], 100 [690], 110 [760], and 120 [830]) of electrodes.

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Table 6.14
CVN Test Temperature Reduction (see 6.27.6)

CVN Bar Size		Temperature Reduction	
	mm	°F	°C
Full-size standard bar	10 × 10	0	0
	10 × 9	0	0
	10 × 8	0	0
3/4 size bar	10 × 7.5	5	3
	10 × 7	8	4
2/3 size bar	10 × 6.7	10	6
	10 × 6	15	8
1/2 size bar	10 × 5	20	11
	10 × 4	30	17
1/3 size bar	10 × 3.3	35	19
	10 × 3	40	22
1/4 size bar	10 × 2.5	50	28

Note:
1. Notch shall be placed on the face of the CVN bar with the lesser dimension.
2. Straight line interpolation for intermediate notched face dimensions is permitted.
3. Temperature reductions account for the 9/5 difference between °C and °F but not the 32° offset and are not exact equivalents (see 1.2)

Table 6.15
Charpy V-Notch Test Acceptance Criteria for Various Sub-Size Specimens (see 6.27.7)

Full Size, 10 × 10 mm		3/4 Size, 10 × 7.5 mm		2/3 Size, 10 × 6.7 mm		1/2 Size, 10 × 5 mm		1/3 Size, 10 × 3.3 mm		1/4 Size, 10 × 2.5 mm	
Ft-lbf	[J]	Ft-lbf	[J]	Ft-lbf	[J]	Ft-lbf	[J]	Ft-lbf	[J]	Ft-lbf	[J]
40[a]	[54]	30	[41]	27	[37]	20	[27]	13	[18]	10	[14]
35	[48]	26	[35]	23	[31]	18	[24]	12	[16]	9	[12]
30	[41]	22	[30]	20	[27]	15	[20]	10	[14]	8	[11]
25	[34]	19	[26]	17	[23]	12	[16]	8	[11]	6	[8]
20	[27]	15	[20]	13	[18]	10	[14]	7	[10]	5	[7]
16	[22]	12	[16]	11	[15]	8	[11]	5	[7]	4	[5]
15	[20]	11	[15]	10	[14]	8	[11]	5	[7]	4	[5]
13	[18]	10	[14]	9	[12]	6	[8]	4	[5]	3	[4]
12	[16]	9	[12]	8	[11]	6	[8]	4	[5]	3	[4]
10	[14]	8	[11]	7	[10]	5	[7]	3	[4]	2	[3]
7	[10]	5	[7]	5	[7]	4	[5]	2	[3]	2	[3]

[a] Table is limited to 40 ft-lbf because the relationship between specimen size and test results has been reported to be non-linear for higher values.

Note:
1. Straight line interpolation for intermediate bar face dimensions is permitted.

Source: Adapted, with permission, from American Society of Mechanical Engineers, *ASTM A370-2017, Standard Test Methods and Definitions for Mechanical Testing of Steel Products*, Table 9

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Table 6.16
Filler Metal Essential Variables—FCAW-S Substrate/Root (see 6.28.1)

	Substrate/ Root	Fill					
	FCAW-S	FCAW-S	FCAW-G	SMAW	GMAW	SAW	Other
AWS Classification	X		X	X	X	X	X
Manufacturer	X		X	X		X	X
Manufacturer's Brand and Trade Name	X		X	X		X	X
Diameter			X	X	X	X	X

Note: An "X" in the column indicates that the essential variable is applicable for the particular welding process and weld type.

Source: Reproduced from AWS D1.8/D1.8M:2016, *Structural Welding Code—Seismic*, Table B.1, American Welding Society.

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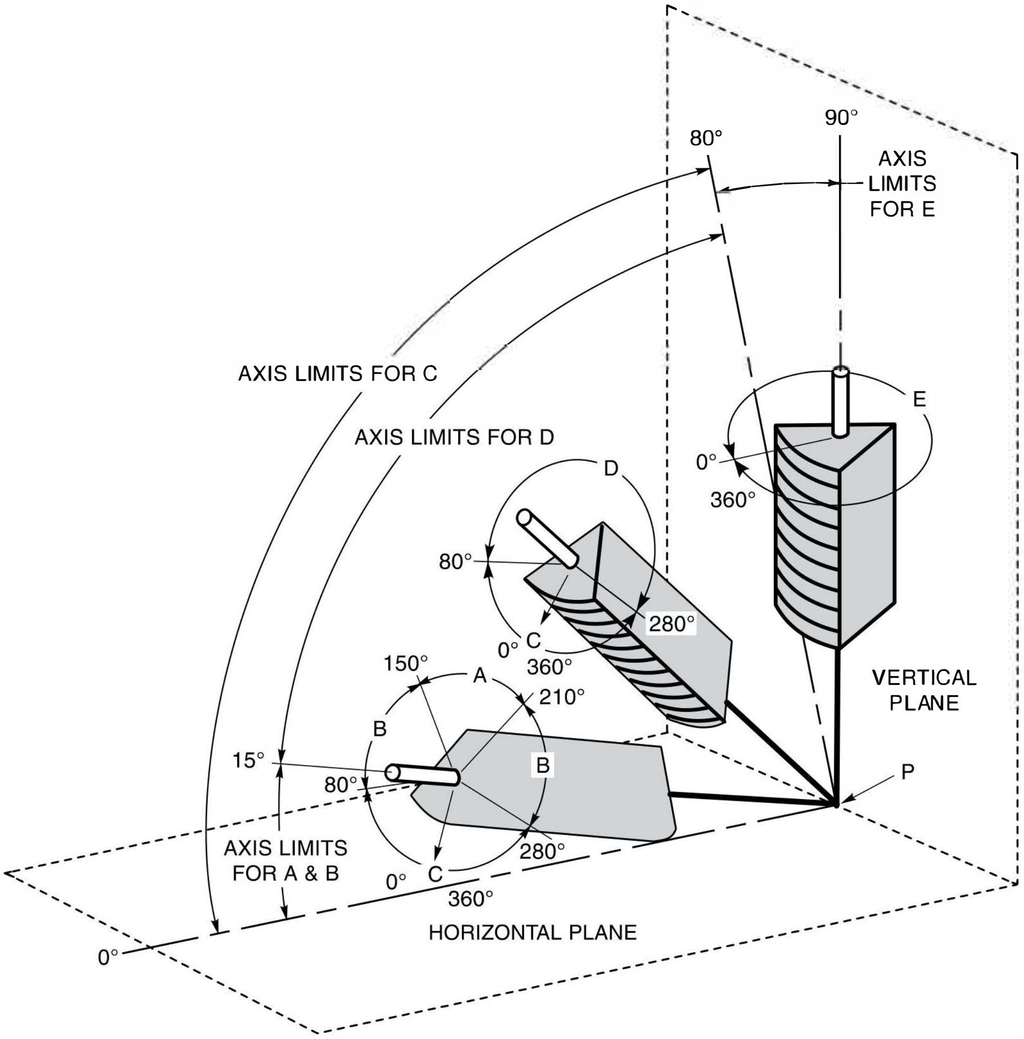
Tabulation of Positions of Groove Welds			
Position	Diagram Reference	Inclination of Axis	Rotation of Face
Flat	A	0° to 15°	150° to 210°
Horizontal	B	0° to 15°	80° to 150° 210° to 280°
Overhead	C	0° to 80°	0° to 80° 280° to 360°
Vertical	D E	15° to 80° 80° to 90°	80° to 280° 0° to 360°



