

AWS D15.1/D15.1M:2012
An American National Standard

Railroad Welding Specification for Cars and Locomotives



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Railroad Welding Specification for Cars and Locomotives

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Prepared by the
American Welding Society (AWS) D15 Committee on Railroad Welding

Under the Direction of the
AWS Technical Activities Committee

Approved for Publication by the
AWS Board of Directors

Abstract

This specification establishes minimum standards for the manufacture and maintenance of railroad equipment. Clauses 4 through 17 cover the general requirements for welding in the railroad industry. Clauses 18 through 24 cover specific requirements for the welding of base metals thinner than 1/8 in [3 mm].



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Foreword

This foreword is not part of AWS D15.1/D15.1M:2012, *Railroad Welding Specification for Cars and Locomotives*, but is included for informational purposes only.

This specification establishes minimum standards for the manufacture and maintenance of railroad equipment. It was developed and is maintained by the D15 Committee on Railroad Welding of the American Welding Society.

Welding of railroad components is vital to the industry. An investigating committee was formed in 1982 which recommended a Railroad Welding Committee be formed to establish minimum welding standards for the industry. This recommendation was made because of confusion and incompleteness of the existing welding specifications and guides as applied to the railroad industry needs. The committee is made up of individuals from all segments of the railroad industry: both users and suppliers, the general public, and representatives of the Association of American Railroads.

The purpose of this specification is to provide a single comprehensive document of welding data that will be used throughout the railroad industry. Also, it should contribute to improvements in welding quality and performance. This document includes data from AWS D1.1/D1.1M, *Structural Welding Code—Steel*; AWS D1.2/D1.2M, *Structural Welding Code—Aluminum*; AWS D1.3/D1.3M, *Structural Welding Code—Sheet Steel*; and AWS D1.6/D1.6M, *Structural Welding Code—Stainless Steel*.

AWS D15.1-86 was titled simply *Railroad Welding Specification*. For the 1993 revision, the suffix *Cars and Locomotives* was added because the locomotive section had been introduced. A later revision was published in 2001, AWS D15.1:2001. The welding of rail is addressed in AWS D15.2, *Recommended Practice for the Welding of Rails and Related Rail Components for Use by Rail Vehicles*.

Several significant modifications have been made in AWS D15.1/D15.1M:2012. A vertical line in the margin indicates a revision from the 2007 edition. Limitations of essential variables for welding procedure qualification and welder performance qualification have been set up in table format (Tables 10.1 and 11.1, respectively). Friction stir welding has been included in the list of approved welding processes. Additional prequalified joint details for FCAW and GMAW have been added (see Figures 7.1G and 7.2A). Table 17.1 (Weld Crater Limitations) has been added. Clause 18 (Welding of Sheet Metal) has been revised.

Comments and suggestions for the improvement of this standard are welcomed. They should be sent to the Secretary, AWS D15 Committee on Railroad Welding, American Welding Society, 8669 Doral Blvd., Doral, FL 33166.

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Railroad Welding Specification for Cars and Locomotives

1. General Requirements

1.1 Scope. This specification covers the minimum welding requirements applicable to welded structures and cast components used in the railroad industry. It is not intended to apply to tank car tanks nor to the welding of rails. Recommended practices for welding railroad rails and related components are included in D15.2, *Recommended Practice for the Welding of Rails and Related Rail Components for Use by Rail Vehicles*. Specifications for welding tank car tanks and components welded directly thereto are outlined in the AAR *Manual of Standards and Specifications for Welding*, Section C—Part III, Specification M-1002 (AAR M-1002 C-III).

Welding symbols shall be those shown in the latest edition of AWS A2.4, *Standard Symbols for Welding, Brazing, and Nondestructive Examination*.

1.2 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.

1.3 Safety. Safety and health issues and concerns are beyond the scope of this standard; some safety and health information is provided, but such issues are not fully addressed herein.

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) Material Safety Data Sheets supplied by materials manufacturers
- (2) Operating Manuals supplied by equipment manufacturers

Applicable Regulatory Agencies

2. Normative References

The standards listed below contain provisions that, through reference in this text, constitute mandatory provisions of this AWS standard. 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:¹

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*;

¹ AWS standards are published by the American Welding Society, 8669 Doral Blvd., Doral, FL 33166.

AWS A5.01M/A5.01, *Procurement Guidelines for Consumables—Welding and Allied Processes—Flux and Gas Shielded Electrical Welding Processes*;

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

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

AWS A5.9/A5.9M, *Specification for Bare Stainless Steel Welding Electrodes and Rods* ;

AWS A5.10/A5.10M, *Specification for Bare Aluminum and Aluminum Alloy Welding Electrodes and Rods* ;

AWS A5.17/A5.17M, *Specification for Carbon Steel Electrodes and Fluxes for Submerged Arc Welding* ;

AWS A5.18/A5.18M, *Specification for Carbon Steel Filler Metals for Gas Shielded Arc Welding* ;

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

AWS A5.22/A5.22M, *Specification for Stainless Steel Electrodes for Flux Cored Arc Welding and Stainless Steel Flux Cored Rods for Gas Tungsten Arc Welding*;

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

AWS A5.28/A5.28M, *Specification for Low-Alloy Steel Electrodes and Rods for Gas Shielded Arc Welding* ;

AWS A5.29/A5.29M, *Low Alloy Steel Electrodes for Flux Cored Arc Welding*;

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

AWS B1.10M/B1.10, *Guide for Nondestructive Examination of Welds*;

AWS B2.1/B2.1M, *Specification for Welding Procedure and Performance Qualification* ;

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

AWS C4.6M (ISO 9013), *Thermal Cutting—Classification of Thermal Cuts—Geometric Product Specification and Quality Tolerances*;

AWS C5.3, *Recommended Practices for Air Carbon Arc Gouging and Cutting* ;

AWS C5.4, *Recommended Practices for Stud Welding* ;

AWS C5.10/C5.10M, *Recommended Practices for Shielding Gases for Welding and Cutting* ;

AWS D1.1/D1.1M, *Structural Welding Code—Steel*;

AWS D1.2/D1.2M, *Structural Welding Code—Aluminum*;

AWS D1.3/D1.3M, *Structural Welding Code—Sheet Steel*;

AWS D1.5M/D1.5, *Bridge Welding Code*;

AWS D1.6/D1.6M, *Structural Welding Code—Stainless Steel*; and

AWS D17.3/D17.3M, *Specification for Friction Stir Welding of Aluminum Alloys for Aerospace Application* .

American National Standards Institute (ANSI) standard:²

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

Association of American Railroads (AAR) standards:³

AAR M-1002, *Specification for Tank Cars*, Appendix W;

² This ANSI standard is published by the American Welding Society, 8669 Doral Blvd., Doral, FL 33166.

³ AAR standards are published by the Association of American Railroads, TTCL, Technical Standards Publications, P.O. Box 11130, Pueblo, CO 81001.

AAR RP-301, *Specification for the Application of Truck Bolster Vertical Wear Liners on Cars with 6" × 11" Journals*;

AAR S-137, *Specification for Coupler Shank Wear Plates and Application* ;

AAR S-269, *Coupler Carrier Wear Plate*;

AAR S-305, *Specification for Surfaces of Truck Center Plates and the Application of Wear Liners on Cars with 6-1/2" × 12" or Larger Journals*;

AAR S-308, *Specification for the Application of Two- Piece Horizontal and Vertical Wear Liners on Cars with 6-1/2" × 12" or Larger Journals*;

AAR S-320, *Specification for the Application of Side Frame Column Friction Wear Plates* ;

AAR S-327, *Side Frame Roof Repair*;

AAR S-402, *Specification for the Welding of Air Brake Pipe and Fittings for Railroad Cars* ;

AAR *Field Manual of Interchange Rules*; and

AAR *Manual of Standards and Recommended Practices*, Section C-II.

ASME International standards:⁴

ASME *Boiler and Pressure Vessel Code*, Section V;

ASME *Boiler and Pressure Vessel Code*, Section VIII; and

ASME *Boiler and Pressure Vessel Code*, Section IX.

ASTM International Standards:⁵

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

ASTM A488, *Practice for Steel Castings, Welding, Qualifications of Procedures and Personnel* ;

ASTM B548, *Method and Specifications for Ultrasonic Inspection of Aluminum—Alloy Plate for Pressure Vessels* ;

ASTM E94, *Guide for Radiographic Testing*;

ASTM E165, *Practice for Liquid Penetrant Inspection Method*;

ASTM E709, *Practice for Magnetic Particle Examination* ;

ASTM E747, *Standard Practice for Design, Manufacture and Material Grouping Classification of Wire Image Quality Indicators (IQI) Used for Radiology*; and

ASTM E1032, *Standard Test Method for Radiographic Examination of Weldments* .

Canadian Standards Association:⁶

CSA W47.1, *Certification of Companies for Fusion Welding of Steel Structures* ; and

CSA W47.2, *Certification of Companies for Fusion Welding of Aluminum Railroad Locomotive Safety Standards and Locomotive Inspection* (49 CFR Part 229).

⁴ ASME standards are published by ASME International, 3 Park Avenue, New York, NY 10016-5990.

⁵ ASTM standards are published by ASTM International, 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959.

⁶ CSA standards are published by the Canadian Standards Association, 178 Rexdale Boulevard, Toronto, Ontario, Canada, M9W 1R3.

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 accommodate usage specific to this document.

cast component. A carbon or alloy steel casting manufactured for locomotive and car equipment.

company. The organization performing welding, including all facilities under common ownership that utilizes the same program of welding standards and documentation (see 5.2.3, 9.4.1, and 9.4.2).

designated inspector (fabrication or production inspector). The individual who is given responsibility by the manufacturer to inspect welding operations and completed welds. Inspection may or may not be the individual's sole responsibility.

essential variables. Those welding parameters considered critical to the welding operation. A change outside of the specified range requires requalification of the welding procedure specification.

fabrication inspection. Tests performed as necessary prior to assembly, during welding, and after welding to ensure that the materials and workmanship meet the requirements of the applicable contract or specification and standard documents.

fabrication inspector. See **designated inspector**.

Fabricator's Engineer. A designated individual with design authority employed by the fabricator, manufacturer, or outside repair facility who is responsible for the ongoing activities within the scope of the specification.

fillers. A nonconsumed metallic strip or bar used in a lap or T-joint to reduce a gap (see Figures 5.1 and 5.3).

fusion-type discontinuity. Slag inclusions, incomplete fusion, or similar discontinuities resulting in incomplete fusion between weld metal and base metal or between weld beads.

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

manufacturer. The original builder, fabricator, or installer of equipment, as well as any company or organization performing repairs or alterations to such equipment.

multiple electrodes. The combination of two or more single or parallel electrode systems used to produce a weld bead. Each of the component systems may have its own independent power source and its own electrode feeder.

Owner. The individual or company that exercises legal ownership of the product or structural assembly produced under this specification.

Owner's Engineer. A designated individual or company with engineering authority that represents or is employed by the Owner, operating railroad, or purchaser, as applicable.

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 electrodes.

pipe. Tubular-shaped product of circular cross section.

piping porosity. Elongated porosity whose major dimension lies in a direction approximately normal to the weld surface. Piping porosity frequently is referred to as "pin holes" when the porosity extends to the weld surface.

production inspector. See **designated inspector**.

tank car tank. Consists of a shell, heads, and sump, together with the welds joining them.

verification inspector. The duly designated person who acts on behalf of the Owner or purchaser on all inspection and quality matters within the scope of the contract documents.

4. General Information

4.1 Base Metals. AWS B2.1/B2.1M, *Specification for Welding Procedure and Performance Qualification*, provides an extensive list of materials grouped into categories to minimize the number of qualification tests required. This in no way implies that materials in one group are interchangeable or equivalent for any given application. See Annex A for additional materials specific to this specification.

4.2 Since railroad equipment may be coated with lead base paint, all suspect coatings shall be removed in a safe manner prior to welding.

4.3 Clauses 1 through 17 give the general requirements for welded construction for metal components 1/8 in [3 mm] or greater in thickness. Unless otherwise stated, these requirements apply to all freight cars, locomotives, and passenger train vehicles. Clauses 18 through 23 cover specific requirements for the welding of base metals less than 1/8 in [3 mm] in thickness. 11 gauge (0.1196 in [3.04 mm]) material may be considered 1/8 in [3 mm] plate or sheet steel.

4.4 Companies shall be responsible for the quality of the welding done by their organization and their subcontractors and shall perform whatever tests are necessary beyond the requirements of this specification to assure that the welds achieve requirements of the design.

4.5 Requirements contained herein constitute acceptable industrial practices. They are not intended as a substitute for engineering judgment with respect to the suitability of application of listed joints to a welded structure.

4.6 Additionally, they are not intended to nullify or void any rules or requirements contained in the U.S. Department of Transportation Locomotive Inspection Act (45 USC-22), or the Federal Railroad Administration's *Railroad Locomotive Safety Standards and Locomotive Inspection* (49 CFR Part 229). Requirements contained herein are not intended to nullify or void the requirements of any law or governmental agency regulation nor any specification of the Association of American Railroads.

4.7 All references to the need for approval shall be interpreted to mean approval by either the Fabricator's Engineer or the Owner's Engineer, as defined in Clause 3, Terms and Definitions. It is understood that in some cases and under some specific contracts, approval will need to be obtained by both the Fabricator's Engineer and the Owner's Engineer. In such cases, the references assigned to only one entity shall apply to both entities.

4.8 Specific areas of application to locomotives and passenger train vehicles include, but are not limited to the following:

(1) Structural components including primary and secondary load-bearing members of the locomotive under-frame, center plate bearings, truck bolsters, draft gear pockets, equipment bases and supports, collision posts, main generators (alternator), traction motor frames, and car body structures.

(2) Air reservoirs not covered by the provisions of the ASME *Boiler and Pressure Vessel Code*.

(3) Fuel tank manufacture and repair.

(4) Air compressor and air system piping.

(5) Electrical components including eddy current clutches, reverser contacts, and motor commutator terminations.

4.9 Engines and engine components may require specialized processes and procedures unique to the original equipment manufacturer. Repair or rework of the engine and its components shall be in accordance with the original equipment manufacturer's specification, or equivalent.

4.10 The repair and reconditioning of specific car components are described in the AAR *Field Manual of Interchange Rules* and its referenced documents, which may include exceptions or additions, or both, to the provisions of this document (see 8.7).

4.11 Design of joints subject to fatigue loading is outside the scope of this specification. For freight cars and their components requiring fatigue analysis, refer to Chapter VII, "Fatigue Design of Freight Cars," of AAR *Manual of Standards and Recommended Practices*, Section C-II, Volume I.

5. Requirements for All Welding

5.1 Processes. The welding processes covered by Clauses 1 through 17 are shielded metal arc welding (SMAW), submerged arc welding (SAW), gas metal arc welding (GMAW), flux cored arc welding (FCAW), and gas tungsten arc welding (GTAW). This does not preclude the use of other welding processes in the construction, alteration, or repair of railroad components. However, the requirements for the design, qualification, inspection, and testing related to the use of such processes are the responsibility of the Fabricator's Engineer. The company wishing to use such processes shall generate documented evidence to justify their use and to define the essential variables.

5.1.1 Friction Stir Welding (FSW). When using FSW for fabrication purposes in the railcar industry, AWS D17.3/D17.3M:2010, *Specification for Friction Stir Welding of Aluminum for Aerospace Applications*, may be used as a guide for the development of procedure, welding operator, fabrication, and inspection requirements. The resolution of discrepancies between the requirements of this document and AWS D17.3/D17.3M shall be agreed upon by the customer and Fabricator's Engineer. These differences may include, but are not limited to, weld classes, essential variables in procedure qualification, eye examinations and period of effectiveness in welding operator qualification, calibration of welding equipment, qualifications of NDT personnel, NDT inspection requirements for each class of weld, and the acceptance criteria for each class of weld.

5.2 Welding Procedure Qualification

5.2.1 Welding of steels listed in Clauses 7 and 8, Tables 8.1 and 8.2, using SMAW, SAW, GMAW (except short circuiting transfer), and FCAW procedures conforming to the provisions of Clauses 5 through 8 shall be deemed as prequalified and are therefore approved for use without performing procedure qualification tests. Standard Welding Procedure Specifications (SWPSs) published by the AWS Committee on Welding Qualification in accordance with AWS B2.1/B2.1M, *Standard for Welding Procedure and Performance Qualification*, shall also be accepted. The use of Prequalified Welding Procedure Specifications (PWPSs) and Standard Welding Procedure Specifications (SWPSs) is not intended as a substitute for engineering judgment with respect to the suitability of application of these procedures to a welded assembly or weld repair.

5.2.2 Other materials or welding procedure specifications using one of the processes covered by this specification may be used, provided they are qualified by applicable tests as prescribed in Clause 10. The acceptability of qualification to other standards is the Fabricator's Engineer's responsibility, to be exercised based upon the specific structure, or service conditions, or both.

5.2.3 Qualification of a procedure by one company shall not qualify that procedure for any other company (see 9.4.1), unless the company that developed the qualified procedure contracts with a second company to perform the welding to that procedure.

5.2.4 Proprietary procedures for the manufacture of new engine blocks qualified in accordance with the manufacturer's requirements are the responsibility of the manufacturer.

5.2.5 This specification does not define prequalified joints and welding procedure specifications for base metals less than 1/8 in [3 mm] thick. Welding procedure specifications for these materials are qualified in accordance with 18.2.

5.3 Qualification of Welders and Welding Operators

5.3.1 All welders (including tack welders) and welding operators performing work in accordance with this specification shall be qualified in accordance with 9.3, except for those cases defined in 5.3.2 or 5.3.3.

5.3.2 Welders or welding operators who are qualified for the materials, processes, and procedures being used in accordance with one of the following specifications shall be considered qualified to weld within limitations of the essential variables and method of testing specimens of this specification:

- (1) ASME, *Boiler and Pressure Vessel Code*, Section IX
- (2) AAR M-1002, *Specification for Tank Cars*, Appendix W
- (3) AWS D1.1/D1.1M, *Structural Welding Code—Steel*
- (4) AWS D1.2/D1.2M, *Structural Welding Code—Aluminum*
- (5) AWS D1.3/D1.3M, *Structural Welding Code—Sheet Steel*

- (6) AWS D1.5M/D1.5, *Bridge Welding Code*
- (7) AWS D1.6/D1.6M, *Structural Welding Code—Stainless Steel*
- (8) ASTM A488, *Practice for Steel Castings, Welding, Qualifications of Procedures and Personnel*
- (9) AWS B2.1/B2.1M, *Specification for Welding Procedure and Performance Qualification* (qualification by visual inspection alone is prohibited)
- (10) CSA W47.1, *Certification of Companies for Fusion Welding of Steel Structures*
- (11) CSA W47.2, *Certification of Companies for Fusion Welding of Aluminum*

5.3.3 If the operator of a totally automated welding machine has no control over welding variables and no control over the location of the filler metal or heat source, then the operator does not have to be qualified.

5.4 Design of Welded Joints

5.4.1 Drawings and Welding Procedure Specifications

5.4.1.1 When drawings are specified, complete information regarding location, type, and extent of welds shall be clearly documented. Detailed drawings or welding procedure specifications shall indicate clearly, by welding symbols or sketches, details of welded joints and preparation of base material. Width and thickness of fused metallic backing shall be detailed. Where welding symbols do not adequately define requirements, sketches or notes shall be provided.

5.4.1.2 Drawings should note those joints or groups of joints where it is especially important that welding sequence and technique be controlled carefully to minimize shrinkage stresses and distortion.

5.4.1.3 All welding shall be performed in accordance with a written welding procedure specification that meets the requirements of Clauses 7 and 8, for prequalified steel joints or has been qualified in accordance with Clause 10 (see also 5.2.1). A welding procedure specification may cover a range of qualified joint dimensions and welding conditions.

5.4.1.4 When there are special inspection requirements, these shall be noted on the drawings, in the welding procedure specification, or in the contract specification.

- (1) All Class 1 welds shall be identified on the drawing.

5.4.2 Effective Weld Areas, Lengths, and Sizes

5.4.2.1 Groove Welds. The effective area shall be the effective weld length multiplied by the groove weld size.

- (1) The effective weld length for any groove weld shall be the length of the specified weld.
- (2) The effective size of a complete joint penetration groove weld shall be the thickness of the thinner part joined. No increase is permitted for weld reinforcement.
- (3) The effective size of a partial joint penetration groove weld shall be defined by 7.1 for prequalified procedures or in accordance with 10.6.2.
- (4) The minimum weld size for all partial joint penetration groove welds shall conform to Table 5.1.
- (5) Partial penetration groove welds made from one side shall be designed to prevent tension across the weld root.

5.4.2.2 Fillet Welds. The effective area is the effective weld length measured through the centerline of the theoretical throat multiplied by the theoretical throat. Stress in a fillet weld shall be considered as applied to this effective area, for any direction of applied load. The theoretical throat is the minimum distance minus any convexity between the joint root and the face of fillet weld.

- (1) The minimum length of any fillet weld segment shall be four times the nominal weld size but not less than 1-1/2 in [38 mm] unless limited by part size. In joints connected only by fillet welds, the minimum size of fillet weld to be used shall be as shown in Table 7.2.

- (2) The effective length of a fillet weld is the length of the full size fillet (specified size). No reduction in effective length shall be made for either the start or termination of the weld if the weld is full size throughout its length.

(3) The effective length of a curved fillet weld shall be measured along the centerline of the effective throat. If the weld area of a fillet weld in a hole or slot computed from this length is greater than the area found in 5.4.2.3, the hole or slot area shall be used as the effective area of the fillet weld.