Notes:
1. The horizontal reference plane shall always be taken to lie below the weld under consideration.
2. The inclination of axis shall be measured from the horizontal reference plane toward the vertical reference plane.
3. The angle of rotation of the face shall be determined by a line perpendicular to the theoretical face of the weld which passes through the axis of the weld. The reference position (0°) of rotation of the face invariably points in the direction opposite to that in which the axis angle increases. When looking at point P, the angle of rotation of the face of the weld shall be measured in a clockwise direction from the reference position (0°).

Figure 6.1—Positions of Groove Welds (see 6.3.4)

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Tabulation of Positions of Fillet Welds

Position	Diagram Reference	Inclination of Axis	Rotation of Face
Flat	A	0° to 15°	150° to 210°
Horizontal	B	0° to 15°	125° to 150° 210° to 235°
Overhead	C	0° to 80°	0° to 125° 235° to 360°
Vertical	D E	15° to 80° 80° to 90°	125° to 235° 0° to 360°

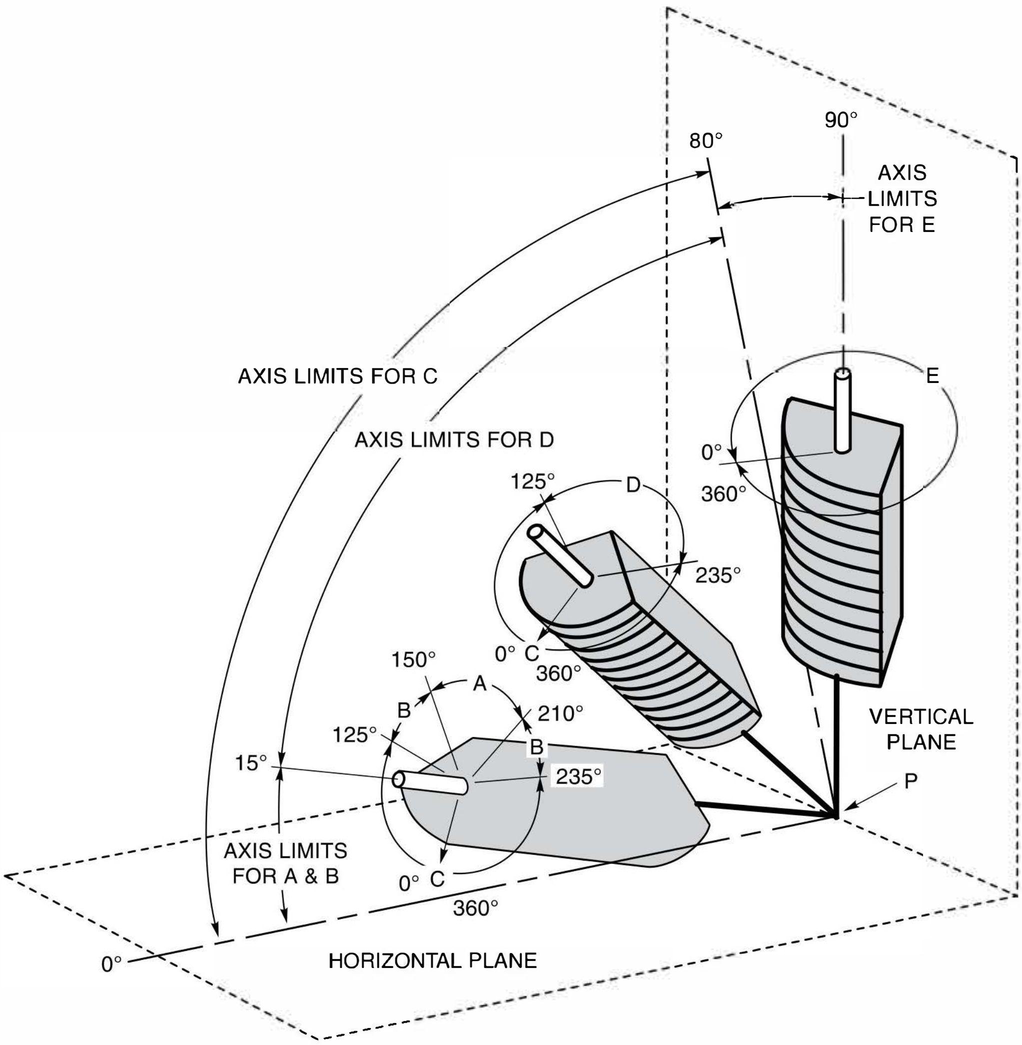

Figure 6.2—Positions of Fillet Welds (see 6.3.4)

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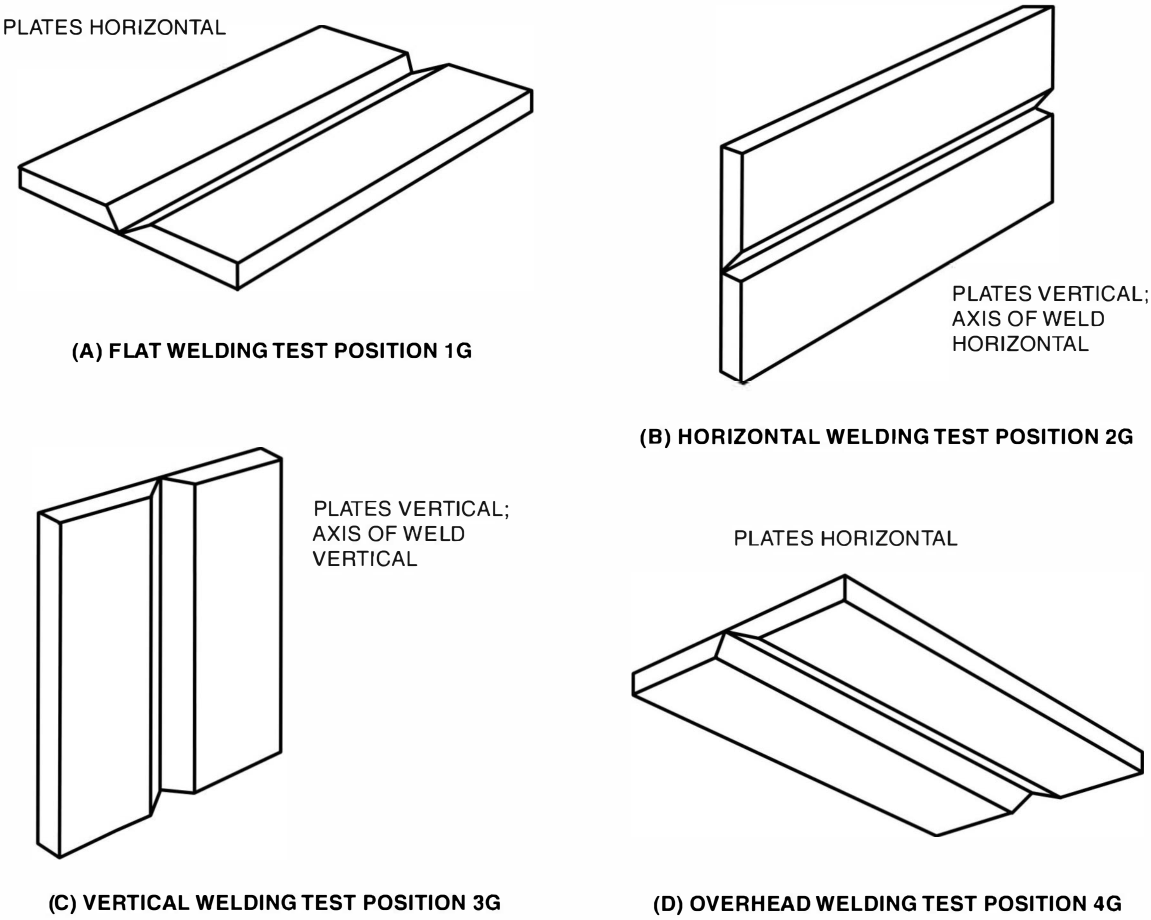

Figure 6.3—Positions Test Plates for Groove Welds (see 6.3.4)

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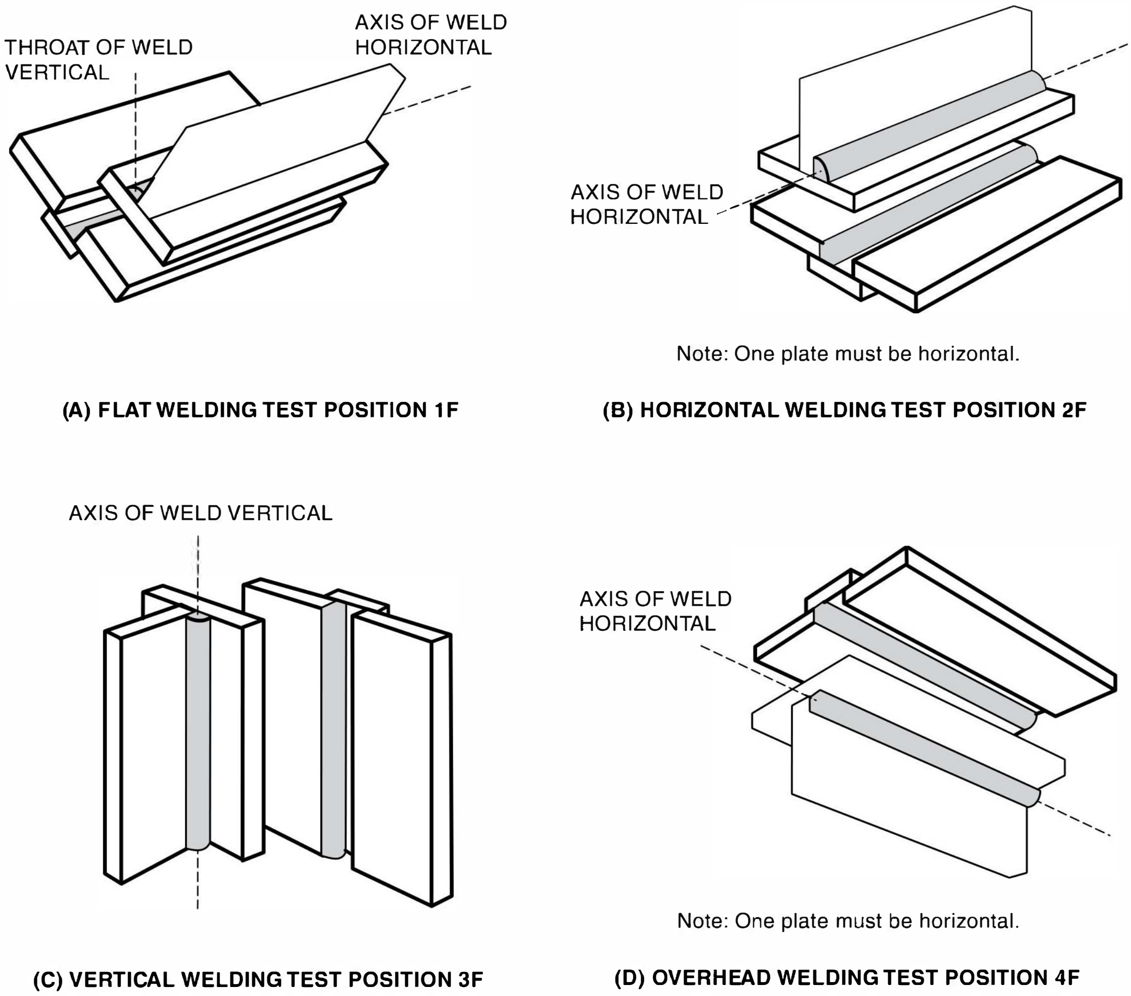