(4) Fillet welds in holes or slots in lap joints shall be in accordance with 5.4.4.2 and shall not be considered as plug or slot welds.

(5) Fillet welds used in skewed T-joints shall be in accordance with 5.4.4.3.

NOTE: Annex C2 contains a formula governing the calculation of effective weld sizes for fillet welds in skewed T-joints. A convenient tabulation of measured legs (W) and acceptable root openings (R) related to effective weld sizes (E) has been provided for dihedral angles between 60° and 135°.

5.4.2.3 Combination Groove and Fillet Welds. The effective throat of a combination partial joint penetration groove weld and fillet weld is the shortest distance from the weld root to the face of the weld, less any convexity (minus 1/8 in [3 mm] for any prequalified groove details requiring such deduction) (see Annex C1).

(1) Limits for fillet weld convexity and concavity are found in 6.4.1.

5.4.2.4 Plug and Slot Welds

(1) The effective area is the nominal area of the hole or slot in the plane of the faying surface.

(2) Plug or slot welds may be used as follows:

- (a) To transmit shear in a lap joint
- (b) To prevent buckling of lapped joint members
- (c) To join component members
- (d) To repair worn members

(3) The minimum center-to-center spacing of plug welds shall be four times the diameter of the hole.

(4) 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 containing it, except those ends which extend to the edge of the joint member.

(5) 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 line spacing in a longitudinal direction on any line shall be two times the length of the slot.

(6) For material less than 1/4 in [6 mm] thick, the depth of filling shall be equal to the thickness. The depth of filling of plug or slot welds in materials 1/4 in to 5/8 in [6 mm to 16 mm] thick shall be equal to the thickness of the base material to 1/16 in [2 mm] under. In material over 5/8 in [16 mm] in thickness it shall be at least one-half the thickness of the base metal, but not less than 5/8 in [16 mm]. In any case, minimum depth of filling need not exceed the thickness of the underlying material.

(7) The allowable loads on plug welds of base metal less than 1/4 in [6 mm] thick shall be limited as follows:

$$P \leq 0.88TDF_B \text{ and } P \leq 0.24D^2F_W$$

where

P = Allowable load, pound force [Newtons]

D = Hole diameter, in [mm]

T = Base metal thickness, in [mm]

F_B = Minimum tensile strength of base metal, psi [MPa] from the applicable material specification

F_W = Minimum tensile strength of weld metal as specified in the applicable AWS Classification, psi [MPa]

5.4.3 Filler Plates

5.4.3.1 Filler plates may be used only in accordance with Figures 5.1 and 5.3 and as described in 5.4.3.2 and 5.4.3.3.

5.4.3.2 A filler plate less than 1/4 in [6 mm] thick shall not be used to transfer stress but shall be kept flush with the welded edges of the stress-carrying joint member. The sizes of welds along such edges shall be increased over the required sizes by an amount equal to the thickness of the filler (see Figure 5.1).

5.4.3.3 Any filler plate 1/4 in [6 mm] or more in thickness shall extend beyond the edges of the joint member and comply with the requirements of Figure 5.3.

5.4.4 Details of Fillet Welds

5.4.4.1 For fillet welds in lap joints, if the fillet size equals the thickness of the edge being welded, there is the possibility of the weld size not being as large as it appears because of edge melting. It is a common practice in material 1/4 in [6 mm] or greater to keep the fillet size 1/16 in [2 mm] less than the thickness to avoid this problem. When this practice is not followed, precautions should be taken to assure the needed throat size [see Figure 5.4(B)].

5.4.4.2 Fillet welds in holes or slots in lap joints may be used to transfer shear or to prevent buckling or separation of lapped joint members. Fillet welds in holes or slots are not to be considered as plug or slot welds.

5.4.4.3 Fillet welds may be used in skewed T-joints having a dihedral angle (Ψ) of not less than 60° nor more than 135° [see Figure 5.4(A) and Annex C2].

5.4.5 Intermittent Fillet Welds

5.4.5.1 Intermittent fillet welds should be avoided in primary load-carrying members.

5.4.5.2 Intermittent fillet welds may be used to transfer calculated stress across a joint or faying surfaces when the strength required is less than that developed by a continuous fillet weld of the smallest permitted size, and to join components of built-up members.

5.4.5.3 The effective length of any segment of intermittent fillet welding shall be not less than four times the weld size, with a minimum of 1-1/2 in [38 mm].

5.4.6 Lap Joints

5.4.6.1 The minimum width of laps on lap joints should be five times the thickness of the thinner joint member and not less than 1 in [25 mm] (see Figure 5.2).

5.4.6.2 Lap joints joining plates or bars subjected to member axial load shall be fillet welded along the edge of both lapped members except where the deflection of the lapped members is sufficiently restrained to prevent opening of the joint under maximum loading (see Figure 5.2).

5.4.7 Mechanical Fasteners. Mechanical fasteners used in bearing type connections shall not be considered as sharing the stress in combination with welds; the welds shall be considered to carry the full load. Consideration should be given to applying bolts first to ensure alignment and limit distortion.

5.4.8 Design Considerations

5.4.8.1 Base Metals. Base metals listed in this standard are intended to be used as a guide in the selection of base metal for the intended application. It is not intended that suitable base metals described by other specifications should be excluded. Use of a base metal specifically described by the listed specifications is not mandatory, as specific designs, manufacturing, and service conditions may dictate the use of a base metal not so described.

5.4.8.2 Allowable Stress (Steel). Refer to Table 5.2 for the allowable design weld stresses.

5.4.8.3 Allowable Stress (Aluminum). The allowable design stresses for welded aluminum structures shall be determined as follows:

(1) Welding of structural aluminum alloys causes local or partial annealing which produces an area of lower strength along the heat-affected zone (HAZ). The resulting variation in mechanical properties in the vicinity of a weld is illustrated by the typical distribution shown in Figure 5.5. When designing welded load carrying members, this decrease in strength shall be taken into consideration in addition to the normal design rules. Allowable stresses for welded members (Table 5.3) shall be determined from the same formulas that are used for nonwelded members. In applying these formulas to welded structures, the tensile strength, δ_{tu} , shall be 90% of the weld qualification test value of strength, δ_{tw} but

not more than 90% of the strength values given in Table 5.3. The yield strengths, δt_y and δc_y , shall be the tensile and compressive yield strengths, δt_{yw} and δc_{yw} , given in Table 5.4.

(2) If less than 15% of the area of a given cross section lies within 1 in [25 mm] of a weld, regardless of material thickness, the effect of welding may be neglected and allowable stresses calculated assuming nonwelded construction. If A_w is equal to or greater than 15% of A , the allowable stress shall be calculated from the following:

$$\delta pw = \delta n - \frac{A_w(\delta n - \delta w)}{A} \quad (\text{Eq. 1})$$

where

δpw = allowable stresses on cross section, part of whose area lies within 1.0 in [25 mm] of a weld

δn = allowable stress for cross section 1.0 in [25 mm] or more from weld (Table 5.5)

δw = allowable stress for cross section if entire area were to lie within 1.0 in [25 mm] of a weld (Table 5.4)

A_w = area of cross section lying within 1.0 in [25 mm] of a weld

A = net area of cross section of a tension flange of a beam, or gross area of cross section of a compression member or compression flange of a beam (a beam flange is considered to consist of that portion of the member further than $2c/3$ from the neutral axis, where c is the distance from the neutral axis to the extreme fiber)

5.4.8.4 Copper-Bearing Steel. When a copper-bearing steel is used and weldability is a factor, it is preferable that the copper content of the base metal does not exceed 0.30%.

5.5 Consumables

5.5.1 Condition. Welding consumables that have been removed from the original package shall be protected and stored so that the welding properties are not affected. Electrodes shall be dry and in condition suitable for use.

5.5.2 Certification. When requested by the Owner's Engineer, the manufacturer shall furnish certification that the filler metal or flux or combination meets the requirements of the appropriate AWS filler metal specification.

5.5.3 Flux for Submerged Arc Welding. Flux used for submerged arc welding shall be dry and free of contamination from dirt, mill scale, or other foreign material. All flux shall be purchased in packages that can be stored, under normal conditions, for at least six months without such storage affecting welding characteristics or weld properties. Flux from damaged packages shall be discarded or shall be dried at a minimum temperature of 500°F [260°C] for one hour before use. Flux that has been wet shall not be used.

5.5.3.1 Recrushed Slag. Recrushed slag may be used provided it has its own marking, using the recrusher's name and trade designation. In addition, each dry batch or dry blend (lot) of flux, as defined in AWS A5.01/A5.01M, *Filler Metal Procurement Guidelines*, shall be tested in conformance with Schedule I of AWS A5.01/A5.01M and classified by the manufacturer or recrusher per AWS A5.17/A5.17M or A5.23/A5.23M, as applicable.

5.5.4 Conformance. Welding electrodes, rods, and flux-electrode combinations shall conform to the applicable AWS filler metal specification.

5.5.5 Shielding Gas. Shielding gases shall conform to the requirements of AWS A5.32M/A5.32, (ISO 14175:2008 MOD), *Welding Consumables—Gases and Gas Mixtures for Fusion Welding and Allied Processes*.

5.5.5.1 For ferrous metals, the gas or gas mixture used for shielding shall have a dew point of -40°F [-40°C] or lower.

5.5.6 Low Hydrogen Shielded Metal Arc Welding Electrodes

5.5.6.1 All low hydrogen electrodes shall be purchased in hermetically sealed containers or shall be baked as prescribed below. After hermetically sealed containers are opened, electrodes shall be consumed or placed in a storage oven held at a temperature of at least 250°F [121°C].

5.5.6.2 Baking Electrodes. Electrodes not purchased in hermetically sealed containers, electrodes from damaged containers and electrodes exposed to the atmosphere for periods greater than those permitted in Table 5.6 shall be baked as follows:

(1) All electrodes having low hydrogen coverings conforming to AWS A5.1/A5.1M shall be baked for at least two hours between 500°F and 800°F [260°C and 427°C], or

(2) All electrodes having low hydrogen coverings conforming to AWS A5.5/A5.5M shall be baked for at least one hour at temperatures between 700°F and 800°F [371°C and 427°C].

Low hydrogen electrodes shall be rebaked no more than one time. Electrodes that have been wet shall not be used.

5.5.6.3 Approved Atmospheric Exposure Time Periods. After hermetically sealed containers are opened or after electrodes are removed from baking or storage ovens, the electrode exposure to the atmosphere shall not exceed the times shown in Table 5.6, Column A for the specific electrode classification including those having optional supplemental designators. Electrodes exposed to the atmosphere for periods less than those allowed by Table 5.6, Column A may be returned to a storage oven maintained at 250°F [121°C] min.; after a minimum storage period of four hours, the electrodes may be reissued.

5.5.6.4 Alternative Atmospheric Exposure Time Periods Established by Tests. Alternative exposure time values shown in Table 5.6, Column B may be used provided testing establishes the maximum allowable time. The testing shall be performed in accordance with the latest edition of AWS A5.5/5.5M, for each electrode classification and each electrode manufacturer. Such tests shall establish that after exposure, the maximum moisture content values of AWS A5.1/A5.1M or AWS A5.5/A5.5M as applicable, are not exceeded. These electrodes shall not be used at combinations of relative humidity and temperature that exceed either the relative humidity or moisture content in the air that prevailed during the testing program.

For proper application of 5.5.6.4, any standard psychrometric chart shall be used in the determination of temperature-relative humidity limits.

5.5.6.5 Electrode Restrictions for M11 Steels. When used for welding M11 steels (refer to AWS B2.1/B2.1M, *Specification for Welding Procedure and Performance Qualification*), electrodes of any classification lower than E100XX should be dried for at least one hour at temperatures between 700°F and 800°F [371°C and 427°C] before being used. Alternatively, special low-moisture content electrodes may be purchased.

Table 5.1
Minimum Weld Size for Partial Joint Penetration Groove Welds

Base Metal Thickness of Thicker Part Joined, in [mm]	Minimum Weld Size, in ^a [mm ^a]
1/8 to 3/16 [3 to 5] incl.	1/16 [2]
Over 3/16 to 1/4 [Over 5 to 6] incl.	1/8 [3]
Over 1/4 to 1/2 [Over 6 to 13] incl.	3/16 [5]
Over 1/2 to 3/4 [Over 13 to 20] incl.	1/4 [6]
Over 3/4 to 1-1/2 [Over 20 to 38] incl.	5/16 [8]
Over 1-1/2 to 2-1/4 [Over 38 to 57] incl.	3/8 [10]
Over 2-1/4 to 6 [Over 57 to 150] incl.	1/2 [13]
Over 6 [Over 150] incl.	5/8 [16]

^a Except that the weld size need not exceed the thickness of the thinner part.

Table 5.2
Allowable Weld Stresses (Steel)

Kind of Stress	Base Metal	Required Filler Metal and Flux ^{b,c}	Allowable Design Stress ^a
Tension and compression parallel to axis of any complete penetration groove weld.	Any listed in Table 8.1	As specified in Table 8.1	Same as for base metal
Tension normal to effective area ^e of complete penetration groove weld.	Any listed in Table 8.1	As specified in Table 8.1	Same as allowable tensile stress for base metal
Compression normal to effective area ^e of complete or partial penetration groove weld.	Any listed in Table 8.1	As specified in Table 8.1	Same as allowable compressive stress for base metal
Shear effective area ^e of complete penetration groove weld and partial penetration groove weld. • Shear stress on effective area ^e of fillet weld regardless of direction of application of load ^f • Tension normal ^d to the axis on the effective throat of a partial-penetration groove weld ^f • Shear stress on the effective area of a plug or slot weld. ^f	Any listed in Table 8.1	As specified in Table 8.1	Same as allowable shear stress for base metal
	Class I of Table 8.1	As specified in Class I of Table 8.1	29.0 ksi [200 MPa]
	Class II of Table 8.1	As specified in Class II of Table 8.1	33.06 ksi [228 MPa]
	Class III of Table 8.1	As specified in Class III of Table 8.1	38.86 ksi [268 MPa]
	Class IV of Table 8.1	As specified in Class IV of Table 8.1	50.46 ksi [348 MPa]

^a These allowable design stresses are based on weld metal properties and do not include a factor of safety. This should be considered in any design using these allowable stress values.

^b The use of chromium-molybdenum filler metal is not recommended for structural components.

^c Only low hydrogen electrodes or their equivalent shall be used to weld ASTM A242, A441, A514, A517, A572, A588, A633, A656, and A709 steels.

^d Fillet welds and partial penetration groove welds joining the component elements of built-up members, such as flange-to-web connections, may be designed without regard to the tension or compressive stresses in those elements parallel to the axis of the weld.

^e See 5.4.2 for effective weld sizes for groove welds and for fillet welds.

^f The allowable stress, regardless of electrode classification used, shall not exceed that given in the table for the weaker base metal being joined.

Table 5.3
Allowable Weld Stresses (Aluminum)

Kind of Stress	Base Metal	Required Filler Metal	Design Stress ^a
Tension and compression parallel to axis of any complete penetration groove weld	Any listed in Tables 5.3 and 5.4	As specified in Annex E	See 5.4.8
Tension normal to weld axis of complete penetration groove welds	Any listed in Table 5.3	As specified in Annex E	See 5.4.8
Compression normal to weld size of complete or partial penetration groove weld	Any listed in Tables 5.3 and 5.4	As specified in Annex E	See 5.4.8
Shear on weld size of complete penetration groove weld and partial-penetration groove weld	Any listed in Tables 5.3 and 5.4	As specified in Annex E	See 5.4.8
Shear stress on effective throat fillet weld regardless of direction of application of load; tension normal not the axis on the effective throat of a partial penetration groove weld; and shear stress on effective area of a plug or slot weld	Any listed in Tables 5.3 and 5.4	As specified in Annex E	18.5 ksi [127 MPa] for ER5183 17.0 ksi [117 MPa] for ER5356 20.0 ksi [138 MPa] for ER5556 and ER5554 12.0 ksi [83 MPa] for ER5654

^a These design stresses are based on weld metal properties and do not include a factor of safety. This should be considered in any design using these design stress values.

Note: See 5.4.2 for effective weld sizes for groove welds and effective throats for fillet welds.

Table 5.4
Minimum Mechanical Properties for Welded Aluminum Alloys^a
(Gas Tungsten Arc or Gas Metal Arc Welding with No Postweld Heat Treatment)

Alloy and Temper	Product and Thickness Range in [mm]	Tension		Compression		Shear		Bearing	
		δ_{tut} ksi [MPa]	δ_{yw}^b ksi [MPa]	δ_{yw}^b ksi [MPa]	δ_{uw}^b ksi [MPa]	T_{uw} ksi [MPa]	T_{yw} ksi [MPa]	δ_{ruw} ksi [MPa]	δ_{bryw} ksi [MPa]
5052-H32, H34	All	25 [172]	13 [90]	13 [90]	16 [110]	7.5 [51]	7.5 [51]	50 [345]	19 [131]
5083-H111	Extrusions	39 [269]	21 [145]	20 [138]	23 [159]	12 [83]	12 [83]	78 [538]	32 [221]
-H116, H321	Sheet and Plate 0.188–1.500 [5–38]	40 [276]	24 [166]	24 [166]	24 [166]	14 [97]	14 [97]	80 [552]	36 [248]
-H116, H321	Plate 1.501–3.000 [38–76]	39 [269]	23 [159]	23 [159]	24 [166]	13 [90]	13 [90]	78 [538]	34 [234]
-H323, H343	Sheet	40 [276]	24 [166]	24 [166]	24 [166]	14 [97]	14 [97]	80 [552]	36 [248]
5086-H111	Extrusions	35 [241]	18 [124]	17 [117]	21 [145]	10 [69]	10 [69]	70 [483]	28 [193]
-H112	Plate 0.250–0.499 [6–13]	35 [241]	17 [117]	17 [117]	21 [145]	9.5 [66]	9.5 [66]	70 [483]	28 [193]
-H112	Plate 0.500–1.000 [13–25]	35 [241]	16 [110]	16 [110]	21 [145]	9 [62]	9 [62]	70 [483]	28 [193]
-H112	Plate 1.001–2.000 [25–51]	35 [241]	14 [97]	14 [97]	21 [145]	8 [55]	8 [55]	70 [483]	28 [193]
-H32, H34, H116	Sheet and Plate	35 [241]	19 [131]	19 [131]	21 [145]	11 [76]	11 [76]	70 [483]	28 [193]
5454-H111	Extrusions	31 [214]	16 [110]	15 [103]	19 [131]	9.5 [66]	9.5 [66]	62 [427]	24 [166]
-H112	Extrusions	31 [214]	12 [83]	12 [83]	19 [131]	7 [48]	7 [48]	62 [427]	24 [166]
-H32, H34	Sheet and Plate	31 [214]	16 [110]	16 [110]	19 [131]	9.5 [66]	9.5 [66]	62 [427]	24 [166]
6061-T6, T651, T6510, T6511 ^c	All	24 [166]	20 [138]	20 [138]	15 [103]	12 [83]	12 [83]	50 [345]	30 [207]
-T6, T651, T6510, T6511 ^d	Over 0.375 [10]	24 [166]	15 [103]	15 [103]	15 [103]	9 [62]	9 [62]	50 [345]	30 [207]
6063-T5, T6	All	17 [117]	11 [76]	11 [76]	11 [76]	6.5 [45]	6.5 [45]	34 [234]	22 [152]
6351-T5 ^e	Extrusions Over 0.375 [10]	24 [166]	20 [138]	20 [138]	15 [103]	12 [83]	12 [83]	50 [345]	30 [207]
-T5II ^d		24 [166]	15 [103]	15 [103]	15 [103]	9 [62]	9 [62]	50 [345]	30 [207]
7005-T5 ^e	Extrusions Up to 0.750 [19]	38 [262]	30 [207]	30 [207]	21 [145]	17 [117]	17 [117]	72 [496]	50 [344]

^a Filler metal used is that recommended in Annex E, Table E.3. Values of δ_{min} are weld qualification test values.

^b +0.2% weld joint mismatch in 10 in [254 mm] gage length across a butt weld.

^c Values when welded with 5183, 5356, or 5556 alloy filler metal regardless of thickness. Values also apply to thickness less than 0.375 in [10 mm] when welded with 4043, 5154, 5254, or 5554 alloy filler metal.

^d Values when welded with 4043, 5154, 5254, or 5554 alloy filler metal.

^e Values when welded with 5356 alloy filler metal.