Figure 6.4—Positions Test Plates for Fillet Welds (see 6.3.4)

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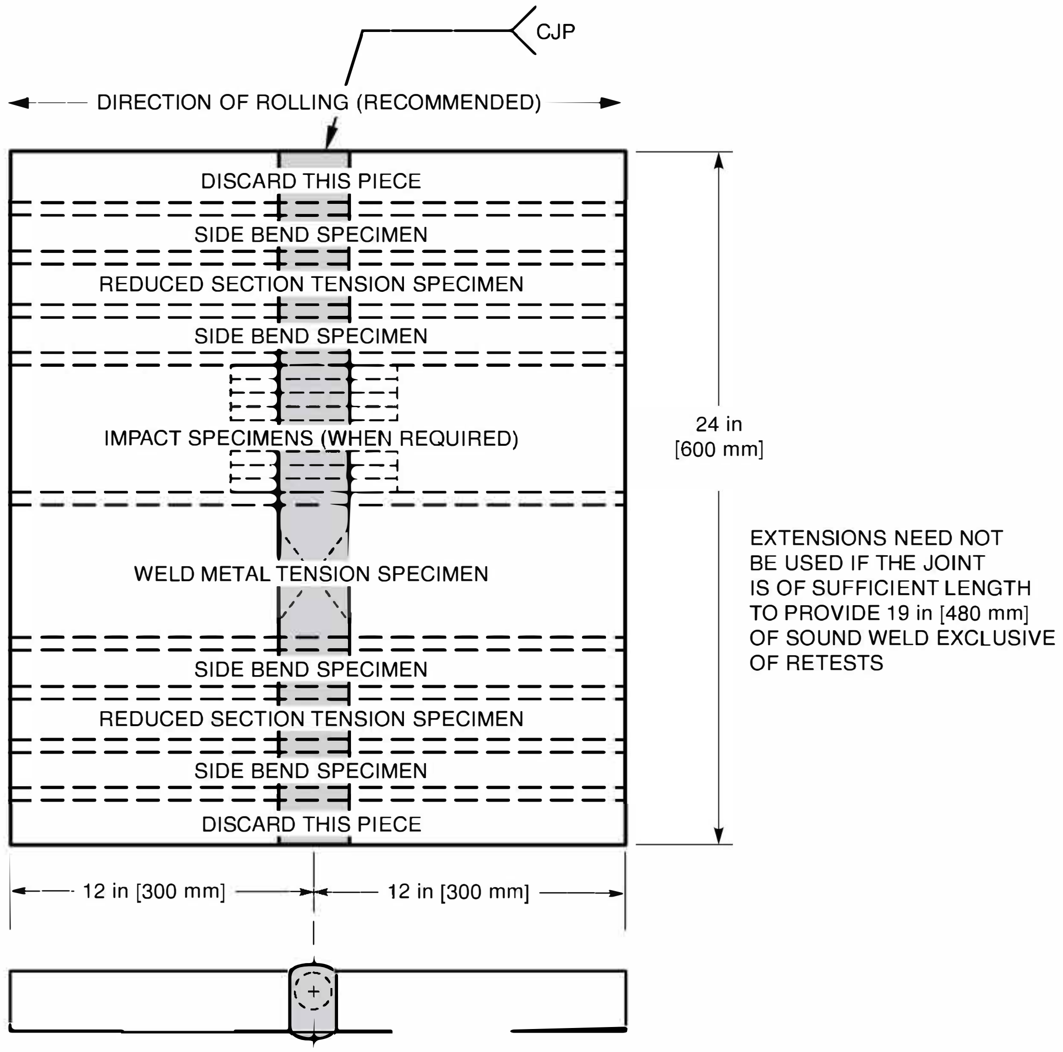

Notes:
1. The groove configuration shown is for illustration only. The groove shape tested shall conform to the production groove shape that is being qualified.
2. When CVN test specimens are required, see Clause 6, Part D for requirements.
3. All dimensions are minimum.

Figure 6.5—Location of Test Specimens on Welded Test Plates—ESW and EGW—WPS Qualification (see 6.10)

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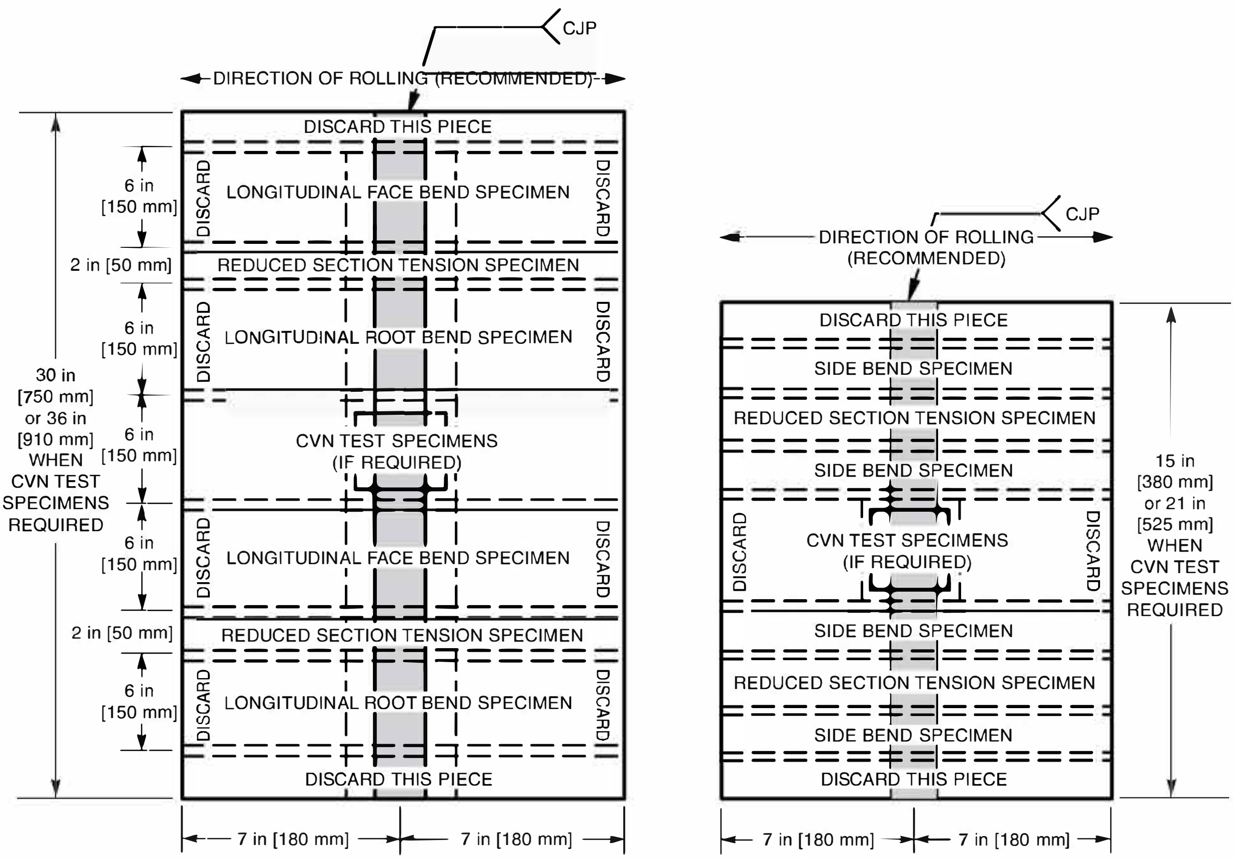
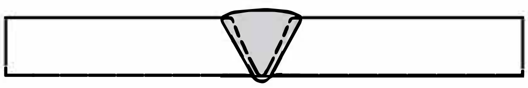