Table 5.5
Minimum Mechanical Properties for Before Welding

Alloy and Temper	Product ^a	Thickness Range, in [mm]	Tension			Compression		Shear		Bearing		Compressive Modulus of Elasticity ^b E, ksi [MPa]
			δ_{tu}	δ_t	δ_{cy}	T_u	T_y	δ_{gru}	δ_{brv}			
5052-H32	Sheet and Plate	All	31 [214]	23 [159]	21 [145]	19 [131]	13 [90]	60 [414]	39 [269]	10 200 [70327]		
-H34	Rolled Rod and	All	34 [234]	26 [179]	24 [166]	20 [138]	15 [103]	65 [448]	44 [303]	10 200 [70327]		
-H36	Bar Draw Tube Sheet	0.006–0.162 [0.2–4]	37 [155]	29 [200]	26 [179]	22 [152]	17 [117]	70 [483]	46 [317]	10 200 [70327]		
5083-H111	Extrusions	up through 0.500 [13]	40 [276]	24 [166]	21 [145]	24 [166]	14 [97]	78 [538]	41 [283]	10 400 [71705]		
-H111	Extrusions	0.501 [13] and over	40 [276]	24 [166]	21 [145]	23 [159]	14 [97]	78 [538]	38 [262]	10 400 [71705]		
-H321, H116	Sheet and Plate	0.1888–1.500 [5–38]	44 [303]	31 [214]	26 [179]	26 [179]	18 [124]	84 [579]	53 [365]	10 400 [71705]		
-H321, H116	Plate	1.501–3.000 [13–76]	41 [283]	29 [200]	24 [166]	24 [166]	17 [117]	78 [538]	49 [338]	10 400 [71705]		
-H323	Sheet	0.051–0.249 [1–6]	45 [310]	34 [234]	32 [221]	26 [179]	20 [138]	88 [607]	58 [400]	10 400 [71705]		
-H343	Sheet	0.051–0.249 [1–6]	50 [345]	39 [269]	37 [155]	29 [200]	23 [159]	95 [655]	66 [455]	10 400 [71705]		
5086-H111	Extrusions	up through 0.500 [13]	36 [248]	21 [145]	18 [124]	21 [145]	12 [83]	70 [483]	36 [248]	10 400 [71705]		
-H111	Extrusions	0.501 [13] and over	36 [248]	21 [145]	18 [124]	21 [145]	12 [83]	70 [483]	34 [234]	10 400 [71705]		
-H112	Plate	0.250–0.499 [6–13]	36 [248]	18 [124]	17 [117]	22 [152]	10 [69]	72 [496]	31 [214]	10 400 [71705]		
-H112	Plate	0.500–1.000 [13–25]	35 [241]	16 [110]	16 [110]	21 [145]	9 [62]	70 [483]	28 [193]	10 400 [71705]		
-H112	Plate	1.001–2.000 [26–51]	35 [241]	14 [97]	15 [103]	21 [145]	8 [55]	70 [483]	28 [193]	10 400 [71705]		
-H112	Plate	2.001–3.000 [51–76]	34 [234]	14 [97]	15 [103]	21 [145]	8 [55]	68 [469]	28 [193]	10 400 [71705]		
-H116, H32	Sheet and Plate	All	40 [276]	28 [193]	26 [179]	24 [166]	16 [110]	78 [538]	48 [331]	10 400 [71705]		
-H34	Drawn Tube	All	44 [303]	34 [234]	32 [221]	26 [179]	20 [138]	84 [579]	58 [400]	10 400 [71705]		
5454-H111	Extrusions	up through 0.500 [13]	33 [228]	19 [131]	16 [110]	20 [138]	11 [76]	64 [441]	32 [221]	10 400 [71705]		
-H111	Extrusions	0.501 [13] and over	33 [228]	19 [131]	16 [110]	19 [131]	11 [76]	64 [441]	30 [207]	10 400 [71705]		
-H112	Extrusions	up through 5.000 [13]	31 [214]	12 [83]	13 [90]	19 [131]	7 [48]	62 [428]	24 [166]	10 400 [71705]		
-H32	Sheet and Plate	0.0200–2.000 [0.5–51]	36 [248]	26 [179]	24 [166]	21 [145]	15 [103]	70 [483]	44 [303]	10 400 [71705]		
-H34	Sheet and Plate	0.020–1.000 [0.5–25]	39 [269]	29 [200]	27 [186]	23 [159]	17 [117]	74 [510]	49 [338]	10 400 [71705]		

(Continued)

Table 5.5 (Continued)
Minimum Mechanical Properties for Before Welding

Alloy and Temper	Product ^a	Thickness Range, in [mm]	Tension			Compression			Shear			Bearing		Compressive Modulus of Elasticity ^b E, ksi [MPa]
			δ_{tu}	δ_t	δ_{cy}	δ_{cy}	δ_{cy}	δ_{cy}	T_u	T_y	T_y	δ_{brn}	δ_{brn}	
6061-T6, T651	Sheet and Plate	0.010–4.000 [0.3–102]	42 [290]	35 [241]	35 [241]	35 [241]	35 [241]	35 [241]	27 [186]	20 [138]	20 [138]	88 [607]	58 [400]	10 100 [69637]
-T6, T651 ^c	Extrusions	up through 1.000 [25]	38 [262]	35 [241]	35 [241]	35 [241]	35 [241]	35 [241]	24 [166]	20 [138]	20 [138]	80 [552]	56 [386]	10 100 [69637]
-T6, T651	Rolled Rod and Bar	up through 8.000 [203]	42 [290]	35 [241]	35 [241]	35 [241]	35 [241]	35 [241]	27 [186]	20 [138]	20 [138]	88 [607]	56 [386]	10 100 [69637]
-T6	Drawn Tube	0.025–0.500 [0.6–13]	42 [290]	35 [241]	35 [241]	35 [241]	35 [241]	35 [241]	27 [186]	20 [138]	20 [138]	88 [607]	56 [386]	10 100 [69637]
-T6	Pipe	up through 0.999 [25]	42 [290]	35 [241]	35 [241]	35 [241]	35 [241]	35 [241]	27 [186]	20 [138]	20 [138]	88 [607]	56 [386]	10 100 [69637]
-T6	Pipe	over 0.999 [25]	38 [262]	35 [241]	35 [241]	35 [241]	35 [241]	35 [241]	24 [166]	20 [138]	20 [138]	80 [552]	56 [386]	10 100 [69637]
6063-T5	Extrusions	up through 0.500 [13]	22 [152]	16 [110]	16 [110]	16 [110]	16 [110]	16 [110]	13 [90]	9 [62]	9 [62]	46 [317]	26 [179]	10 100 [69637]
-T5	Extrusions	over 0.500 [13]	21 [145]	15 [103]	15 [103]	15 [103]	15 [103]	15 [103]	12 [83]	8.5 [58]	8.5 [58]	44 [303]	24 [166]	10 100 [69637]
-T5	Extrusions and Pipe	All	30 [207]	25 [173]	25 [173]	25 [173]	25 [173]	25 [173]	19 [131]	14 [97]	14 [97]	63 [434]	40 [276]	10 100 [69637]
6351-T5	Extrusions	up through 1.00 [25]	38 [262]	35 [241]	35 [241]	35 [241]	35 [241]	35 [241]	24 [166]	20 [138]	20 [138]	80 [552]	56 [386]	10 100 [69637]
7005-T53	Extrusions	up to 0.7 [18]	50 [345]	44 [303]	43 [297]	43 [297]	43 [297]	43 [297]	28 [193]	25 [173]	25 [173]	95 [655]	73 [503]	10 500 [72395]

^a Most product and thickness ranges are taken from the Aluminum Association's 1979 edition of "Aluminum Standards and Data."

^b Typical values. For deflection calculations an average modulus of elasticity is used; numerically this is 100 ksi [690 MPa] lower than the values in this column.

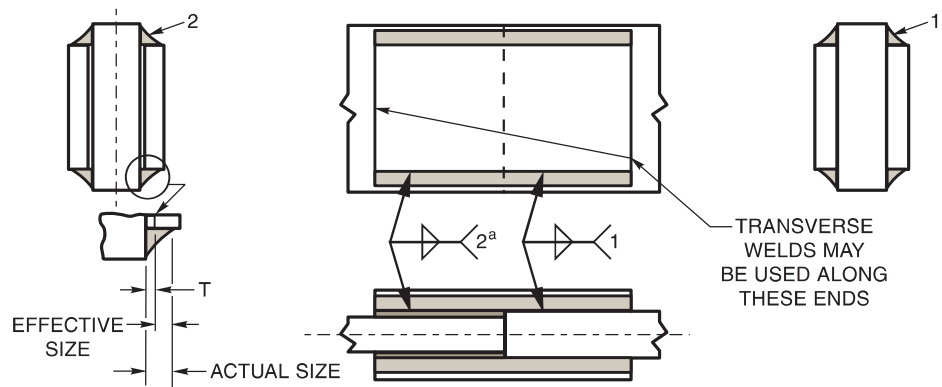
^c Values also apply to -T6511 temper.

Table 5.6
Allowable Atmospheric Exposure
of Low Hydrogen Electrodes

Electrode	Column A (hours)	Column B (hours)
A5.1/A5.1M		
E70XX	4 max.	
E70XXR	9 max.	Over 4 to 10 max.
E70XXHZR	9 max.	
E7018M	9 max.	
A5.5/A5.5M		
E70XX-X	4 max	Over 4 to 10 max.
E80XX-X	2 max.	Over 2 to 10 max.
E90XX-X	1 max.	Over 1 to 5 max.
E100XX-X	1/2 max.	Over 1/2 to 4 max.
E110XX-X	1/2 max.	Over 1/2 to 4 max.
E120XX-X	1/2 max.	Over 1/2 to 4 max.
E70XX-X R	9 max.	
E80XX-X R	9 max.	
E90XX-X R	9 max.	
E100XX-X R	9 max.	
E110XX-X R	9 max.	
E120XX-X R	9 max.	

Notes:

1. Column A: Electrodes exposed to atmosphere for longer periods than shown shall be baked before use.
2. Column B: Electrodes exposed to atmosphere for longer periods than those established by testing shall be baked before use.
3. Entire table: Electrodes shall be issued and held in quivers, or other small open containers. Heated containers are not mandatory.
4. The optional supplemental designator, R, designates a low hydrogen electrode that has been tested for covering moisture content after exposure to a moist environment for 9 hours and has met the maximum level allowed in AWS A5.1/A5.1M, *Specification for Carbon Steel Electrodes for Shielded Metal Arc Welding*, and AWS A5.5/A5.5M, *Specification for Low-Alloy Steel Electrodes for Shielded Metal Arc Welding*.



^aThe 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 T.

Figure 5.1—Fillers Less than 1/4 in [6 mm] Thick

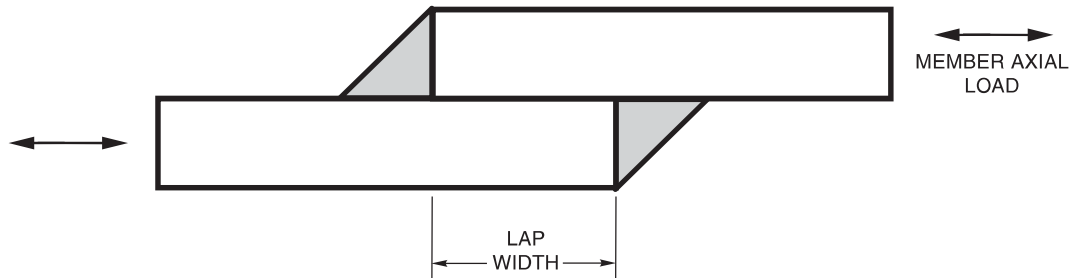
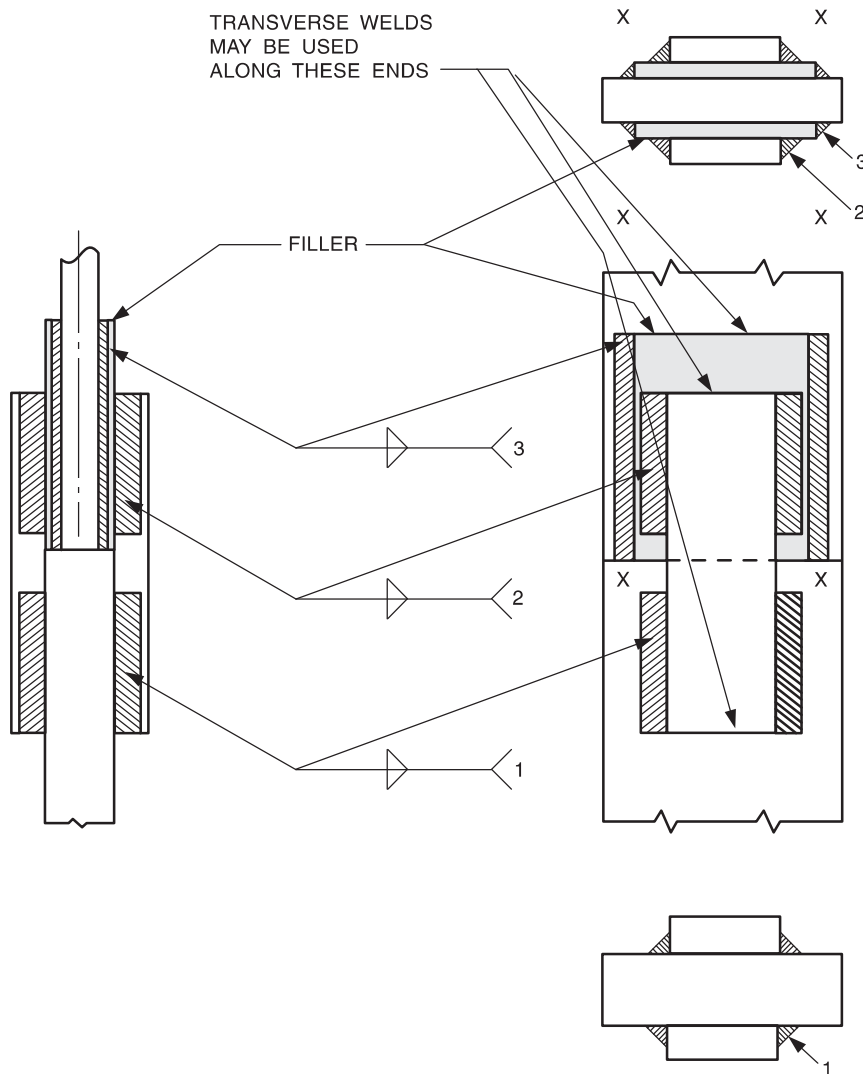


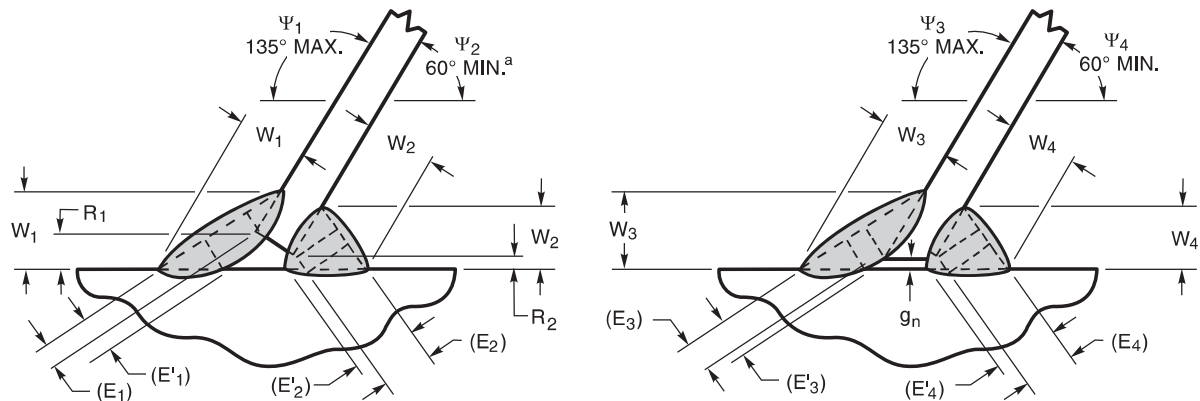
Figure 5.2—Lap Width and Member Axial Load



Notes:

1. The effective area of weld 2 shall equal that of weld 1. The length of weld 2 shall be sufficient to avoid overstressing the filler in shear along planes x-x.
2. The effective area of weld 3 shall at least equal that of weld 1, and there shall be no overstress of the ends of weld 3 resulting from the eccentricity of the forces acting on the filler.

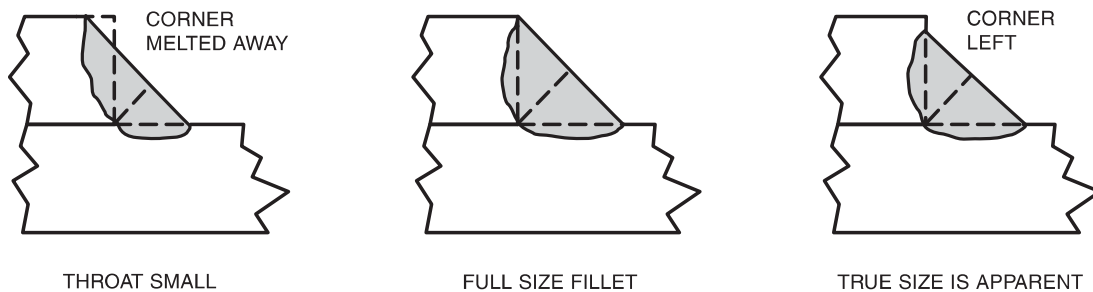
Figure 5.3—Fillers 1/4 in [6 mm] or Thicker



(A) SKEWED T-JOINTS

^a Angles smaller than 60° are permitted; however, in such cases, the weld is considered to be a partial joint penetration groove weld.

Note: (E)(n)' (E')(n) = effective throats dependent on magnitude of root opening (R) (see 7.3.1). Subscript (n) represents 1, 2, 3, or 4.



(B) FILLET WELD SIZE

The corner has melted away in the weld at the left, making the weld size much smaller than it appears. For the weld on the right, the corner has been left so that the weld size can be more readily determined (see 5.4.4.1).

Figure 5.4—Details for Fillet Welds

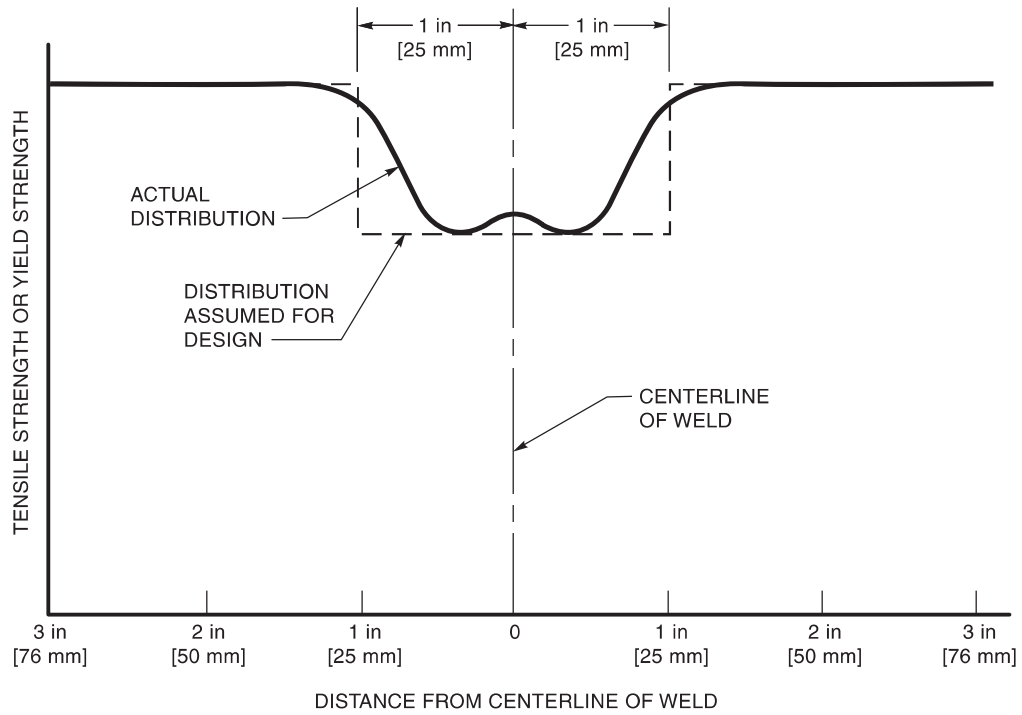


Figure 5.5—Distribution of Mechanical Properties in the Vicinity of an Aluminum Weld

6. Technique and Workmanship

6.1 General

6.1.1 Scope. This clause shall apply to the production and inspection of welded assemblies and structures produced by any of the processes specified in 5.1.

6.1.2 Equipment. All welding and cutting equipment shall be so designed and manufactured and shall be in such condition as to enable qualified welders, welding operators, and tack welders to follow the procedures and attain the results prescribed elsewhere in this specification.

6.1.3 Welding Conditions. Welding shall not be allowed when the surfaces to be welded are wet or exposed to rain, snow, or high wind, or when the ambient temperature in the area to be welded is below 0°F [−18°C]. These conditions do not alter or preclude the minimum preheat or interpass temperatures required by the welding procedure specification.

6.1.4 Maximum Preheat and Interpass Temperatures, Aluminum Alloys. Heat-treatable aluminum alloys and aluminum alloys containing three or more percent magnesium shall not be preheated nor have an interpass temperature in excess of 250°F [121°C].

6.2 Preparation of Base Metal

6.2.1 Steel and Aluminum Base Metals

6.2.1.1 Thermal Cutting Criteria. Thermal cutting of aluminum alloys is limited to the plasma-arc cutting (PAC) and laser beam cutting (LBC) processes. In thermal cutting, the equipment shall be so adjusted and manipulated as to avoid cutting beyond (inside) the prescribed lines. The roughness of all thermal cut surfaces shall be no greater than that defined by the American National Standards Institute (ANSI) surface roughness value of 1000 μin [25 μm] for material up to 4 in [102 mm] thick and 2000 μin [50 μm] for material 4 in to 8 in [102 mm to 203 mm] thick, with the following exception: the ends of members not subject to calculated stress at the ends shall not exceed a surface roughness value of 2000 μin [50 μm]. ASME B46.1, *Surface Texture (Surface Roughness, Waviness, and Lay)* is the reference standard. AWS C4.6M (ISO 9013), *Thermal Cutting—Classification of Thermal Cuts Geometric Product Specification and Quality Tolerances*, may be used as a guide for evaluating surface roughness of these edges. For materials up to and including 4 in [102 mm] thick, use Sample No. 3, and for materials over 4 in up to 8 in [102 mm up to 203 mm] thick, use Sample No. 2.