(1) LONGITUDINAL BEND SPECIMENS **(2) TRANSVERSE BEND SPECIMENS**



Notes:
1. The groove configuration shown is for illustration only. The groove shape tested shall conform to the production groove shape that is being qualified.
2. When CVN tests are required, the specimens shall be removed from their locations, as shown in Figure 6.28.
3. All dimensions are minimum.

Figure 6.6—Location of Test Specimens on Welded Test Plate Over 3/8 in [10 mm] Thick—WPS Qualification (see 6.10)

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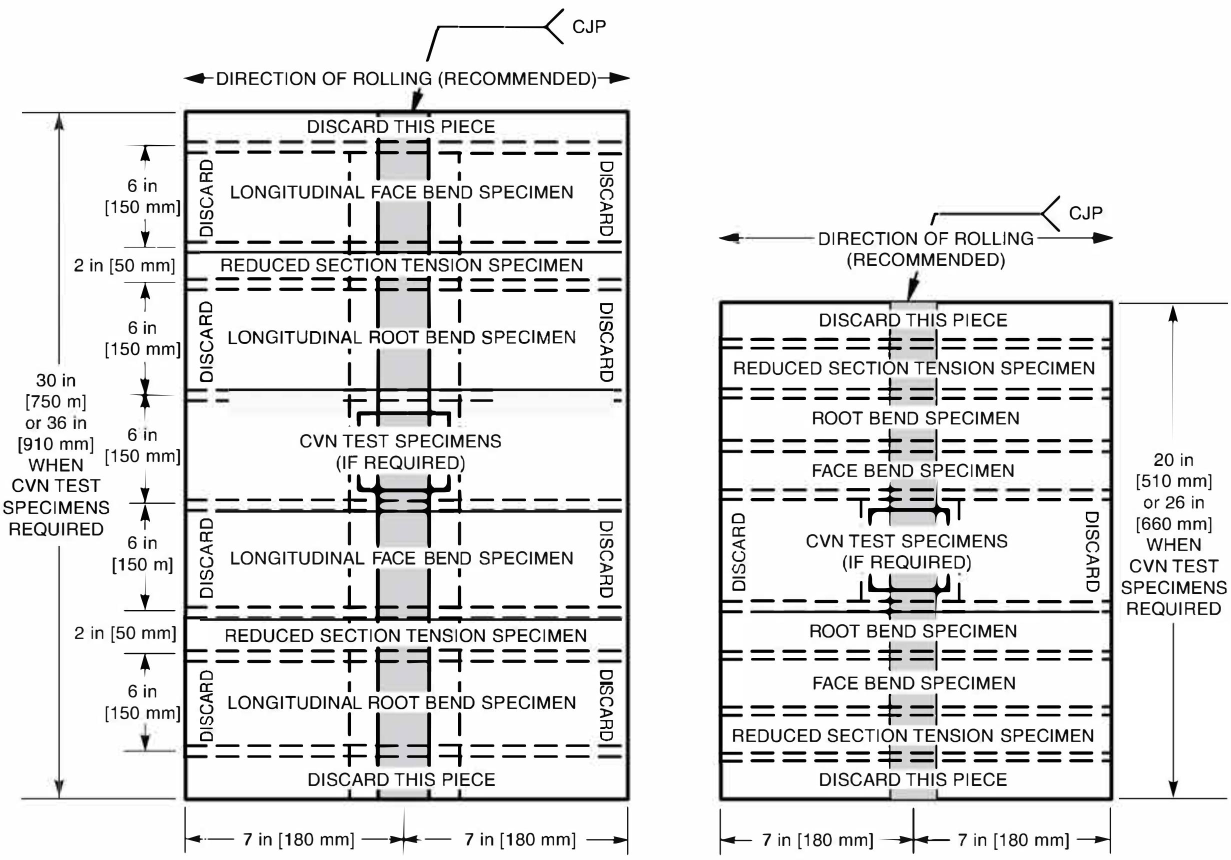
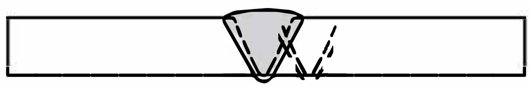


(1) LONGITUDINAL BEND SPECIMENS **(2) TRANSVERSE BEND SPECIMENS**



Notes:
1. The groove configuration shown is for illustration only. The groove shape tested shall conform to the production groove shape that is being qualified.
2. When CVN tests are required, the specimens shall be removed from their locations, as shown in Figure 6.28.
3. All dimensions are minimum.
4. For 3/8 in [10 mm] plate, a side-bend test may be substituted for each of the required face- and root-bend tests. See Figure 6.6(2) for plate length and location of specimens.