Roughness exceeding these values and notches or gouges no more than 3/16 in [5 mm] deep on otherwise satisfactory surfaces shall be removed by machining or grinding. Cut surfaces and edges shall be left free of slag. Depressions caused by removal of discontinuities shall be faired to the cut surfaces with a slope not exceeding one in ten. In cut edges, notches or gouges less than 7/16 in [11 mm] deep in base metal up to 4 in [102 mm] thick may, with the approval of the Fabricator's Engineer, be repaired by welding. Any approved weld repairs shall be made by (1) suitably preparing the discontinuity, (2) welding with a qualified procedure, (3) observing the applicable requirements of this standard, and (4) grinding the completed weld smooth and flush with the adjacent surface.

6.2.1.2 Repair of Discontinuities. In the repair of internal discontinuities, the amount of metal removed shall be the minimum necessary to remove the discontinuity or to determine that the permissible limit is not exceeded. All repairs of discontinuities by welding shall conform to the applicable provisions of this specification.

In the repair of discontinuities:

(1) The limits of acceptability and the repair of visually observed edge discontinuities shall be in accordance with Table 6.1 in which the length of discontinuity is the visible long dimension on the cut edge of the metal and the depth is the distance that the discontinuity extends into the plate from the cut edge.

(2) For discontinuities over 1 in [25 mm] in length with depth greater than 1 in [25 mm], discovered by visual inspection of cut edges of plate before welding or during examination of welded joints by radiographic or ultrasonic testing, the following procedures should be observed:

(a) Where discontinuities such as (W), (X), or (Y) in Figure 6.1 are observed prior to completing the joint, the size and shape of the discontinuity shall be determined by ultrasonic testing. The area of the discontinuity shall be determined as the area of total loss of back reflection, when tested in accordance with the procedure of ASTM A435, *Specification for Straight Beam Ultrasonic Examination of Steel Plates for Pressure Vessels*, or ASTM B548, *Method and Specifications for Ultrasonic Inspection of Aluminum—Alloy Plate for Pressure Vessels*.

(b) For acceptance, the area of the discontinuity (or the aggregate area of multiple discontinuities) shall not exceed 4% of the complete area (length $\times$ width) with the following exception: if the length of the discontinuity or the aggregate width of discontinuities on any transverse section, as measured perpendicular to the length, exceeds 20% of the plate width, the 4% plate area shall be reduced by the percentage amount of the width exceeding 20%. (For example, if a discontinuity is 30% of the plate width, the area of discontinuity cannot exceed 3.6% of the complete area.) The discontinuity on the cut edge of the plate shall be gouged out to a depth of 1 in [25 mm] beyond its intersection with the surface by chipping, air carbon or plasma arc gouging, machining, or grinding, and repaired by welding in layers not exceeding 1/8 in [3 mm] in thickness.

(c) If a discontinuity, **Z**, (Figure 6.1), not exceeding the allowable area in (b) above, is discovered after the joint has been completed and is determined to be 1 in [25 mm] or more away from the weld face, as measured on the surface, no repair of the discontinuity is required. If the discontinuity, **Z**, is less than 1 in [25 mm] away from the face of the weld, it shall be gouged out to a distance of 1 in [25 mm] from the fusion zone of the weld by chipping, air carbon or plasma arc gouging, machining, or grinding. It shall then be repaired by welding for at least four layers not exceeding 1/8 in [3 mm] in thickness per layer.

(d) If the area of the discontinuity, **W**, **X**, **Y**, or **Z** (Figure 6.1) exceeds the allowable in (b) above, the component or subcomponent shall be rejected and replaced, or repaired with the approval of the Fabricator's Engineer.

(e) The aggregate length of weld repair shall not exceed 20% of the length of the edge without approval of the Fabricator's Engineer.

(f) All repairs shall be in accordance with this standard. Gouging of the discontinuity may be done from either surface or edge.

6.2.2 Steel Base Metal Only

6.2.2.1 Edge and Surface Requirements. Surfaces to be welded shall be smooth, uniform, and free from fins, tears, cracks, and other discontinuities that would adversely affect the quality or strength of the weld. Surfaces to be welded and surfaces adjacent to a weld shall also be free from loose or thick scale, slag, surface oxides, moisture, grease, and other foreign material that would prevent proper welding or produce objectionable fumes. Mill scale that can withstand vigorous wire brushing, or a thin rust-inhibiting film is permissible.

6.2.2.2 Acceptable Joint Preparation Methods. Machining, air carbon or plasma arc cutting, oxygen cutting, oxygen gouging, chipping, grinding, or equivalent methods may be used for joint preparation, backgouging, or the removal of unacceptable work or metal.

6.2.3 Aluminum Base Metal Only

6.2.3.1 Base Metal Preparation

(1) Edge preparation shall be accomplished by shearing, sawing, plasma-arc cutting, chipping, or machining. Grinding of aluminum, except as a final weld contouring and finishing operation, is not recommended. When grinding is necessary, care shall be taken to select nonloading-type abrasive specifically intended for use on aluminum, and the abrasive shall be maintained free of lubricants and other foreign material.

(2) Following thermal cutting of heat-treatable alloys, 1/8 in [3 mm] of material shall be removed from cut edges by machining, except that cut edges of heat-treatable aluminum alloy material may be used without machining when the cut area is separated from the immediate weld area and is not part of the welded joint.

6.2.3.2 Joint Preparation and Backgouging Methods. Machining, sawing, chipping, or grinding may be used for joint preparation, backgouging, the removal of temporary welds, or the removal of unacceptable work or metal.

6.2.3.3 Surface Requirements. All surfaces to be welded shall be free from thick aluminum oxide, dirt, paint, grease, cutting fluids, and moisture. Caution should be exercised in the use of chemicals. Health and safety concerns should be recognized according to ANSI Z49.1, *Safety in Welding, Cutting, and Allied Processes*. When cleaning aluminum base metals:

(1) Heavily oiled base metal should be degreased either chemically or with a recommended solvent or detergent.

(2) Thick aluminum oxide should be removed with a brush of stainless steel or other recommended material, or by chemical methods.

6.2.3.4 Brushes for Cleaning Aluminum. Brushes shall be kept exclusively for aluminum and be kept clean. The interval between cleaning and welding shall be kept as short as possible.

6.3 Steel and Aluminum Assembly Criteria

6.3.1 Root Opening. Parts to be joined by fillet welds shall be brought into as close contact as practicable. The root opening, *R*, shall not exceed 3/16 in [5 mm]. If the root opening is 1/16 in [2 mm] or greater, the fillet weld size shall be increased by the amount of the separation, or the manufacturer shall demonstrate that the required fillet weld size has been obtained.

6.3.1.1 Faying Surfaces. Separation between faying surfaces of lap joints, plug and slot welds, and of butt joints landing on a backing shall not exceed 1/16 in [2 mm].

6.3.1.2 Fillers. Use of fillers is prohibited except as specified on the drawings or as specially approved by the Fabricator's Engineer and Owner's Engineer and made in accordance with 5.4.3.

6.3.2 Maximum Root Opening. Members to be joined by partial joint penetration groove welds parallel to the length of the member shall be brought into as close contact as practicable. The root opening between members shall not exceed 3/16 in [5 mm].

6.3.3 Butt Joint Alignment. Parts to be joined at butt joints shall be carefully aligned. A weld joint mismatch not exceeding 30% of the thickness of the thinner part joined, but in no case more than 1/8 in [3 mm], shall be permitted as a departure from the theoretical alignment. Measurements of weld joint mismatch shall be based upon the centerline of parts unless otherwise shown on the drawing.

6.3.4 Out-of-Tolerance Joints. Dimensions of the cross section of groove welded joints varying from those shown on the detail drawings by more than the tolerances permitted in Table 6.2 shall be referred to the Fabricator's Engineer for approval or correction.

6.3.4.1 Excessive Root Opening. Root openings wider than those permitted in Table 6.2, but not greater than twice the thickness of the thinner member or 3/4 in [19 mm], whichever is less, may be corrected by welding to acceptable dimensions prior to joining members by welding. Root openings larger than the above may be welded only with the approval of the Fabricator's Engineer.

6.3.4.2 Gouging. Grooves produced by gouging shall be in accordance with groove profile dimensions as specified in the welding procedure specification.

6.3.4.3 Fixturing. Members to be welded shall be brought into alignment and held in position by fixtures, strongbacks, bolts, clamps, wedges, guy lines, struts, or other suitable devices, or by tack welds until the welding has been completed. The use of fixtures is recommended. They shall have sufficient stiffness and strength to counteract the forces resulting from the temperature changes in the weldment. Similarly, tack welds shall have sufficient effective weld size and length to develop the necessary strength.

6.3.4.4 Backing. Backing, when specified, should preferably be in intimate contact with the surfaces of both plates, but in no event shall the separation exceed 1/16 in [2 mm].

6.3.4.5 Complete Joint Penetration Groove Welds. Complete joint penetration manual or semiautomatic groove welds to be welded from both sides in base metal thicknesses of 1/4 in [6 mm] or thicker, or to be welded in positions other than flat, shall have the root of the weld cleaned to sound metal before depositing the root-pass from the second side to assure complete joint penetration. Groove welds made with the use of fused metallic backing shall have the weld metal thoroughly fused with the backing.

6.3.4.6 Transverse Groove Weld Requirements (Load-Bearing). Transverse groove welds in load carrying members shall have the full weld size for the entire length of the joint. Where weld run-off tabs are used, each weld pass shall start and stop at least twice the thickness of the thicker member beyond the edges of the members being joined.

6.3.5 Tack Welds. Tack welds shall be made by a qualified welder or tack welder in accordance with a written, qualified, or prequalified welding procedure specification and subject to the same quality requirements as the final welds. Tack welds which are to be incorporated into the final weld shall be made with filler metal of the same composition as that used for the final weld and shall be cleaned thoroughly before incorporation. Tack welds not incorporated in the final weld and not shown on the drawing shall be removed.

6.4 Weld Profiles

6.4.1 Fillet Welds. Faces of fillet welds may be slightly convex, flat, or slightly concave, as shown in Figures 6.2(A) and (B), with none of the unacceptable profiles shown in Figure 6.2(C). Except at outside corner joints, the convexity C of a weld or individual surface bead shall not exceed the values given in Figure 6.2 [see Figures 6.2(A), 6.2(B), and 6.2(C)].

6.4.2 Groove Welds. Groove welds shall preferably be made with a slight reinforcement, unless otherwise specified. The convexity (reinforcement) shall not exceed the following:

- (1) Up to 1/2 in [13 mm] thick inclusive, 3/32 in [2 mm]
- (2) Over 1/2 in to 1 in [13 mm to 25 mm] thick inclusive, 1/8 in [3 mm]
- (3) Over 1 in [25 mm] thick, 5/32 in [4 mm]

The reinforcement shall have gradual transition to the plane of the base metal surface [see Figure 6.2(D)]. Unacceptable groove weld profiles are shown for butt joints in Figure 6.2(E).

6.4.3 Joint Surface Reinforcement. Surfaces of joints required to be flush shall be finished so as not to reduce the thickness of the thinner base metal or weld metal by more than 1/32 in [1 mm] or 5% of the thickness, whichever is smaller, nor leave reinforcement that exceeds 1/32 in [1 mm]. However, all reinforcement shall be removed where the weld forms part of a faying or contact surface. Any reinforcement shall blend smoothly into the plate surfaces with transition areas free from undercut. Chipping may be used, provided it is followed by grinding. Where surface finishing is required, its roughness value shall not exceed 250 μin [6 μm]. Surfaces finished to values of over 125 μin through 250 μin [3 μm through 6 μm] shall be finished parallel to the direction of primary stress. Surfaces finished to values of 125 μin [3 μm] or less may be finished in any direction.

6.4.4 Joint End Profile. Ends of joints required to be flush shall be finished so as not to reduce the width beyond the detailed width or the actual width furnished, whichever is greater, by more than 1/8 in [3 mm] or so as not to leave weld material at each end that exceeds 1/8 in [3 mm]. Ends of welds in joints shall be faired to adjacent plate or shape edges at a slope not to exceed 1 in 10.

6.4.5 Overlap in Fillets. Overlap in fillet welds shall not be permitted.

6.4.6 Overlap in Groove Welds. Overlap in groove welds shall not be permitted.

6.5 Repairs—After Welding

6.5.1 Joint Preparation Methods. The removal of weld metal or portions of the base metal shall only be done by machining, grinding, chipping, oxygen gouging, air carbon arc, or plasma arc gouging. Thermal gouging shall not be used on quenched and tempered steel or aluminum alloys. Unacceptable portions of the weld shall be removed without substantial removal of the base metal.

6.5.2 Extent of Repairs. The manufacturer has the option of either repairing an unacceptable weld or removing and replacing the entire weld, except as modified by 6.5.6. The repaired or replaced weld shall be retested by the method originally used, and the same technique and quality acceptance criteria shall be applied.

6.5.3 Inspection Methods and Repair of Cracks. For cracks in weld or base metal, extent of the crack shall be ascertained by use of acid etching, magnetic particle inspection, dye penetrant inspection, radiographic, ultrasonic, or other equally positive means. The crack shall be removed to sound metal. It shall be verified that the crack has been removed before the joint is rewelded.

6.5.4 Distortion Control (Steel). If required, steel members distorted by welding shall be straightened by mechanical means or by carefully supervised application of a limited amount of localized heating. Heating of M-1 material (refer to AWS B2.1/B2.1M, *Specification for Welding Procedure and Performance Qualification*) shall be limited to 1200°F [649°C]. All other materials require a written procedure approved by the Fabricator's Engineer. Quenched and tempered steels shall not be heated in excess of their specific tempering temperature.

6.5.5 Distortion Control (Aluminum). Aluminum members distorted by welding shall be straightened at an ambient temperature by mechanical means or by the carefully supervised application of a controlled amount of localized heat in conjunction with mechanical means. If localized heating is to be applied in any straightening operation, the complete

procedure shall be filed with, and approved by, the Fabricator's Engineer. This procedure shall adhere to the maximum temperature values listed in Table 6.3 and the following:

6.5.5.1 Except for those stresses resulting from the mechanical straightening method used in conjunction with the application of heat, the part to be heated for straightening shall be free from external forces.

6.5.5.2 Maximum holding times for the forming and straightening of aluminum alloys at various temperatures are given in Table 6.3. The following items shall be considered when heating aluminum alloys:

(1) For aluminum alloys 1XXX, 3XXX, and 5XXX series alloys with magnesium contents less than 3% and for cast alloy 443.0, there are no restrictions on the temperature except that as the temperature is increased, properties may be diminished.

(2) For 5XXX series alloys with magnesium contents greater than 3%, holding within the temperature range from 150°F to 450°F [66°C to 232°C] shall be avoided in order to minimize the possibility of sensitization to exfoliation and stress corrosion cracking. The length of time at temperature is a critical factor in determining the degree of sensitization. Hot forming techniques shall include quick heat up to a temperature not to exceed 550°F [288°C], to minimize loss of mechanical properties. Forming shall be completed before the metal cools below 450°F [232°C]. The metal should then be fan cooled to drop the metal temperature from 450°F to 150°F [232°C to 65°C] in the minimum time possible to prevent sensitization.

(3) For 6XXX alloys, distortion removal shall be done at a temperature below 450°F [232°C]. The time that the structure is held at temperature while removing the weld distortion shall not exceed those times shown in Table 6.3.

(4) For 7005 alloy, distortion removal shall be done preferably in the "0," annealed, or "W" solution heat treated condition, and then the structure shall be given the appropriate thermal treatment after straightening.

(5) For heat-treatable aluminum alloy castings, straightening shall be done in the "T4" condition before age hardening. The preheat shall not exceed 300°F [149°C] and should be of very short duration so as not to affect the heat treated properties.

6.5.6 Prior approval of the Fabricator's Engineer shall be obtained for repairs to base metal (other than those required by 6.2). Repair of delayed cracks or a revised design to compensate for deficiencies requires prior approval of both the Fabricator's Engineer and the Owner's Engineer.

6.5.7 Engineer Notification. The Fabricator's Engineer shall be notified before improperly fitted and welded members are cut apart.

6.5.8 Accessibility for Repair. If, after an unacceptable weld has been made, work is performed which has rendered that weld inaccessible or has created new conditions that make corrections of the unacceptable weld dangerous or ineffectual, then the original conditions shall be restored by removing welds or members, or both, before the corrections are made. If this is not done, the deficiency shall be compensated for by additional work performed according to a revised design approved by the Fabricator's Engineer.

6.5.9 Repair of Mislocated Holes. When base metal with mislocated holes is to be restored to its original condition by welding, the following requirements shall apply:

6.5.9.1 Restoration by welding is not recommended unless required for structural reasons.

6.5.9.2 Restoration of holes by welding in base metal subject to tensile stress is prohibited, except when approved by the Fabricator's Engineer.

6.6 Arc Strikes. Arc strikes outside the area of permanent welds should be avoided on any base metal. Cracks or blemishes caused by arc strikes shall be ground to a smooth contour and inspected to ensure soundness.

6.7 Cleaning and Protective Coatings

6.7.1 Painting. Welded joints shall not be painted or otherwise covered before the welds are examined and approved.

6.7.2 Cleaning of Multipass Welds. Before welding over previously deposited metal, all slag shall be removed and the weld and adjacent base metal shall be clean. This requirement shall apply not only to successive layers but also to successive beads and to the crater area when welding is resumed after any interruption. It shall not, however, restrict the welding of plug and slot welds in accordance with 8.6.

6.7.3 Cleaning of Single-Pass Welds. Slag shall be removed from all completed welds. The weld and adjacent base metal shall be cleaned by brushing or other suitable means.

6.7.4 Weld Appearance. Where appearance is important, weld spatter, adhesions, scratches, etc., shall be removed by wire brushing, grinding, sanding, or polishing, as required.

6.8 Weld Termination

6.8.1 Run-off Tabs (Steel). Welds shall be terminated at the end of a joint in a manner that will ensure sound welds. Whenever necessary, this shall be done by use of a run-off tab. The tab(s) shall be removed unless shown on the drawing or permitted to remain by the Fabricator's Engineer. When runoff tabs are removed, the ends of the weld shall be made smooth and flush with the edges of abutting members.

6.8.2 Run-off Tabs (Aluminum). For aluminum alloys, when it is impossible to terminate a weld on an extension bar or runoff tab, prior consideration to weld termination should be given so as to terminate the weld in a low stress area. The techniques for terminating a fillet weld or a cover pass bead within a joint shall consist of the following:

6.8.2.1 Reversing the direction of travel for a minimum distance of 0.5 in [13 mm] while increasing travel speed to reduce crater size.

6.8.2.2 Providing suitable buildup and removing the crater area flush with the weld surface by mechanical means.

6.9 Groove Weld Backing

6.9.1 Fused Metallic Backing. Groove welds made with the use of a fused metallic backing shall have the weld metal thoroughly fused with the backing for the full length of the weld.

6.9.2 Full-Length Backing. Permanent backing shall be made continuous for the full length of the weld. All necessary joints in the backing shall be complete joint penetration welded butt joints meeting all the workmanship requirements of Clause 6.

6.9.3 Temporary Backing. Temporary backing (other than steel) for steel groove welds shall be of an unfuseable material such as copper, brass, or ceramic. Temporary backing for aluminum may be of austenitic stainless steel, glass tape, ceramic materials, or an anodized aluminum alloy of the same group number (in AWS B2.1/B2.1M, *Specification for Welding Procedure and Performance Qualification*). Copper backing shall not be used for aluminum.

6.10 Heat Input Control for Quenched and Tempered Steel

6.10.1 When quenched and tempered steels are welded, the heat input shall be restricted in accordance with the steel producer's recommendations. The use of stringer beads to avoid overheating is strongly recommended.

6.10.2 Oxygen gouging of quenched and tempered steels is not permitted.

6.10.3 If the weld is to be stress relieved, the welding procedure specification is not prequalified and shall be qualified in accordance with Clause 10.

6.11 Stress Relief Heat Treatment. Where required by the contract drawings or specifications, welded assemblies shall be stress-relieved by heat treating. Finish machining preferably shall be done after stress relieving. For aluminum alloys, specific thermal practices shall be determined for each alloy and temper.

6.12 Peening

6.12.1 Steel Base Metal

6.12.1.1 Peening may be used on intermediate weld layers for control of shrinkage stresses in thick welds to prevent cracking. No such peening shall be done on the root or surface layer of the weld or the base metal at the edges of the weld. Care should be taken to prevent overlapping or cracking of the weld or base metal.

6.12.1.2 For the purpose of enhanced fatigue performance, peening may be done in accordance with a written procedure approved by the Fabricator's Engineer. Such peening shall be done after the weld has been inspected.

6.12.1.3 The use of manual slag hammers, chisels, and lightweight vibrating tools for the removal of slag and spatter is not considered peening.

6.12.2 Aluminum Base Metal. Weld peening of aluminum alloys may be used subject to approval by the Fabricator's Engineer.

6.13 Workmanship for Stud Arc Welding (SW)

6.13.1 Design and Details. The design of studs shall be suitable for welding to steel members with automatically timed stud welding equipment connected to a suitable source of direct current, electrode negative (DCEN). The type, diameter, and length of the stud shall be as specified by drawings, specifications, or special provisions as approved by the Fabricator's Engineer. At the time of welding, the studs and areas on the base metal to which the studs are to be applied shall be free from rust, scale, oil, or other injurious material to the extent necessary to obtain satisfactory welds.

6.13.2 Gun Position. While in operation, the welding gun shall be held in position without movement until the weld metal has solidified.