Figure 6.7—Location of Test Specimens on Welded Test Plate 3/8 in [10 mm] Thick and Under—WPS Qualification (see 6.10)

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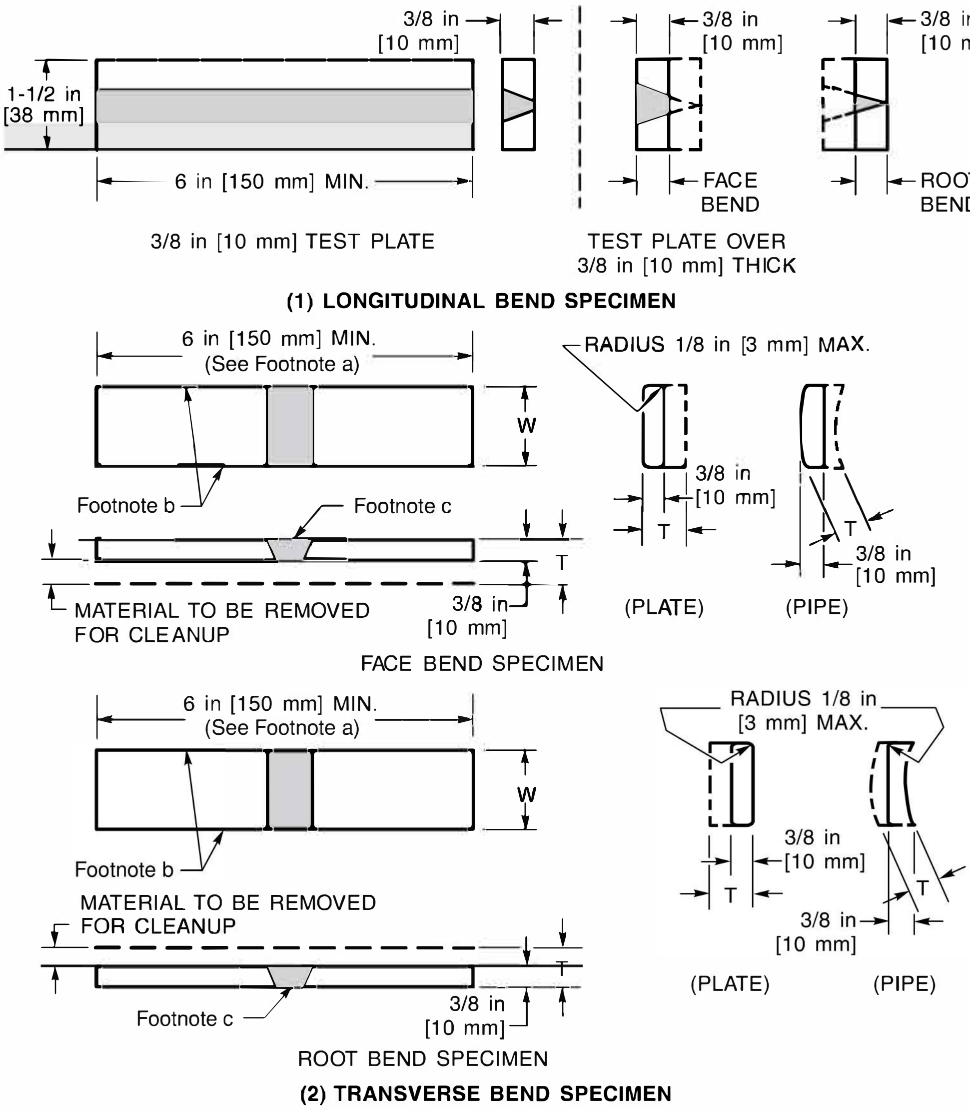

Dimensions	
Test Weldment	Test Specimen Width, W in [mm]
Plate	1-1/2 |40]
Test pipe or tube ≤ 4 in [100 mm] in diameter	1 [25]
Test pipe or tube > 4 in [100 mm] in diameter	1-1/2 (40]

[a] A longer specimen length may be necessary when using a wraparound type bending fixture or when testing steel with a yield strength of 90 ksi [620 MPa] or more.

[b] These edges may be thermal cut and may or may not be machined.

[c] The weld reinforcement and backing, if any, shall be removed flush with the surface of the specimen (see 7.23.3.1 and 7.23.3.2). If a recessed backing is used, this surface may be machined to a depth not exceeding the depth of the recess to remove the backing; in such a case, the thickness of the finished specimen shall be that specified above. Cut surfaces shall be smooth and parallel.

Notes:

1. T = plate or pipe thickness.
2. When the thickness of the test plate is less than 3/8 in [10 mm], the nominal thickness shall be used for face and root bends.

Figure 6.8—Face and Root Bend Specimens (see 6.10.3.1)

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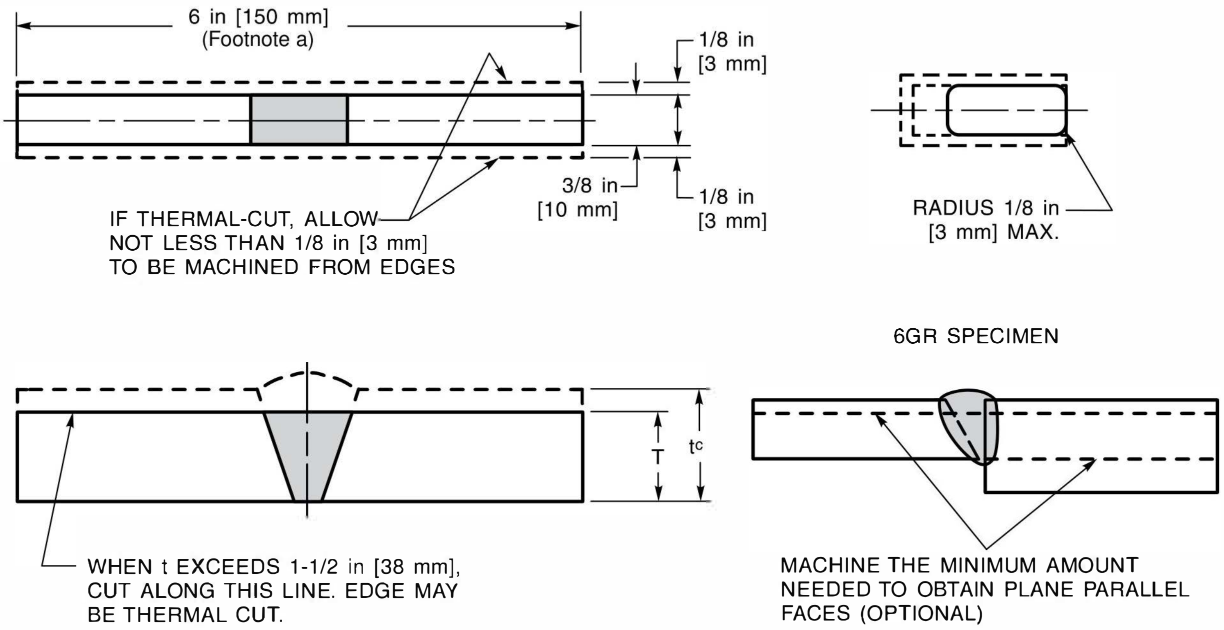

t, in	T, in
3/8 to 1-1/2	t
> 1-1/2	(Footnote b)

t, mm	T, mm
10 to 38	t
> 38	(Footnote b)

[a] A longer specimen length may be necessary when using a wraparound-type bending fixture or when testing steel with a yield strength of 90 ksi [620 MPa] or more.
[b] For plates over 1-1/2 in [38 mm] thick, the specimen shall be cut into approximately equal strips with T between 3/4 in [20 mm] and 1-1/2 in [38 mm] and test each strip.
[c] t = plate or pipe thickness.