6.13.3 Minimum Temperature. Stud arc welding shall not be done when the base metal temperature is below 0°F [–18°C] nor when the surface is wet or exposed to rain or snow.

6.13.4 Arc Shield. An arc shield (ferrule) of heat-resistant ceramic or other suitable material shall be used with each stud. After welding, arc ferrules shall be broken free.

6.13.5 Minimum Temperature (Aluminum). For aluminum, the minimum base metal temperature at the time of welding shall be 50°F [10°C].

NOTE: For additional information on arc stud welding, see AWS C5.4, Recommended Practices for Stud Welding.

6.13.6 Use of Alternate Process. As an alternate method, studs may be welded by fillet welding in accordance with a written procedure using a low hydrogen process.

6.13.7 Repair of Stud Welds. Welded studs on which a full 360° flash is not obtained may be repaired by fillet welding with low hydrogen process. The repair weld shall extend at least 1/4 in [6 mm] beyond each end of the discontinuity being repaired.

6.13.8 Acceptance Criteria. The first two studs welded, after being allowed to cool, shall be bent to an angle of 30° from their original axis by striking the studs with a hammer. Two consecutive studs meeting this criterion, without evidence of a failure, constitute acceptance. If a failure does occur in the fusion zone of either stud, the procedure shall be corrected, and the test repeated until successful.

6.14 Workpiece Leads

6.14.1 Connection Requirements. The workpiece leads shall be attached directly to the piece or part of the car or locomotive being welded and located as near as possible to the weld area. To prevent damage to journal bearings, the workpiece lead shall not, under any circumstances, be attached to the following:

6.14.1.1 Any part of an assembled truck under a car or locomotive being welded.

6.14.1.2 The rail on which the car or locomotive is standing.

6.14.2 Battery Equipped Vehicles. Any vehicle so equipped shall have the battery switch opened to prevent damage to the electronic and electrical components.

6.14.3 Self-Propelled Vehicles. Any vehicle so equipped shall have the reverser centered and the handle removed to prevent unintended motion of the vehicle.

6.15 Welding Air Brake Pipe. Air brake pipe and pipe fittings are to be welded in accordance with the most current edition of AAR S-402, *Specification for the Welding of Air Brake Pipe and Fittings for Railroad Cars*, or other governing specifications.

Table 6.1
Limits on Acceptability and Repair of Cut Edge Discontinuities

Description of Discontinuity	Repair Required
Any discontinuity 1 in [25 mm] or less in length	None
Any discontinuity over 1 in [25 mm] in length with 1/8 in [3 mm] maximum depth	None, but the depth should be determined ^a
Any discontinuity over 1 in [25 mm] in length with depth over 1/8 in [3 mm] but not greater than 1/4 in [6 mm]	Remove, need not weld
Any discontinuity over 1 in [25 mm] in length with depth over 1/4 in [6 mm] but not greater than 1 in [25 mm]	Completely remove and weld. Aggregate length of welding shall not exceed 20% of the length of the plate edge being repaired
Any discontinuity over 1 in [25 mm] in length with depth greater than 1 in [25 mm]	See 6.2.1.2(2)

^a A spot check of 10% of the discontinuities on the cut edge in question should be explored by grinding to determine depth. If the depth of any one of the discontinuities explored exceeds 1/8 in [3 mm], then all of the discontinuities remaining on that edge shall be explored by grinding to determine depth. If none of the discontinuities explored in the 10% spot check has a depth exceeding 1/8 in [3 mm], then the remainder of the discontinuities on that edge need not be explored.

Table 6.2
Joint Dimension Tolerances

	Root Not Gouged, in [mm]	Root Gouged, in [mm]
Root face of joint	±1/16 [2]	Not limited
Root opening of joints without fused metallic backing	±1/16 [2]	+1/16 [2]
Root opening of joints with fused metallic backing	+1/4 [6] -1/16 [2]	Not applicable
Groove angle of joint	+10° -5°	+10° -5°

Table 6.3
Maximum Exposure Time at Temperature
Preparatory to Forming or Welding Aluminum Alloys

$\left(\begin{array}{c} \text{Holding} \\ \text{Temperature} \\ ^\circ\text{F } [^\circ\text{C}] \end{array} \right)^a$	$\left(\begin{array}{c} 6005\text{-T5} \\ 6351\text{-T5} \\ 6061\text{-T4} \\ 6061\text{-T5} \\ \text{Alclad } 6061\text{-T4} \\ \text{Alclad } 6061\text{-T5} \\ 6063\text{-T5} \end{array} \right)^b$	$\left(\begin{array}{c} 1060, 1100 \\ 3003, 3004 \\ \text{Alclad } 3003 \\ \text{Alclad } 3004 \\ 5005 \\ 5050, 5052 \\ 5454, 5652 \\ 443.0 \end{array} \right)^b$	$\left(\begin{array}{c} 5083 \\ 5086 \\ 5154 \\ 5254 \\ 5456 \\ 514.0 \\ 535.0 \end{array} \right)^c$	$\begin{array}{c} 356.0\text{-T4} \\ \text{A444.0-T4} \\ 7005\text{-T6} \end{array}$
800 [425]	NR ^d	50 hours	50 hours	50 hours
500 [260]	NR	50 hours	50 hours	NR
450 [232]	5 minutes	50 hours	50 hours	NR
425 [218]	15 minutes	50 hours	50 hours	NR
400 [204]	30 minutes	50 hours	50 hours	NR
375 [191]	1–2 hours	50 hours	NR	NR
350 [177]	8–10 hours	50 hours	NR	NR
230–325 [110–163]	50 hours	50 hours	NR	NR

^a Equal formability may be obtained with shorter periods of heating at correspondingly higher temperature. Time at temperature for clad alloys should be kept at a minimum to prevent diffusion of the cladding into the core alloy. Heating should be as rapid as possible, particularly for temperatures 400°F [204°C] and above. Excessive time to approach the desired temperatures can have deleterious effects similar to those resulting from excess time at temperature.

^b Losses in strength for these alloys in the T6 temper shall not exceed about 5% when heated at the temperature and for the periods shown. Strength of the T4 temper alloys will increase.

^c These alloys shall be annealed at 650°F [343°C] and above.

^d NR = Not recommended.

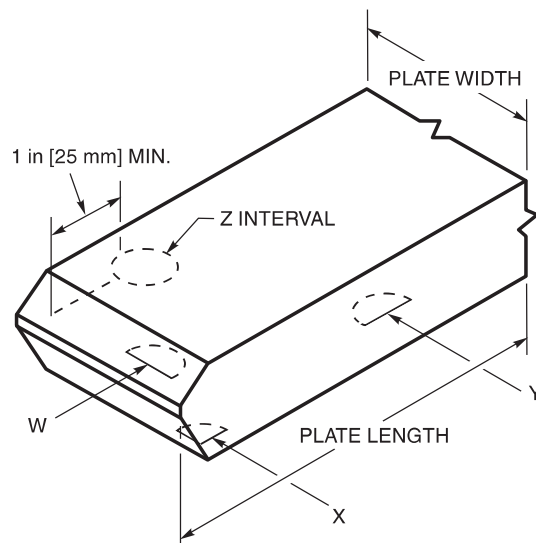
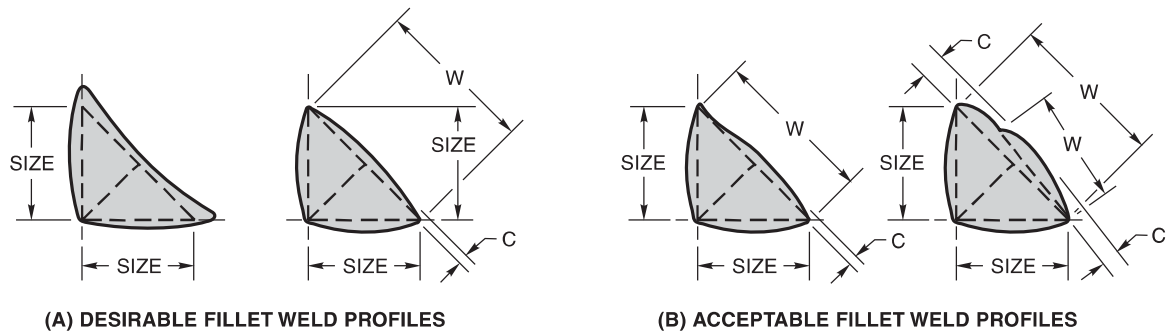
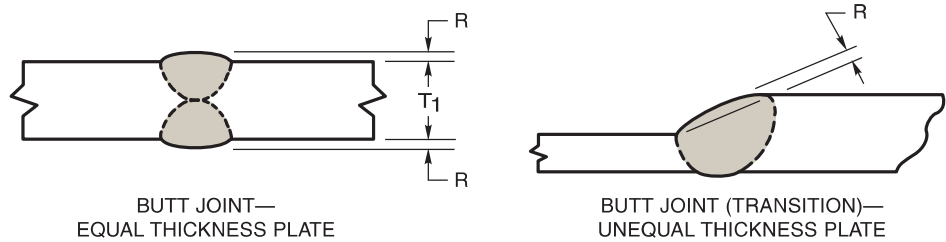
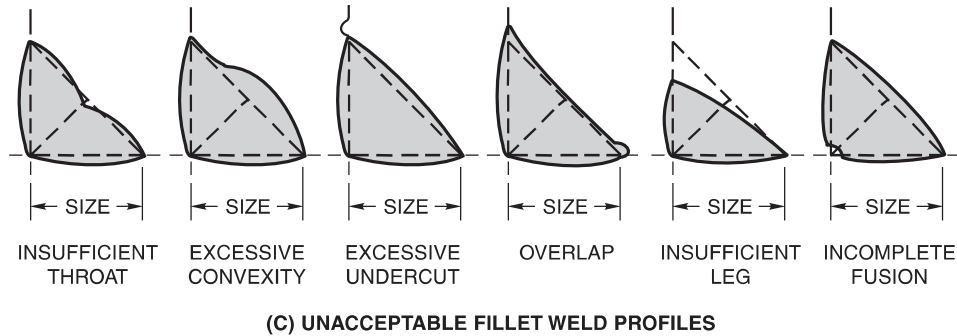


Figure 6.1—Cut Edge Discontinuity



Note: Convexity, C, of a weld or individual surface bead with dimension W shall not exceed the value of the following table:

WIDTH OF WELD FACE OR INDIVIDUAL SURFACE BEAD, W	MAX. CONVEXITY, C
$W \leq 5/16$ in [8 mm]	1/16 in [2 mm]
$W > 5/16$ in [8 mm] to $W < 1$ in [25 mm]	1/8 in [3 mm]
$W \geq 1$ in	3/16 in [5 mm]



Note: Reinforcement R shall not exceed that specified in 6.4.2.

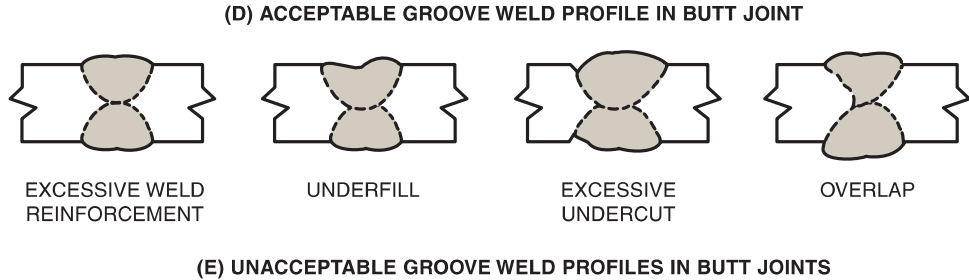


Figure 6.2—Acceptable and Unacceptable Weld Profiles

7. Prequalified Welding Procedure Specifications—Joint Design Details

Prequalification requires compliance with Clauses 5 through 8 of this specification.

7.1 Groove Weld Size (Effective Weld Size)

7.1.1 Partial Joint Penetration Groove Welds. The weld size of a partial joint penetration groove weld shall be the depth of bevel, less 1/8 in [3 mm] for grooves having a groove angle less than 60° but not less than 45° at the root of the groove, when deposited by shielded metal arc or submerged arc welding, or when deposited in the vertical or overhead welding positions by gas metal arc or flux cored arc welding. The weld size of a partial joint penetration groove weld shall be the depth of bevel, without reduction, for grooves having the following:

7.1.1.1 A groove angle of 60°, or greater, at the root.

7.1.1.2 A groove angle not less than 45° at the root of the groove when deposited in flat or horizontal positions by GMAW or FCAW (see Figure 7.2 as appropriate).

7.1.2 Effective Size of Flare-Groove Welds. The effective size of flare-groove welds when filled flush shall be as shown in Table 7.1. 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.

7.1.2.1 Special Conditions. For a given set of procedural conditions, if the manufacturer has demonstrated the ability to consistently provide larger weld sizes than those shown in Table 7.1, the manufacturer may establish such larger weld sizes by qualification.

7.1.2.2 Required Testing. Qualification required by 7.1.2.1 shall consist of sectioning the radiused member, normal to its axis, at the midlength and terminal ends of the weld. Such sectioning shall be made on a number of combinations of material sizes representative of the range used by the manufacturer in construction or as required by the Fabricator's Engineer.

7.1.3 Minimum Weld Size. The minimum weld size of a partial joint penetration groove weld shall be as specified in Table 5.1.

7.2 Joint Designs

7.2.1 Prequalified Joints. Joints meeting the following requirements are designated as prequalified:

7.2.1.1 Conformance with the details specified in 7.3 through 7.6 and techniques specified in Clause 8.

7.2.1.2 Use of one of the following welding processes in accordance with the requirements of Clauses 5 through 8 as applicable; SMAW, SAW, GMAW (except short circuiting transfer), or FCAW.

7.2.2 Testing. Joints meeting the requirements of 7.2.1 may be used without performing the joint welding procedure qualification tests prescribed in Clause 10.

7.2.3 Short-Circuit Gas Metal Arc Welding (GMAW-S). The welding procedure specification for all joints welded by short circuiting transfer gas metal arc welding shall be qualified by tests prescribed in Clause 10.

7.2.4 Groove Profiles. Grooves produced by gouging shall be in accordance with groove profiles as in Figures 7.1 and 7.2.

7.3 Fillet Welds

7.3.1 The details of fillet welds to be used without joint welding procedure qualifications are listed in 5.4 and detailed in Figure 5.4.

7.3.2 The minimum size of a fillet weld shall be in accordance with Table 7.2.

7.4 Details of Plug and Slot Welds

7.4.1 Joint Details. The details and dimensions of plug and slot welds listed in 7.4.2 may be used without performing the welding procedure qualification prescribed in Clause 10, provided the technique provisions of 8.6, as applicable, are met.

7.4.2 Hole or Slot Dimensions. The diameter of the holes for a plug weld and the width of a slot for slot weld shall be not less than the thickness of the part containing it plus 5/16 in [8 mm]. The maximum diameter of the hole or width of slot shall not exceed the minimum diameter of the hole or width of slot plus 1/8 in [3 mm], or 2-1/4 times the thickness of the part, whichever is greater.

7.4.3 Maximum Slot Length. The length of the slot shall not exceed ten (10) times the thickness of the part containing it.

7.5 Complete Joint Penetration Groove Welds

7.5.1 Complete joint penetration groove welds in butt, corner, and T-joints, that may be used without performing the joint welding procedure qualification test prescribed in Clause 10, are detailed in Figures 7.1A through 7.1L, and are subject to the limitations specified in 7.5.2. (The symbols used in the figures are explained in Table 7.3.)

7.5.2 Tolerances. Welds specified in 7.5.1 may vary in design or detail drawings within the limits of tolerances shown in the “As Detailed” column in Figures 7.1A through 7.1L. Fit-up tolerances may be applied to the dimensions shown on the detail drawings.

7.5.2.1 Joint Details. Groove preparations detailed for prequalified SMAW joints may be used for prequalified GMAW or FCAW joints.

7.6 Partial Joint Penetration Groove Welds. Partial joint penetration groove welds that may be used without performing the joint welding procedure qualification tests prescribed in Clause 10 are detailed in Figures 7.2A through 7.2K, and are subject to the limitations specified in 7.6.2. (The symbols used in Figures 7.2A through 7.2K are explained in Table 7.3.)

7.6.1 Groove Welds Without Backing. Groove welds without steel backing, welded from one side, and groove welds welded from both sides, but without backgouging, are considered partial joint penetration groove welds.

7.6.2 Tolerances. Dimensions specified in 7.6 may vary in design or detail drawings within the limits or tolerances shown in the “As Detailed” column in Figures 7.2A through 7.2K. Fit-up tolerances may be applied to the dimensions shown on detailed drawings.

7.6.3 Working Drawings. The shop or working drawings shall specify groove depth(s) as applicable for the configuration and weld size, S, specified in Figures 7.2A through 7.2K.

7.6.4 Joint Details. Groove preparations detailed for prequalified SMAW joints may be used for prequalified GMAW and FCAW.

Table 7.1
Minimum and Maximum Plug Diameter and Slot Width

Base Metal Thickness (t)		Minimum		Maximum is greater of			
		in	mm	in	mm	in	mm
in	mm	$t + 5/16$	$t + 7.94$	$\text{Min} + 1/8$	$\text{Min.} + 3.17$	$t \times 2 \ 1/4$	$t \times 57.15$
1/4	6.35	9/16	14.29	11/16	17.46	9/16	14.29
5/16	7.94	5/8	15.87	3/4	19.05	45/64	17.86
3/8	9.52	11/16	17.46	13/16	20.64	27/32	21.43
7/16	11.11	3/4	19.05	7/8	22.22	63/64	25.00
1/2	12.70	13/16	20.64	15/16	23.81	1-1/8	28.57
9/16	14.29	7/8	22.22	1	25.40	1-17/64	32.15
5/8	15.87	15/16	23.81	1-1/16	26.97	1-13/32	35.72
11/16	17.46	1	25.40	1-1/8	28.57	1-35/64	39.29
3/4	19.05	1-1/16	26.97	1-3/16	30.16	1-11/16	42.86
13/16	20.64	1-1/8	28.57	1-1/4	31.75	1-53/64	46.43
7/8	22.22	1-3/16	30.16	1-5/16	33.34	1-31/32	50.01
15/16	23.81	1-1/4	31.75	1-3/8	34.92	2-7/64	53.58
1	25.40	1-5/16	33.34	1-7/16	36.51	2-1/4	57.15

Table 7.2
Effective Size of Flare-Groove Welds Filled Flush (see 7.1.2)

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

^aExcept GMAW-S.

Note: R = radius of outside surface.

Table 7.3
Minimum Fillet Weld Size

Base Metal Thickness of Thicker Part Joined (T), in [mm]	Minimum Size of Fillet, in ^{a, b} [mm] ^{a, b}
$T \leq 1/4$ [6]	1/8 [3]
$1/4$ [6] < $T \leq 1/2$ [13]	3/16 [5]
$1/2$ [13] < $T \leq 3/4$ [19]	1/4 [6]
$3/4$ [19] < T	5/16 [8]

^a Except that the weld size need not exceed the thickness of the thinner member joined. For this exception, particular care should be taken to provide sufficient preheat to ensure weld soundness.

^b For non-low hydrogen processes, single pass welds shall be used unless a Procedure Qualification is performed in accordance with 10.6.3.

Table 7.4
Legend for Figures 7.1A–7.1L and 7.2A–7.2K

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

Symbols for Base Metal Thickness and Penetration

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

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

Symbols for Welding Processes if not SMAW

S — SAW
 G — GMAW
 F — FCAW

Welding Processes

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

Welding Positions

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

Dimensions

R — Root Opening
 α, β — Groove Angles
 f — Root Face
 r — J- or U-groove Radius
 D, D₁, D₂ — PJP Groove Weld
 Depth of Groove
 S, S₁, S₂ — PJP Groove Weld
 Sizes corresponding to D, D₁, D₂, respectively

Joint Designation

The lower case letters (e.g., f and r) are used to differentiate between joints that would otherwise have the same joint designation.

Notes for Figures 7.1A–7.1L and 7.1A–7.2K

^a Not prequalified for gas metal arc welding using short circuiting transfer.

^b Gouge root to sound metal before welding second side.

^c Minimum weld size (S) as shown in Table 5.1; S as specified on drawings.

^d If fillet welds are used to reinforce groove welds in corner and T-joints, they shall be at least 1/4T₁, but need not exceed 3/8 in [9.6 mm].

^e 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.

^f Double-groove welds may have grooves of unequal depth, provided they conform to the limitations of Note E. Also, the weld size (S), less any reduction applies individually to each groove.

^g The orientation of the two members in the joints may vary from 135° to 180° provided that the basic joint configuration (groove angle, root face, root opening) remain the same and that the design weld size is maintained.

^h For corner and T-joints, the member orientation may be changed provided the groove angle is maintained as specified.

ⁱ The member orientation may be changed provided that the groove dimensions are maintained as specified.

^j The orientation of two members in the joints may vary from 45° to 135° for corner joints and from 45° to 90° for T-joints, provided that the basic joint configuration (groove angle, root face, root opening) remain the same and that the design weld size is maintained.

^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.

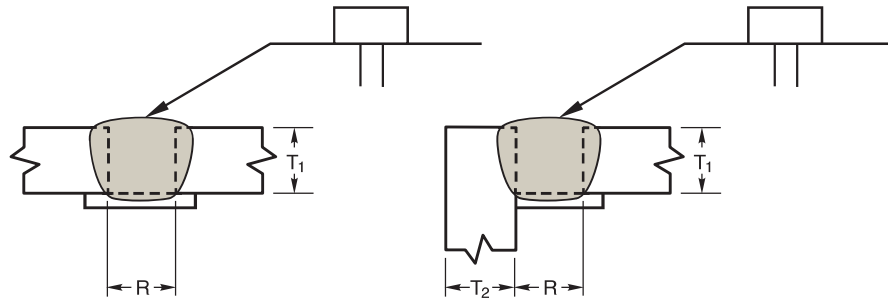
^l Weld Size (S) shall be based on joints welded flush.