Figure 6.9—Side Bend Specimens (see 6.10.3.1)

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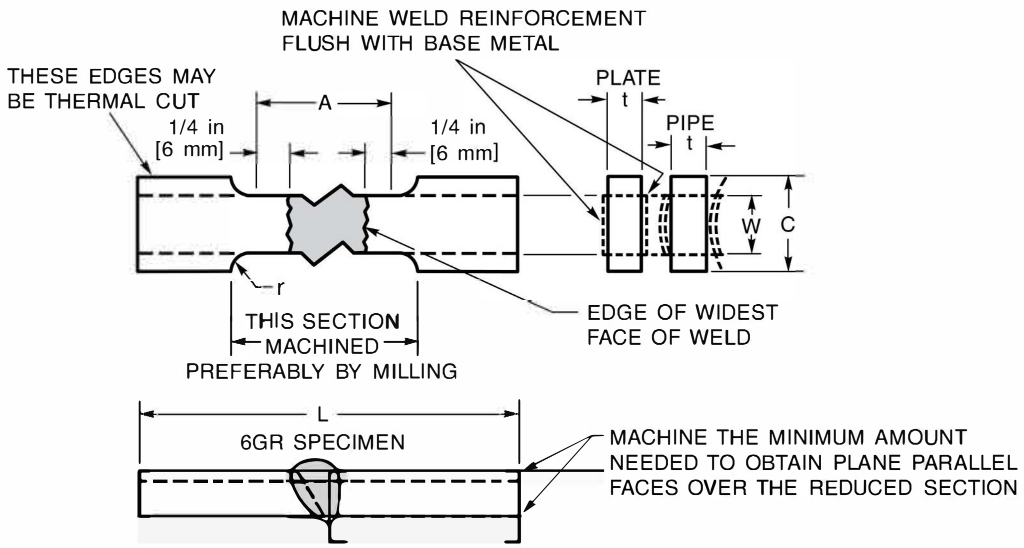

Dimensions in inches [mm]

	Test Plate Nominal Thickness, Tp			Test Pipe	
	Tp ≤ 1 in [25 mm]	1 in [25 mm] < Tp < 1-1/2 in [38 mm]	Tp ≥ 1-1/2 in [38 mm]	2 in [50 mm] & 3 in [75 mm] Diameter	6 in [150 mm] & 8 in [200 mm] Diameter or Larger Job Size Pipe
A—Length of reduced section	Widest face of weld + 1/2 in [12 mm], 2-1/4 in [60 mm] min.			Widest face of weld + 1/2 in [12 mm], 2-1/4 in [60 mm] min.	
L—Overall length, min[a]	As required by testing equipment			As required by testing equipment	
W—Width of reduced section[b,c]	3/4 in [20 mm] min.	3/4 in [20 mm] min.	3/4 in [20 mm] min.	1/2 ± 0.01 (12 ± 0.025)	3/4 in [20 mm] min.
C—Width of grip section[c,d]	W + 1/2 in [12 mm] min.	W + 1/2 in [12 mm] min.	W + 1/2 in [12 mm] min.	W + 1/2 in [12 mm] min.	W + 1/2 in [12 mm] min.
t—Specimen thickness[e,f]	Tp	Tp	Tp/n (Note f)	Maximum possible with plane parallel faces within length A	
r—Radius of fillet, min.	1/2 in [12 mm]	1/2 in [12 mm]	1/2 in [12 mm]	1 in [25 mm]	1 in [25 mm]

[a] It is desirable, if possible, to make the length of the grip section large enough to allow the specimen to extend into the grips a distance equal to two-thirds or more of the length of the grips.

[b] The ends of the reduced section shall not differ in width by more than 0.004 in [0.1 mm]. Also, there may be a gradual decrease in width from the ends to the center, but the width of either end shall not be more than 0.015 in [0.38 mm] larger than the width at the center.

[c] Narrower widths (W and C) may be used when necessary. In such cases, the width of the reduced section should be as large as the width of the material being tested allows. If the width of the material is less than W, the sides may be parallel throughout the length of the specimen.

[d] For standard plate-type specimens, the ends of the specimen shall be symmetrical with the center line of the reduced section within 1/4 in [6 mm].

[e] The dimension t is the thickness of the specimen as provided for in the applicable material specifications. The minimum nominal thickness of 1-1/2 in [38 mm] wide specimens shall be 3/16 in [5 mm] except as allowed by the product specification.

[f] For plates over 1-1/2 in [38 mm] thick, specimens may be cut into approximately equal strips. Each strip shall be at least 3/4 in [20 mm] thick. The test results of each strip shall meet the minimum requirements.

Note: Due to limited capacity of some tensile testing machines, alternate specimen dimensions for Table 6.9 steels may be used when approved by the Engineer.