^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.

See Notes on Page 36

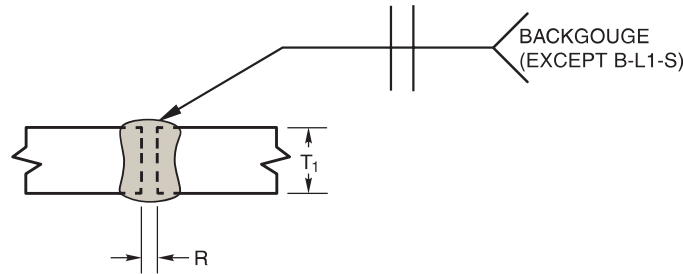
Square-groove weld (1)
Butt joint (B)
Corner joint (C)



All dimensions: in [mm]

Welding Process	Joint Designation	Base Metal Thickness (U = Unlimited)		Groove Preparation			Permitted Welding Positions	Gas Shielding for FCAW	Notes
		T ₁	T ₂	Root Opening	Tolerances				
					As Detailed (see 7.5.2)	As Fit-Up (see 6.3)			
SMAW	B-L1a	1/4 [6] max.	—	R = T ₁	+1/16, -0 [+2, -0]	+1/4, -1/16 [+6, -2]	All	—	g
	C-L1a	1/4 [6] max.	U	R = T ₁	+1/16, -0 [+2, -0]	+1/4, -1/16 [+6, -2]	All	—	—
FCAW GMAW	B-L1a-GF	3/8 [10] max.	—	R = T ₁	+1/16, -0 [+2, -0]	+1/4, -1/16 [+6, -2]	All	Not Required	a, g

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



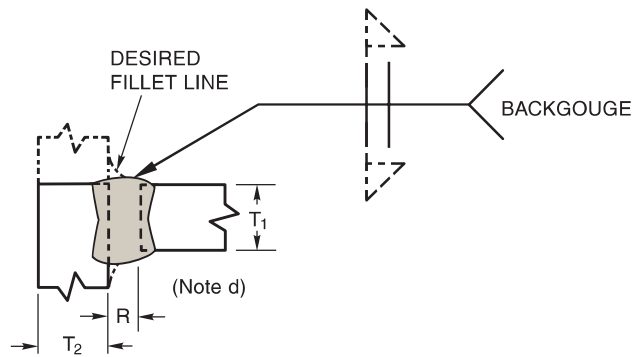
All dimensions: in [mm]

Welding Process	Joint Designation	Base Metal Thickness		Groove Preparation			Permitted Welding Positions	Gas Shielding for FCAW	Notes
		(U = Unlimited)		Root Opening	Tolerances				
		T ₁	T ₂		As Detailed (see 7.5.2)	As Fit-Up (see 6.3)			
SMAW	B-L1b	1/4 [6] max.	—	$R = \frac{T_1}{2}$	+1/16, -0 [+2, -0]	+1/16, -1/8 [+2, -3]	All	—	b, g
GMAW FCAW	B-L1b-GF	3/8 [10] max.	—	R = 0 to 1/8 [3]	+1/16, -0 [+2, -0]	+1/16, -1/8 [+2, -3]	All	Not Required	a, b, g
SAW	B-L1-S	3/8 [10] max.	—	R = 0	±0	+1/16, -0 [+2, -0]	F	—	g
SAW	B-L1a-S	3/8 [10] max.	—	R = 0	±0	+1/16, -0 [+2, -0]	F	—	b, g

Figure 7.1A—Prequalified Complete Joint Penetration (CJP) Groove Welded Joint Details

See Notes on Page 36

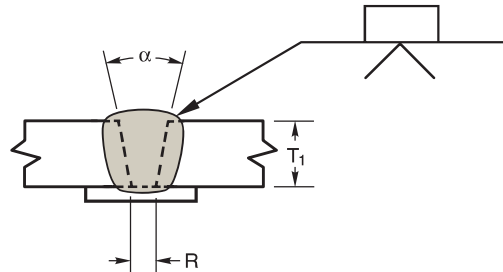
Square-groove weld (1)
T-joint (T)
Corner joint (C)



All dimensions: in [mm]

Welding Process	Joint Designation	Base Metal Thickness (U = Unlimited)		Groove Preparation			Permitted Welding Positions	Gas Shielding for FCAW	Notes
		T ₁	T ₂	Root Opening	Tolerances				
					As Detailed (see 7.5.2)	As Fit-Up (see 6.3)			
SMAW	TC-L1b	1/4 [6] max.	U	$R = \frac{T_1}{2}$	+1/16, -0 [+2, -0]	+1/16, -1/8 [+2, -3]	All	—	b, d
GMAW FCAW	TC-L1-GF	3/8 [10] max.	U	R = 0 to 1/8 [3]	+1/16, -0 [+2, -0]	+1/16, -1/8 [+2, -3]	All	Not Required	a, b, d
SAW	TC-L1-S	3/8 [10] max.	U	R = 0	±0	+1/16, -0 [+2, -0]	F	—	b, d

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



All dimensions: in [mm]

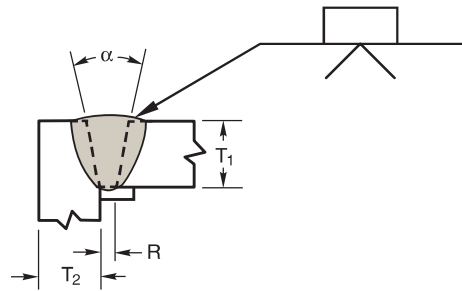
Tolerances	
As Detailed (see 7.5.2)	As Fit-Up (see 6.3)
$R = +1/16, -0$ [+2, -0]	$+1/4, -1/16$ [+6, -2]
$\alpha = +10^\circ, -0^\circ$	$+10^\circ, -5^\circ$

Welding Process	Joint Designation	Base Metal Thickness (U = Unlimited)		Groove Preparation		Permitted Welding Positions	Gas Shielding for FCAW	Notes
		T_1	T_2	Root Opening	Groove Angle			
SMAW	B-U2a	U	—	$R = 1/4$ [6]	$\alpha = 45^\circ$	All	—	g
				$R = 3/8$ [10]	$\alpha = 30^\circ$	F, OH, V	—	g
				$R = 1/2$ [13]	$\alpha = 20^\circ$	F, OH, V	—	g
				$R = 3/16$ [5]	$\alpha = 30^\circ$	F, OH, V	Required	a, g
GMAW FCAW	B-U2a-GF	U	—	$R = 3/8$ [10]	$\alpha = 30^\circ$	F, OH, V	Not Required	a, g
				$R = 1/4$ [6]	$\alpha = 45^\circ$	F, OH, V	Not Required	a, g
SAW	B-L2a-S	2 [51] max.	—	$R = 1/4$ [6]	$\alpha = 30^\circ$	F	—	g
SAW	B-U2-S	U	—	$R = 5/8$ [16]	$\alpha = 20^\circ$	F	—	g

Figure 7.1B—Prequalified Complete Joint Penetration (CJP) Groove Welded Joint Details

See Notes on Page 36

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



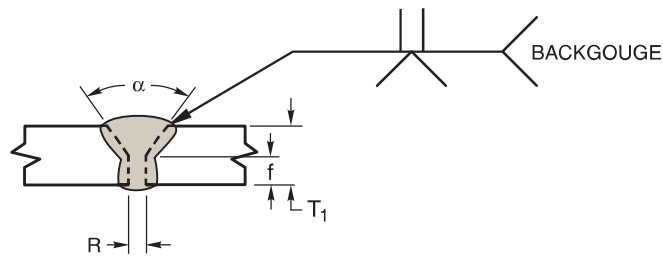
All dimensions: in [mm]

Tolerances	
As Detailed (see 7.5.2)	As Fit-Up (see 6.3)
$R = +1/16, -0$ [+2, -0]	$+1/4, -1/16$ [+6, -2]
$\alpha = +10^\circ, -0^\circ$	$+10^\circ, -5^\circ$

Welding Process	Joint Designation	Base Metal Thickness (U = Unlimited)		Groove Preparation		Permitted Welding Positions	Gas Shielding for FCAW	Notes
		T ₁	T ₂	Root Opening	Groove Angle			
SMAW	C-U2a	U	U	R = 1/4 [6]	$\alpha = 45^\circ$	All	—	h
				R = 3/8 [10]	$\alpha = 30^\circ$	F, OH, V	—	h
				R = 1/2 [13]	$\alpha = 20^\circ$	F, OH, V	—	h
				R = 3/16 [5]	$\alpha = 30^\circ$	F, OH, V	Required	a
GMAW FCAW	C-U2a-GF	U	U	R = 3/8 [10]	$\alpha = 30^\circ$	F, OH, V	Not Required	a, h
				R = 1/4 [6]	$\alpha = 45^\circ$	F, OH, V	Not Required	a, h
SAW	C-L2a-S	2 [51] max.	U	R = 1/4 [6]	$\alpha = 30^\circ$	F	—	h
SAW	C-U2-S	U	U	R = 5/8 [16]	$\alpha = 20^\circ$	F	—	h

Figure 7.1C—Prequalified Complete Joint Penetration (CJP) Groove Welded Joint Details

See Notes on Page 36

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

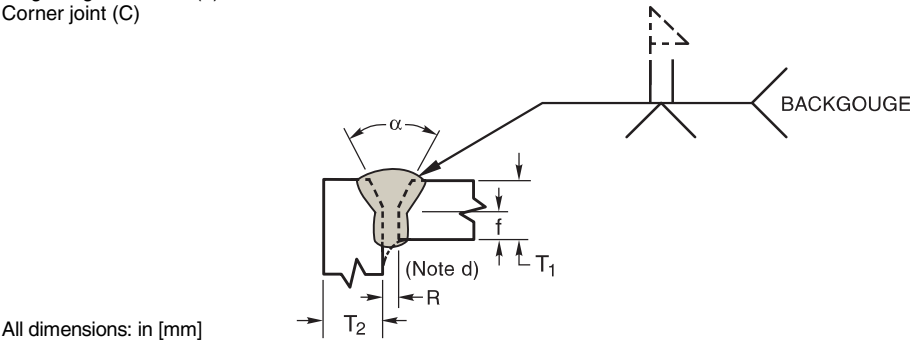
All dimensions: in [mm]

Welding Process	Joint Designation	Base Metal Thickness (U = Unlimited)		Groove Preparation			Permitted Welding Positions	Gas Shielding for FCAW	Notes
		T ₁	T ₂	Root Opening Root Face Groove Angle	Tolerances				
					As Detailed (see 7.5.2)	As Fit-Up (see 6.3)			
SMAW	B-U2	U	—	R = 0 to 1/8 [3]	+1/16, −0 [+2, −0]	+1/16, −1/8 [+2, −3]	All	—	b, g
				f = 0 to 1/8 [3]	+1/16, −0 [+2, −0]	Not Limited			
				α = 60°	+10°, −0°	+10°, −5°			
GMAW FCAW	B-U2-GF	U	—	R = 0 to 1/8 [3]	+1/16, −0 [+2, −0]	+1/16, −1/8 [+2, −3]	All	Not Required	a, b, g
				f = 0 to 1/8 [3]	+1/16, −0 [+2, −0]	Not Limited			
				α = 60°	+10°, −0°	+10°, −5°			
SAW	B-L2c-S	Over 1/2 to 1 [Over 13 to 25]	—	R = 0 f = 1/4 [6] max. α = 60°	R = ±0	+1/16, −0 [+2, −0]	F	—	b, g
		Over 1 to 1-1/2 [Over 25 to 38]	—	R = 0 f = 1/2 [13] max. α = 60°	f = +0, −f	±1/16 [±2]			
		Over 1-1/2 to 2 [Over 38 to 51]	—	R = 0 f = 5/8 [16] max. α = 60°	α = +10°, −0°	+10°, −5°			

**Figure 7.1C (Continued)—Prequalified Complete Joint Penetration (CJP)
Groove Welded Joint Details**

See Notes on Page 36

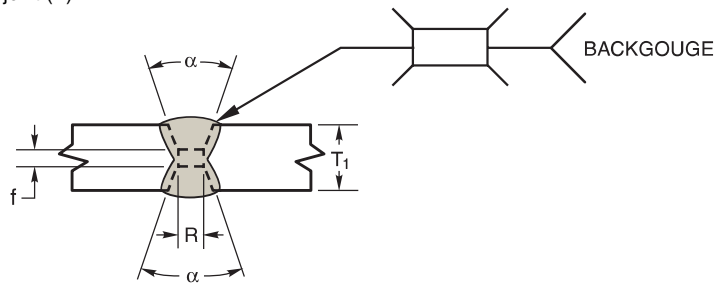
Single-V-groove weld (2)
Corner joint (C)



Welding Process	Joint Designation	Base Metal Thickness (U = Unlimited)		Groove Preparation			Permitted Welding Positions	Gas Shielding for FCAW	Notes
		T ₁	T ₂	Root Opening Root Face Groove Angle	Tolerances				
					As Detailed (see 7.5.2)	As Fit-Up (see 6.3)			
SMAW	C-U2	U	U	R = 0 to 1/8 [3]	+1/16, −0 [+2, −0]	+1/16, −1/8 [+2, −3]	All	—	b, d, j
				f = 0 to 1/8 [3]	+1/16, −0 [+2, −0]	Not Limited			
				α = 60°	+10°, −0°	+10°, −5°			
GMAW FCAW	C-U2-GF	U	U	R = 0 to 1/8 [3]	+1/16, −0 [+2, −0]	+1/16, −1/8 [+2, −3]	All	Not Required	a, b, d, j
				f = 0 to 1/8 [3]	+1/16, −0 [+2, −0]	Not Limited			
				α = 60°	+10°, −0°	+10°, −5°			
SAW	C-U2b-S	1 [25] max.	U	R = 0 to 1/8 [3]	±0	+1/16, −0 [+2, −0]	F	—	b, d, j
				f = 1/4 [6] max.	+0, −1/4 [−6]	±1/16 [±2]			
				α = 60°	+10°, −0°	+10°, −5°			

Figure 7.1D—Prequalified Complete Joint Penetration (CJP) Groove Welded Joint Details

See Notes on Page 36

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

All dimensions: in [mm]

Tolerances

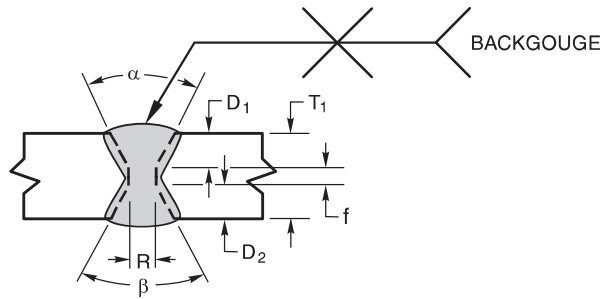
		As Detailed (see 7.5.2)	As Fit-Up (see 6.3)
	R = ±0		+1/4, -0 [+6, -0]
	f = +1/16, -0 [+2, -0]		±1/16 [±2]
	α = +10°, -0°		+10°, -5°
Spacer	SAW	±0	+1/16, -0 [+2, -0]
	SMAW	±0	+1/8, -0 [+3, -0]

Welding Process	Joint Designation	Base Metal Thickness (U = Unlimited)		Groove Preparation			Permitted Welding Positions	Gas Shielding for FCAW	Notes
		T ₁	T ₂	Root Opening	Root Face	Groove Angle			
SMAW	B-U3a	U	—	R = 1/4 [6]	f = 0 to 1/8 [3]	α = 45°	All	—	b, e, g
		Spacer = 1/8 [3] × R		R = 3/8 [10]	f = 0 to 1/8 [3]	α = 30°	F, OH, V		
				R = 1/2 [13]	f = 0 to 1/8 [3]	α = 20°	F, OH, V		
GMAW FCAW	B-U3a-GF	U	—	R = 1/4 [6]	f = 0 to 1/8 [3]	α = 45°	All	—	b, e, g
		Spacer = 1/8 [3] × R		R = 3/8 [10]	f = 0 to 1/8 [3]	α = 30°	F, OH, V		
				R = 1/2 [13]	f = 0 to 1/8 [3]	α = 20°	F, OH, V		
SAW	B-U3a-S	U Spacer = 1/4 [6] × R	—	R = 5/8 [16]	f = 0 to 1/4 [6]	α = 20°	F	—	b, e, g

**Figure 7.1D (Continued)—Prequalified Complete Joint Penetration (CJP)
Groove Welded Joint Details**

See Notes on Page 36

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



All dimensions: in [mm]

For B-U3c-S only

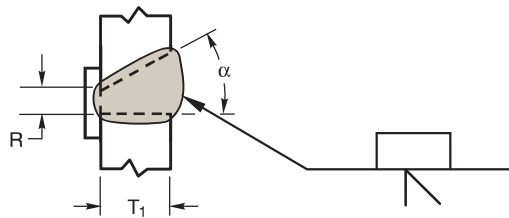
T ₁			D ₁		
Over			to		
2 [50]	2-1/2 [60]	1-3/8 [35]			
2-1/2 [60]	3 [80]	1-3/4 [45]			
3 [80]	3-5/8 [90]	2-1/8 [55]			
3-5/8 [90]	4 [100]	2-3/8 [60]			
4 [100]	4-3/4 [120]	2-3/4 [70]			
4-3/4 [120]	5-1/2 [140]	3-1/4 [80]			
5-1/2 [140]	6-1/4 [160]	3-3/4 [95]			
For T ₁ > 6-1/4 [160] or T ₁ ≤ 2 [50] D ₁ = 2/3 (T ₁ - 1/4 [6])					

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 7.5.2)	As Fit-Up (see 6.3)			
SMAW	B-U3b	U	—	R = 0 to 1/8 [3]	+1/16, −0 [+2, −0]	+1/16, −1/8 {+2, −3}	All	—	d, e, h, j
				f = 0 to 1/8 [3]	+1/16, −0 [+2, −0]	Not limited			
				α = β = 60°	+10°, −0°	+10°, −5°			
GMAW FCAW	B-U3-GF	U	—	R = 0 to 1/8 [3]	+1/16, −0 [+2, −0]	+1/16, −1/8 {+2, −3}	All	Not Required	a, d, h, j
				f = 0 to 1/8 [3]	+1/16, −0 [+2, −0]	Not limited			
				α = β = 60°	+10°, −0°	+10°, −5°			
SAW	B-U3c-S	U	—	R = 0	+1/16, −0 [+2, −0]	+1/16, −0 [+2, −0]	F	—	d, h, j
				f = 1/4 [6] min.	+1/4, −0 [+6, −0]	+1/4, −0 [+6, −0]			
				α = β = 60°	+10°, −0°	+10°, −5°			
To find D ₁ see table above: D ₂ = T ₁ − (D ₁ + f)									

Source: Adapted from AWS D1.1/D1.1M:2010, *Structural Welding Code—Steel*, Figure 3.4, American Welding Society.