Figure 6.10—Reduced-Section Tension Specimens (see 6.10.3.4)

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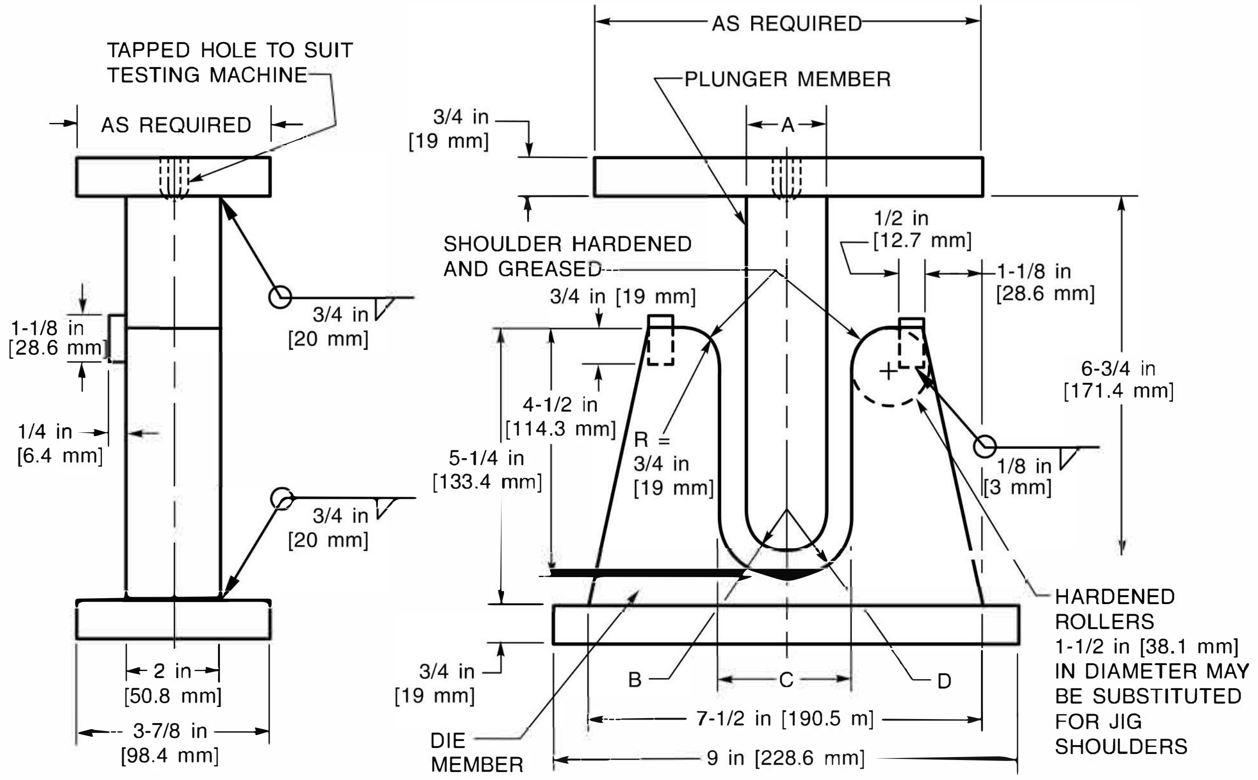

Specified or Actual Base Metal Yield Strength	A in [mm]	B in [mm]	C in [mm]	D in [mm]
50 ksi [345 MPa] & under	1-1/2 [38.1]	3/4 [19.0]	2-3/8 [60.3]	1-3/16 [30.2]
over 50 ksi [345 MPa] to 90 ksi [620 MPa]	2 [50.8]	1 [25.4]	2-7/8 [73.0]	1-7/16 [36.6]
90 ksi [620 MPa] & over	2-1/2 [63.5]	1-1/4 [31.8]	3-3/8 [85.7]	1-11/16 [42.9]

Note: Plunger and interior die surfaces shall be machine-finished.

Figure 6.11—Guided Bend Test Jig (see 6.10.3.1)

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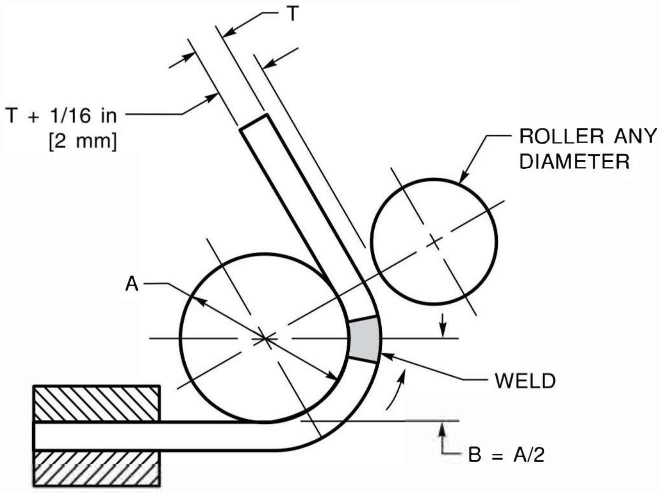
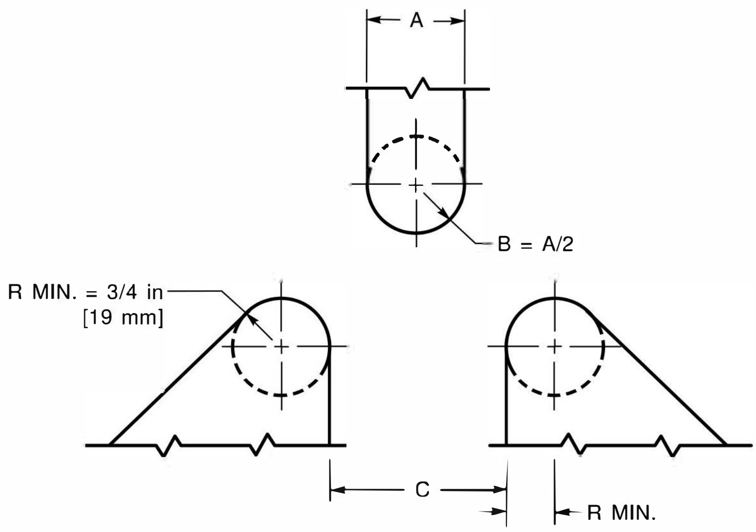


Specified or Actual Base Metal Yield Strength, ksi [MPa]	A in	B in	A mm	B mm
50 [345] & under	1-1/2	3/4	38.1	19.0
over 50 [345] to 90 [620]	2	1	50.8	25.4
90 [620] over	2-1/2	1-1/4	63.5	31.8

Figure 6.12—Alternative Wraparound Guided Bend Test Jig (see 6.10.3.1)



Specified or Actual Base Metal Yield Strength, ksi [MPa]	A in	B in	C in	A mm	B mm	C mm
50 [345] & under	1-1/2	3/4	2-3/8	38.1	19.0	60.3
over 50 [345] to 90 [620]	2	1	2-7/8	50.8	25.4	73.0
90 [620] & over	2-1/2	1-1/4	3-3/8	63.5	31.8	85.7

Figure 6.13—Alternative Roller-Equipped Guided Bend Test Jig for Bottom Ejection of Test Specimen (see 6.10.3.1)

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