**Figure 7.1D (Continued)—Prequalified Complete Joint Penetration (CJP)
Groove Welded Joint Details**

See Notes on Page 36

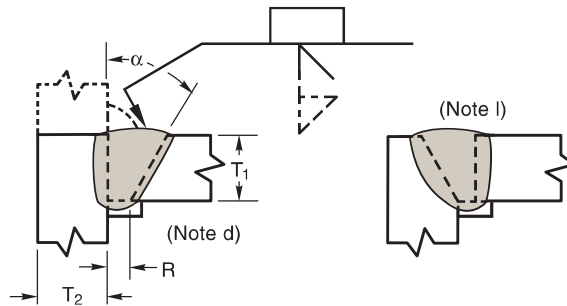
Single-bevel-groove weld (4)
Butt joint (B)

Tolerances

As Detailed (see 7.5.2)	As Fit-Up (see 6.3)
$R = +1/16, -0$ [+2, -0]	$+1/4, -1/16$ [+6, -2]
$\alpha = +10^\circ, -0^\circ$	$+10^\circ, -5^\circ$

All dimensions: in [mm]

Welding Process	Joint Designation	Base Metal Thickness (U = Unlimited)		Groove Preparation		Permitted Welding Positions	Gas Shielding for FCAW	Notes
		T ₁	T ₂	Root Opening	Groove Angle			
SMAW	B-U4a	U	—	$R = 1/4$ [6]	$\alpha = 45^\circ$	All	—	g
				$R = 3/8$ [10]	$\alpha = 30^\circ$	All	—	g
				$R = 3/16$ [5]	$\alpha = 30^\circ$	All	Required	a, g
GMAW FCAW	B-U4a-GF	U	—	$R = 1/4$ [6]	$\alpha = 45^\circ$	All	Not Required	a, g
				$R = 3/8$ [10]	$\alpha = 30^\circ$	F	Not Required	a, g

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

Tolerances

As Detailed (see 7.5.2)	As Fit-Up (see 6.3)
$R = +1/16, -0$ [+2, -0]	$+1/4, -1/16$ [+6, -2]
$\alpha = +10^\circ, -0^\circ$	$+10^\circ, -5^\circ$

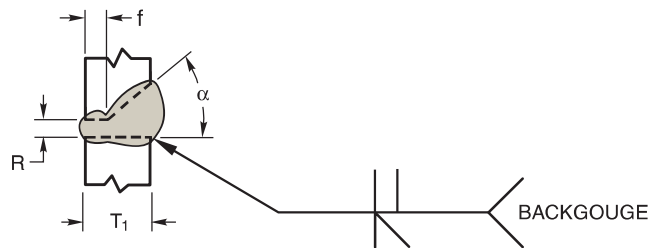
All dimensions: in [mm]

Welding Process	Joint Designation	Base Metal Thickness (U = Unlimited)		Groove Preparation		Permitted Welding Positions	Gas Shielding for FCAW	Notes
		T ₁	T ₂	Root Opening	Groove Angle			
SMAW	TC-U4a	U	U	$R = 1/4$ [6]	$\alpha = 45^\circ$	All	—	d, h, k
				$R = 3/8$ [10]	$\alpha = 30^\circ$	F, OH, V	—	d, h, k
				$R = 3/16$ [5]	$\alpha = 30^\circ$	All	Required	a, d, h, k
GMAW FCAW	TC-U4a-GF	U	U	$R = 1/4$ [6]	$\alpha = 45^\circ$	All	Not Required	a, d, h, k
				$R = 3/8$ [10]	$\alpha = 30^\circ$	F	Not Required	a, d, h, k
SAW	TC-U4a-S	U	U	$R = 1/4$ [6]	$\alpha = 45^\circ$	F	—	d, h, k
				$R = 3/8$ [10]	$\alpha = 30^\circ$			

Figure 7.1E—Prequalified Complete Joint Penetration (CJP) Groove Welded Joint Details

See Notes on Page 36

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



All dimensions: in [mm]

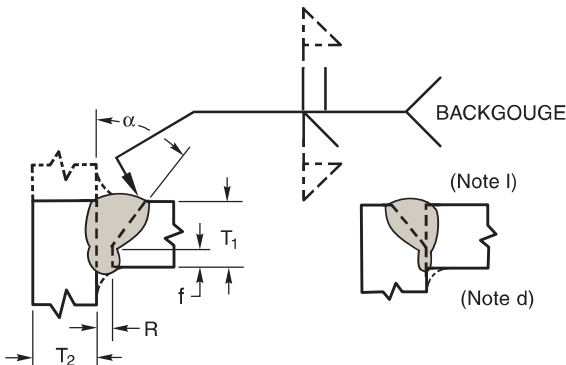
Welding Process	Joint Designation	Base Metal Thickness (U = Unlimited)		Groove Preparation			Permitted Welding Positions	Gas Shielding for FCAW	Notes
		T ₁	T ₂	Root Opening Root Face Groove Angle	Tolerances				
					As Detailed (see 7.5.2)	As Fit-Up (see 6.3)			
SMAW	B-U4b	U	—	R = 0 to 1/8 [3]	+1/16, −0 [+2, −0]	+1/16, −1/8 [+2, −3]	All	—	b, g
				f = 0 to 1/8 [3]	+1/16, −0 [+2, −0]	Not Limited			
				α = 45°	+10°, −0°	10°, −5°			
GMAW FCAW	B-U4b-GF	U	—	R = 0 to 1/8 [3]	+1/16, −0 [+2, −0]	+1/16, −1/8 [+2, −3]	All	Not Required	a, b, g
				f = 0 to 1/8 [3]	+1/16, −0 [+2, −0]	Not Limited			
				α = 45°	+10°, −0°	10°, −5°			

Figure 7.1F—Prequalified Complete Joint Penetration (CJP) Groove Welded Joint Details

See Notes on Page 36

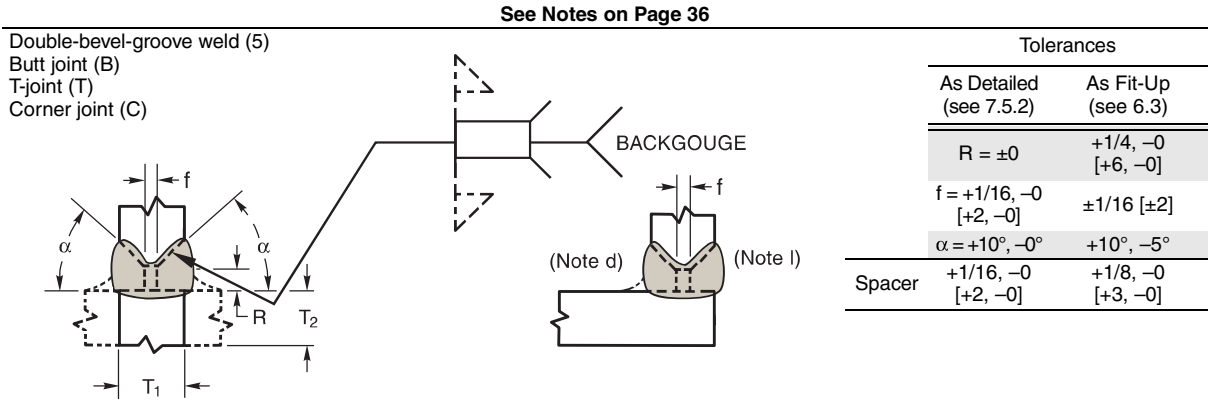
Single-bevel-groove weld (4)
T-joint (T)
Corner joint (C)

All dimensions: in [mm]



Welding Process	Joint Designation	Base Metal Thickness (U = Unlimited)		Groove Preparation			Permitted Welding Positions	Gas Shielding for FCAW	Notes
		T ₁	T ₂	Root Opening Root Face Groove Angle	Tolerances				
					As Detailed (see 7.5.2)	As Fit-Up (see 6.3)			
SMAW	TC-U4b	U	U	R = 0 to 1/8 [3]	+1/16, −0 [+2, −0]	+1/16, −1/8 [+2, −3]	All	—	b, d, j, k
				f = 0 to 1/8 [3]	+1/16, −0 [+2, −0]	Not Limited			
				α = 45°	+10°, −0°	10°, −5°			
GMAW FCAW	TC-U4b-GF	U	U	R = 0 to 1/8 [3]	+1/16, −0 [+2, −0]	+1/16, −1/8 [+2, −3]	All	Not Required	a, b, d, j, k
				f = 0 to 1/8 [3]	+1/16, −0 [+2, −0]	Not Limited			
				α = 45°	+10°, −0°	10°, −5°			
SAW	TC-U4b-S	U	U	R = 0	±0	+1/4, −0 [+6, −0]	F	—	b, d, j, k
				f = 1/8 [3] max.	+0, −1/8 [+0, −3]	±1/16 [±2]			
				α = 60°	+10°, −0°	10°, −5°			

Figure 7.1F (Continued)—Prequalified Complete Joint Penetration (CJP)
Groove Welded Joint Details



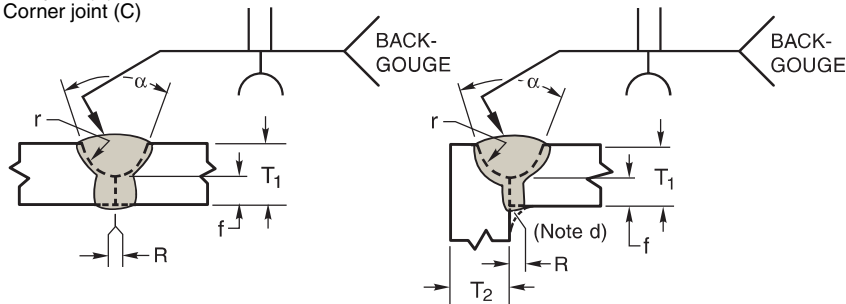
All dimensions: in [mm]

Welding Process	Joint Designation	Base Metal Thickness (U = Unlimited)		Groove Preparation			Permitted Welding Positions	Gas Shielding for FCAW	Notes
		T ₁	T ₂	Root Opening	Root Face	Groove Angle			
SMAW	B-U5b	U Preferably 5/8 or Thicker Spacer = 1/8 [3] × R	—	R = 1/4 [6]	f = 0 to 1/8 [3]	$\alpha = 45^\circ$	All	—	b, e, g
	TC-U5a	U Preferably 5/8 or Thicker Spacer = 1/8 [3] × R	U	R = 1/4 [6] R = 3/8 [10]	f = 0 to 1/8 [3] f = 0 to 1/8 [3]	$\alpha = 45^\circ$ $\alpha = 30^\circ$	All F, OH	—	b, d, e, j, k b, d, e, j, k
GMAW	B-U5b-GF	U Preferably 5/8 or Thicker Spacer = 1/8 [3] × R	—	R = 1/4 [6]	f = 0 to 1/8 [3]	$\alpha = 45^\circ$	All	—	b, e, g
	TC-U5a-GF	U Preferably 5/8 or Thicker Spacer = 1/8 [3] × R	—	R = 1/4 [6] R = 3/8 [10]	f = 0 to 1/8 [3] f = 0 to 1/8 [3]	$\alpha = 45^\circ$ $\alpha = 30^\circ$	All F, OH	—	b, e, g, j, k b, e, g, j, k

Figure 7.1G—Prequalified Complete Joint Penetration (CJP) Groove Welded Joint Details

See Notes on Page 36

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



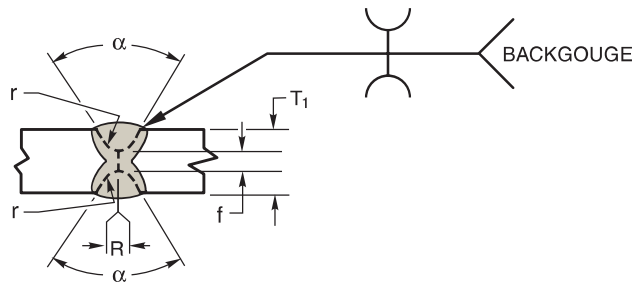
Tolerances

As Detailed (see 7.5.2)	As Fit-Up (see 6.3)
$R = +1/16, -0$ [+2, -0]	$+1/16, -1/8$ [+2, -3]
$\alpha = +10^\circ, -0^\circ$	$+10^\circ, -5^\circ$
$f = \pm 1/16 [\pm 2]$	Not Limited
$r = +1/8, -0$ [+3, -0]	$+1/8, -0$ [+3, -0]

All dimensions: in [mm]

Welding Process	Joint Designation	Base Metal Thickness (U = Unlimited)		Groove Preparation				Permitted Welding Positions	Gas Shielding for FCAW	Notes
		T_1	T_2	Root Opening	Groove Angle	Root Face	Groove Radius			
SMAW	B-U6	U	U	$R = 0 \text{ to } 1/8 [3]$	$\alpha = 45^\circ$	$f = 1/8 [3]$	$r = 1/4 [6]$	All	—	b, g
				$R = 0 \text{ to } 1/8 [3]$	$\alpha = 20^\circ$	$f = 1/8 [3]$	$r = 1/4 [6]$	F, OH	—	b, g
	C-U6	U	U	$R = 0 \text{ to } 1/8 [3]$	$\alpha = 45^\circ$	$f = 1/8 [3]$	$r = 1/4 [6]$	All	—	b, d, j
				$R = 0 \text{ to } 1/8 [3]$	$\alpha = 20^\circ$	$f = 1/8 [3]$	$r = 1/4 [6]$	F, OH	—	b, d, j
GMAW FCAW	B-U6-GF	U	U	$R = 0 \text{ to } 1/8 [3]$	$\alpha = 20^\circ$	$f = 1/8 [3]$	$r = 1/4 [6]$	All	Not Required	b, d, j
	C-U6-GF	U	U	$R = 0 \text{ to } 1/8 [3]$	$\alpha = 20^\circ$	$f = 1/8 [3]$	$r = 1/4 [6]$	All	Not Required	a, b, d, j

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



Tolerances

As Detailed (see 7.5.2)	As Fit-Up (see 6.3)
For B-U7 and B-U7-GF	
$R = +1/16, -0$ [+2, -0]	$+1/16, -1/8$ [+2, -3]
$\alpha = +10^\circ, -0^\circ$	$+10^\circ, -5^\circ$
$f = \pm 1/16, -0$	Not Limited
$r = +1/4, -0$ [+6, -0]	$\pm 1/16 [\pm 2]$
For B-U7-S	
$R = \pm 0$	$+1/16, -0$ [+2, -0]
$\alpha = +10^\circ, -0^\circ$	$+10^\circ, -5^\circ$
$f = \pm 0, -1/4$	$\pm 1/16 [\pm 2]$
$r = +1/4, -0$ [+6, -0]	$\pm 1/16$

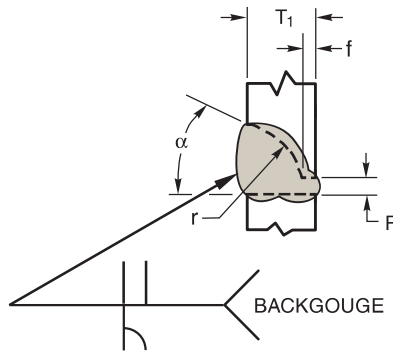
All dimensions: in [mm]

Welding Process	Joint Designation	Base Metal Thickness (U = Unlimited)		Groove Preparation				Permitted Welding Positions	Gas Shielding for FCAW	Notes
		T_1	T_2	Root Opening	Groove Angle	Root Face	Groove Radius			
SMAW	B-U7	U	—	$R = 0 \text{ to } 1/8 [3]$	$\alpha = 45^\circ$	$f = 1/8 [3]$	$r = 1/4 [6]$	All	—	b, e, g
				$R = 0 \text{ to } 1/8 [3]$	$\alpha = 20^\circ$	$f = 1/8 [3]$	$r = 1/4 [6]$	F, OH	—	b, e, g
GMAW FCAW	B-U7-GF	U	—	$R = 0 \text{ to } 1/8 [3]$	$\alpha = 20^\circ$	$f = 1/8 [3]$	$r = 1/4 [6]$	All	Not Required	a, b, e, g
SAW	B-U7-S	U	—	$R = 0$	$\alpha = 20^\circ$	$f = 1/4 [6]$ max.	$r = 1/4 [6]$	F	—	b, e, g

Figure 7.1H—Prequalified Complete Joint Penetration (CJP) Groove Welded Joint Details

See Notes on Page 36

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



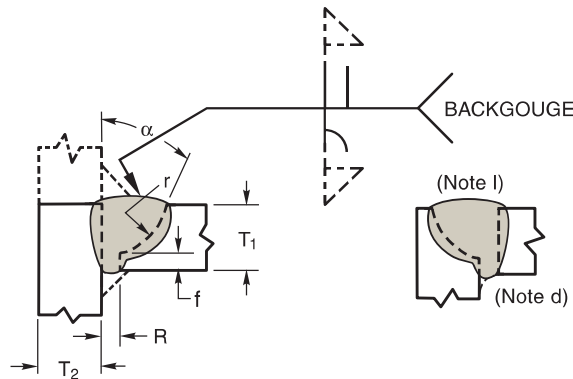
All dimensions: in [mm]

Tolerances

As Detailed (see 7.5.2)	As Fit-Up (see 6.3)
$R = +1/16, -0$ [+2, -0]	$+1/16, -1/8$ [+2, -3]
$\alpha = +10^\circ, -0^\circ$	$+10^\circ, -5^\circ$
$f = \pm 1/16, -0$ [±2, -0]	Not Limited
$r = +1/4, -0$ [+6, -0]	$\pm 1/16$ [±2]

Welding Process	Joint Designation	Base Metal Thickness (U = Unlimited)		Groove Preparation				Permitted Welding Positions	Gas Shielding for FCAW	Notes
		T ₁	T ₂	Root Opening	Groove Angle	Root Face	Groove Radius			
SMAW	B-U8	U	—	R = 0 to 1/8 [3]	$\alpha = 45^\circ$	f = 1/8 [3]	r = 3/8 [10]	All	—	b
GMAW FCAW	B-U8-GF	U	—	R = 0 to 1/8 [3]	$\alpha = 30^\circ$	f = 1/8 [3]	r = 3/8 [10]	All	Not Required	a, b

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



All dimensions: in [mm]

Tolerances

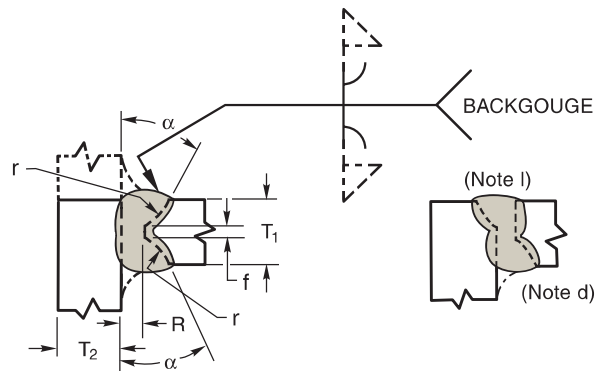
As Detailed (see 7.5.2)	As Fit-Up (see 6.3)
$R = +1/16, -0$ [+2, -0]	$+1/16, -1/8$ [+2, -3]
$\alpha = +10^\circ, -0^\circ$	$+10^\circ, -5^\circ$
$f = \pm 1/16, -0$ [±2, -0]	Not Limited
$r = +1/4, -0$ [+6, -0]	$\pm 1/16$ [±2]

Welding Process	Joint Designation	Base Metal Thickness (U = Unlimited)		Groove Preparation				Permitted Welding Positions	Gas Shielding for FCAW	Notes
		T ₁	T ₂	Root Opening	Groove Angle	Root Face	Groove Radius			
SMAW	TC-U8a	U	U	R = 0 to 1/8 [3] R = 0 to 1/8 [3]	$\alpha = 45^\circ$ $\alpha = 30^\circ$	f = 1/8 [3]	r = 3/8 [10]	All F, OH	—	b, d, j, k
GMAW FCAW	TC-U8a-GF	U	U	R = 0 to 1/8 [3]	$\alpha = 30^\circ$	f = 1/8 [3]	r = 3/8 [10]	All	Not Required	a, b, d, j, k

Figure 7.1I—Prequalified Complete Joint Penetration (CJP) Groove Welded Joint Details

See Notes on Page 36

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



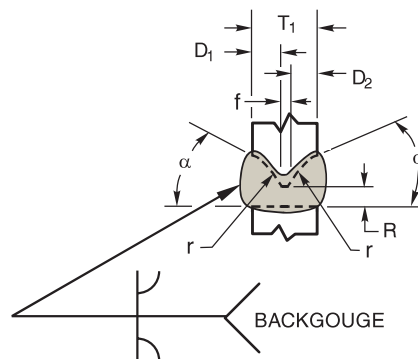
All dimensions: in [mm]

Tolerances	
As Detailed (see 7.5.2)	As Fit-Up (see 6.3)
$R = +1/16, -0$ [+2, -0]	$+1/16, -1/8$ [+2, -3]
$\alpha = +10^\circ, -0^\circ$	$+10^\circ, -5^\circ$
$f = \pm 1/16, -0$ [±2, -0]	Not Limited
$r = +1/8, -0$ [+3, -0]	$\pm 1/16$ [±2]

Welding Process	Joint Designation	Base Metal Thickness (U = Unlimited)		Groove Preparation				Permitted Welding Positions	Gas Shielding for FCAW	Notes
		T ₁	T ₂	Root Opening	Groove Angle	Root Face	Groove Radius			
SMAW	TC-U9a	U	U	$R = 0 \text{ to } 1/8$ [3] $R = 0 \text{ to } 1/8$ [3]	$\alpha = 45^\circ$ $\alpha = 30^\circ$	$f = 1/8$ [3] $f = 1/8$ [3]	$r = 3/8$ [10] $r = 3/8$ [10]	All F, OH	—	b, d, e, j, k
GMAW FCAW	TC-U9a-GF	U	U	$R = 0 \text{ to } 1/8$ [3]	$\alpha = 30^\circ$	$f = 1/8$ [3]	$r = 3/8$ [10]	All	Not Required	a, b, d, e, j, k

Figure 7.1J—Prequalified Complete Joint Penetration (CJP) Groove Welded Joint Details

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



All dimensions: in [mm]

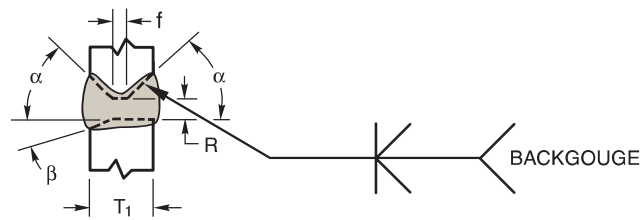
Tolerances	
As Detailed (see 7.5.2)	As Fit-Up (see 6.3)
$R = +1/16, -0$ [+2, -0]	$+1/16, -1/8$ [+2, -3]
$\alpha = +10^\circ, -0^\circ$	$+10^\circ, -5^\circ$
$f = +1/16, -0$ [+2, -0]	Not Limited
$r = +1/8, -0$ [+3, -0]	$\pm 1/16$ [±2]

Welding Process	Joint Designation	Base Metal Thickness (U = Unlimited)		Groove Preparation				Permitted Welding Positions	Gas Shielding for FCAW	Notes
		T ₁	T ₂	Root Opening	Groove Angle	Root Face	Groove Radius			
SMAW	B-U9	U	—	$R = 0 \text{ to } 1/8$ [3]	$\alpha = 45^\circ$	$f = 1/8$ [3]	$r = 3/8$ [10]	All	—	b, e, g
GMAW FCAW	B-U9-GF	U	—	$R = 0 \text{ to } 1/8$ [3]	$\alpha = 30^\circ$	$f = 1/8$ [3]	$r = 3/8$ [10]	All	Not Required	a, b, e, g

Figure 7.1K—Prequalified Complete Joint Penetration (CJP) Groove Welded Joint Details

See Notes on Page 36

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



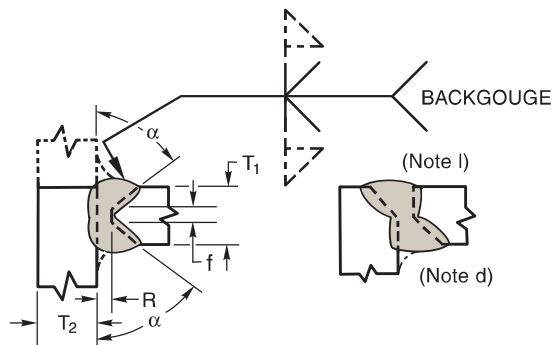
All dimensions: in [mm]

Welding Process	Joint Designation	Base Metal Thickness (U = Unlimited)		Groove Preparation			Permitted Welding Positions	Gas Shielding for FCAW	Notes
				Root Opening Root Face Groove Angle	Tolerances				
		T ₁	T ₂		As Detailed (see 7.5.2)	As Fit-Up (see 6.3)			
SMAW	B-U5a	U	—	R = 0 to 1/8 [3]	+1/16, −0 [+2, −0]	+1/16, −1/8 [+2, −3]	All	—	b, e, g
				f = 0 to 1/8 [3]	+1/16, −0 [+2, −0]	Not Limited			
				α = 45° β = 0° to 15°	α + β ^{+10°} _{−0°}	α + β ^{+10°} _{−5°}			
GMAW FCAW	B-U5-GF	U	—	R = 0 to 1/8 [3]	+1/16, −0 [+2, −0]	+1/16, −1/8 [+2, −3]	All	Not Required	a, b, e, g
				f = 0 to 1/8 [3]	+1/16, −0 [+2, −0]	Not Limited			
				α = 45° β = 0° to 15°	α + β = +10°, −0°	α + β = +10°, −5°			

Figure 7.1L—Prequalified Complete Joint Penetration (CJP) Groove Welded Joint Details

See Notes on Page 36

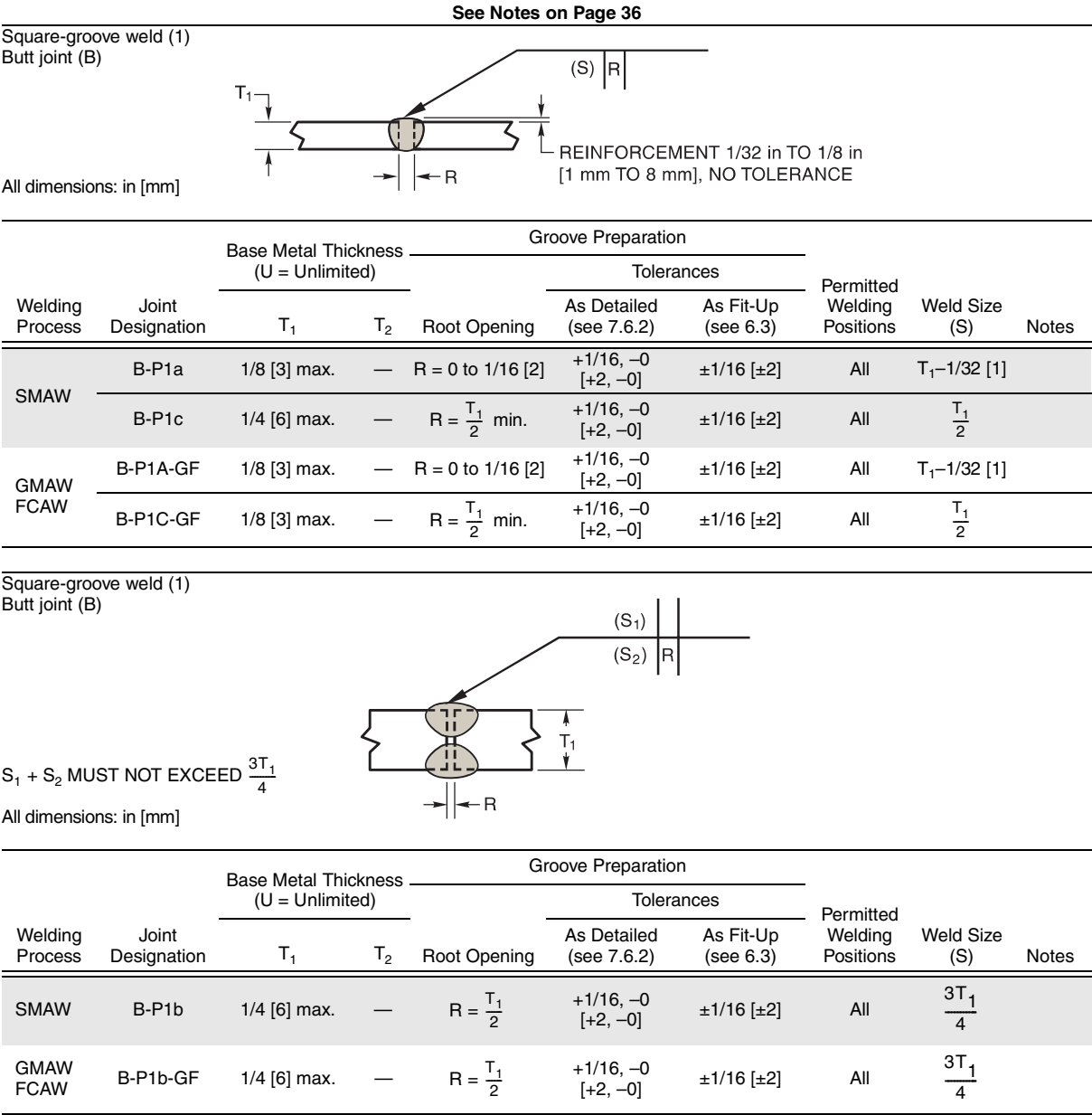
Double-bevel-groove weld (5)
T-joint (T)
Corner joint (C)



All dimensions: in [mm]

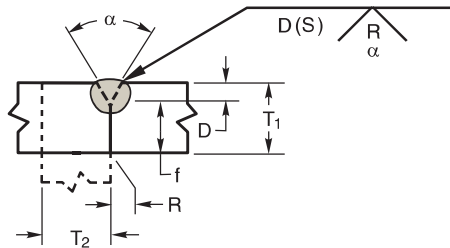
Welding Process	Joint Designation	Base Metal Thickness (U = Unlimited)		Groove Preparation			Permitted Welding Positions	Gas Shielding for FCAW	Notes
		T ₁	T ₂	Root Opening Root Face Groove Angle	Tolerances				
					As Detailed (see 7.5.2)	As Fit-Up (see 6.3)			
SMAW	TC-U5b	U	U	R = 0 to 1/8 [3]	+1/16, −0 [+2, −0]	+1/16, −1/8 [+2, −3]	All	—	b, d, e, j, k
				f = 0 to 1/8 [3]	+1/16, −0 [+2, −0]	Not Limited			
				α = 45°	+10°, −0°	+10°, −5°			
GMAW FCAW	TC-U5-GF	U	U	R = 0 to 1/8 [3]	+1/16, −0 [+2, −0]	+1/16, −1/8 [+2, −3]	All	Not Required	a, b, d, e, j, k
				f = 0 to 1/8 [3]	+1/16, −0 [+2, −0]	Not Limited			
				α = 45°	+10°, −0°	+10°, −5°			
SAW	TC-U5-S	U	U	R = 0	±0	+1/16, −0 [+2, −0]	F	—	b, d, e, j, k
				f = 3/16 [5] max.	+0, −3/16 [+0, −5]	±1/16 [±2]			
				α = 60°	+10°, −0°	+10°, −5°			

**Figure 7.1L (Continued)—Prequalified Complete Joint Penetration (CJP)
Groove Welded Joint Details**



See Notes on Page 36

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



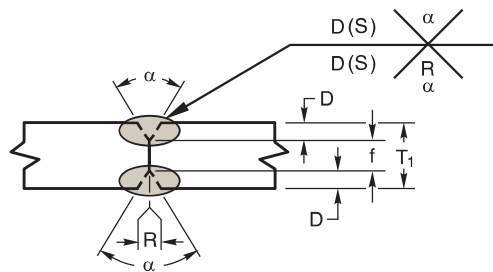
All dimensions: in [mm]

Welding Process	Joint Designation	Base Metal Thickness (U = Unlimited)		Groove Preparation			Permitted Welding Positions	Weld Size (S)	Notes
		T ₁	T ₂	Root Opening Root Face Groove Angle	Tolerances				
					As Detailed (see 7.6.2)	As Fit-Up (see 6.3)			
SMAW	BC-P2	1/4 [6] min.	U	R = 0	±0	+1/16, -0 [+2, -0]	All	D	c, i
				f = 1/8 [3] min.	±1/16 [±2]	±1/16 [±2]			
				α = 60°	+10°, -0°	+10°, -5°			
				R = 0	±0	+1/16, -0 [+2, -0]	All	D-1/8	c, i
				f = 1/8 [3] min.	±1/16 [±2]	±1/16 [±2]			
				α = 45°	+10°, -0°	+10°, -5°			
GMAW FCAW	BC-P2-GF	1/4 [6] min.	U	R = 0	±0	+1/16, -0 [+2, -0]	All	D	a, i
				f = 1/8 [3] min.	±1/16 [±2]	±1/16 [±2]			
				α = 60°	+10°, -0°	+10°, -5°			
				R = 0	±0	+1/16, -0 [+2, -0]	All	D-1/8 [3]	a, c, i
				f = 1/8 [3] min.	±1/16 [±2]	±1/16 [±2]			
				α = 45°	+10°, -0°	+10°, -5°			
SAW	BC-P2-S	7/16 [11] min.	U	R = 0	±0	+1/16, -0 [+2, -0]	F	D	c, i
				f = 1/4 [6] min.	±1/16 [±2]	±1/16 [±2]			
				α = 60°	+10°, -5°	+10°, -5°			

Figure 7.2B—Prequalified Partial Joint Penetration (PJP) Groove Welded Joint Details

See Notes on Page 36

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

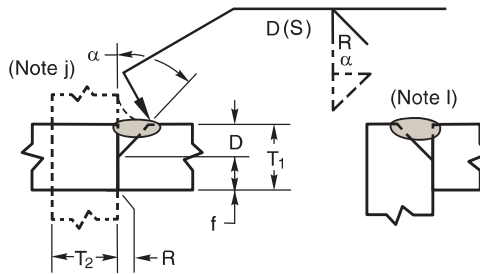


All dimensions: in [mm]

Welding Process	Joint Designation	Base Metal Thickness (U = Unlimited)		Groove Preparation			Permitted Welding Positions	Weld Size (S)	Notes
		T ₁	T ₂	Root Opening Root Face Groove Angle	Tolerances				
					As Detailed (see 7.6.2)	As Fit-Up (see 6.3)			
SMAW	B-P3	1/2 [13] min.	—	R = 0	±0	+1/16, −0 [+2, −0]	All	D	c, f, i
				f = 1/8 [3] min.	±1/16 [±2]	±1/16 [±2]			
				α = 60°	+10°, −0°	+10°, −5°			
				R = 0	±0	+1/16, −0 [+2, −0]	All	D−1/8 [3]	c, f, i
				f = 1/8 [3] min.	±1/16 [±2]	±1/16 [±2]			
				α = 45°	+10°, −0°	+10°, −5°			
GMAW FCAW	B-P3-GF	1/2 [13] min.	—	R = 0	±0	+1/16, −0 [+2, −0]	All	D	a, c, f, i
				f = 1/8 [3] min.	±1/16 [±2]	±1/16 [±2]			
				α = 60°	+10°, −0°	+10°, −5°			
				R = 0	±0	+1/16, −0 [+2, −0]	All	D−1/8 [3]	a, c, f, i
				f = 1/8 [3] min.	±1/16 [±2]	±1/16 [±2]			
				α = 45°	+10°, −0°	+10°, −5°			
SAW	B-P3-S	3/4 [19] min.	—	R = 0	±0	+1/16, −0 [+2, −0]	F	D	c, f, i
				f = 1/4 [6] min.	±1/16 [±2]	±1/16 [±2]			
				α = 60°	+10°, −5°	+10°, −5°			

Figure 7.2C—Prequalified Partial Joint Penetration (PJP) Groove Welded Joint Details

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



All dimensions: in [mm]

Welding Process	Joint Designation	Base Metal Thickness (U = Unlimited)		Groove Preparation			Permitted Welding Positions	Weld Size (S)	Notes
		T ₁	T ₂	Root Opening Root Face Groove Angle	Tolerances				
					As Detailed (see 7.6.2)	As Fit-Up (see 6.3)			
SMAW	BTC-P4	U	U	R = 0	±0	+1/16, -0 [+2, -0]	All	D	c, i, k
				f = 1/8 [3] min.	±1/16 [±2]	±1/16 [±2]			
				α = 60°	+10°, -0°	+10°, -5°			
				R = 0	±0	+1/16, -0 [+2, -0]	All	D-1/8 [3]	c, i, k
				f = 1/8 [3] min.	±1/16 [±2]	±1/16 [±2]			
				α = 45°	+10°, -0°	+10°, -5°			
GMAW FCAW	BTC-P4-GF	1/4 [6] min.	U	R = 0	±0	+1/16, -0 [+2, -0]	All	D	a, c, i, k
				f = 1/8 [3] min.	±1/16 [±2]	±1/16 [±2]			
				α = 60°	+10°, -0°	+10°, -5°			
				R = 0	±0	+1/16, -0 [+2, -0]	F, H	D	a, c, i, k
				f = 1/8 [3] min.	±1/16 [±2]	±1/16 [±2]			
				α = 45°	+10°, -0°	+10°, -5°	V, OH	D-1/8 [3]	
SAW	TC-P4-S	7/16 [11] min.	U	R = 0	±0	+1/16, -0 [+2, -0]	F	D	c, i, k
				f = 1/4 [6] min.	±1/16 [±2]	±1/16 [±2]			
				α = 60°	+10°, -5°	+10°, -5°			

Figure 7.2D—Prequalified Partial Joint Penetration (PJP) Groove Welded Joint Details

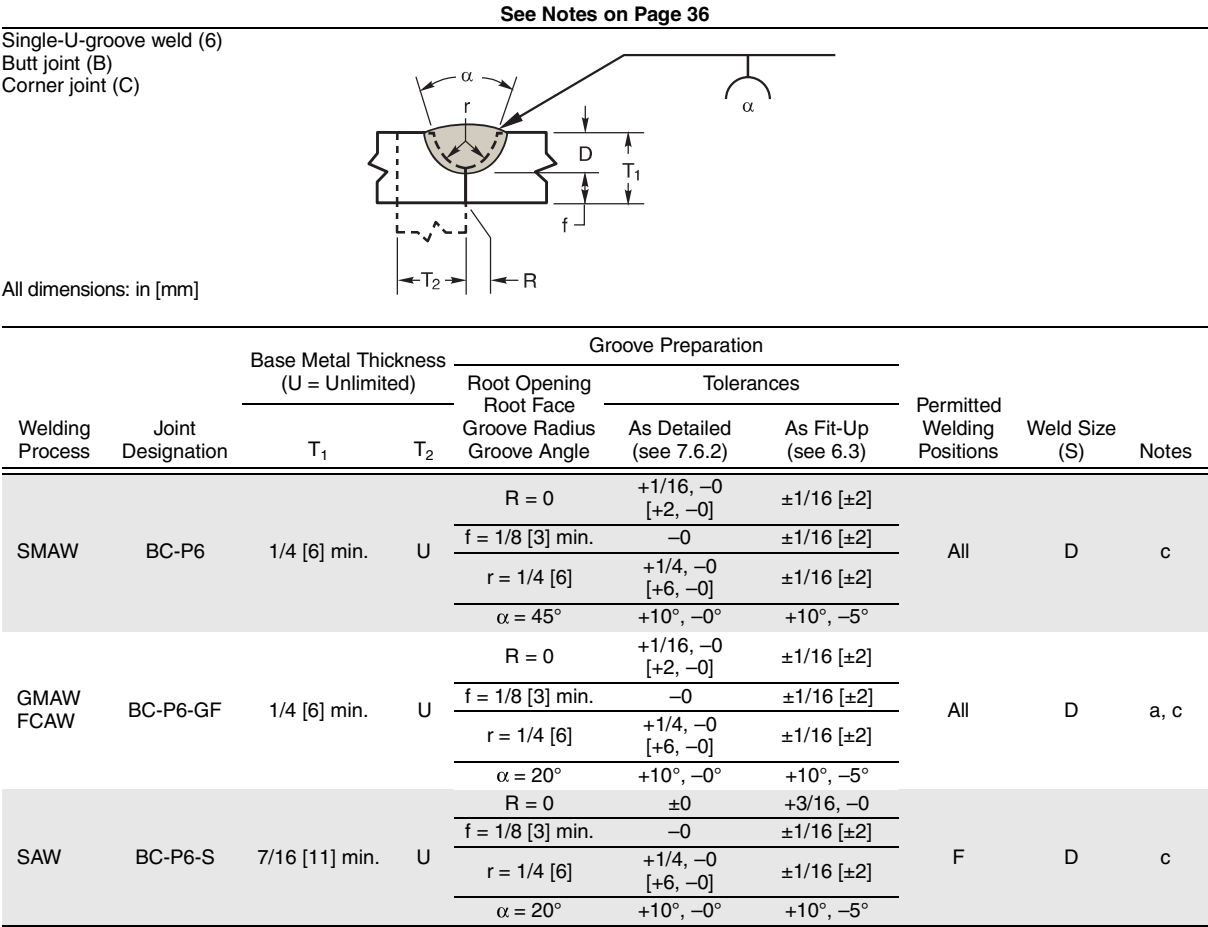
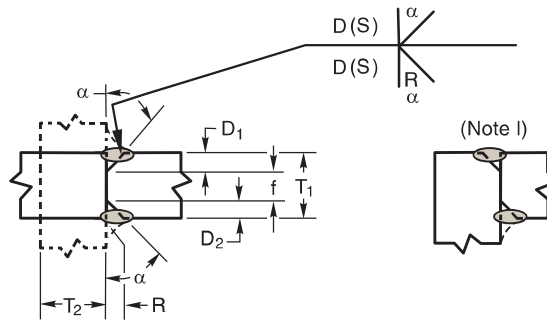


Figure 7.2E—Prequalified Partial Joint Penetration (PJP) Groove Welded Joint Details

See Notes on Page 36

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



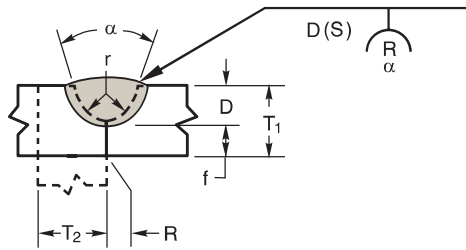
All dimensions: in [mm]

Welding Process	Joint Designation	Base Metal Thickness (U = Unlimited)		Groove Preparation			Permitted Welding Positions	Weld Size (S)	Notes
		T ₁	T ₂	Root Opening Root Face Groove Angle	Tolerances				
					As Detailed (see 7.6.2)	As Fit-Up (see 6.3)			
SMAW	BTC-P5	5/16 [8] min.	U	R = 0	±0	+1/16, −0 [+2, −0]	All	D	c, f, i, k
				f = 1/8 [3] min.	±1/16 [±2]	±1/16 [±2]			
				α = 60°	+10°, −0°	+10°, −5°			
				R = 0	±0	+1/16, −0 [+2, −0]	All	D−1/8 [3]	c, f, i, k
				f = 1/8 [3] min.	±1/16 [±2]	±1/16 [±2]			
				α = 45°	+10°, −0°	+10°, −5°			
GMAW FCAW	BTC-P5-GF	1/2 [13] min.	U	R = 0	±0	+1/16, −0 [+2, −0]	All	D	a, c, f, i, k
				f = 1/8 [3] min.	±1/16 [±2]	±1/16 [±2]			
				α = 60°	+10°, −0°	+10°, −5°			
				R = 0	±0	+1/16, −0 [+2, −0]	F, H	D	
				f = 1/8 [3] min.	±1/16 [±2]	±1/16 [±2]			
				α = 45°	+10°, −0°	+10°, −5°			
SAW	TC-P5-S	3/4 [19] min.	U	R = 0	±0	+1/16, −0 [+2, −0]	F	D	c, f, i, k
				f = 1/4 [6] min.	±1/16 [±2]	±1/16 [±2]			
				α = 60°	+10°, −5°	+10°, −5°			

Figure 7.2F—Prequalified Partial Joint Penetration (PJP) Groove Welded Joint Details

See Notes on Page 36

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

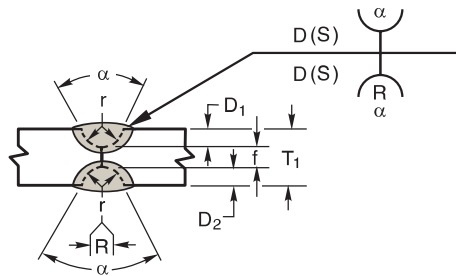


All dimensions: in [mm]

Welding Process	Joint Designation	Base Metal Thickness (U = Unlimited)		Groove Preparation			Permitted Welding Positions	Weld Size (S)	Notes
		T ₁	T ₂	Root Opening Root Face Groove Radius Groove Angle	Tolerances				
					As Detailed (see 7.6.2)	As Fit-Up (see 6.3)			
SMAW	BC-P6	1/4 [6] min.	U	R = 0	+1/16, −0 [+2, −0]	+1/8, −1/16 [+3, −2]	All	D	c, i
				f = 1/8 [3] min.	Unlimited	±1/16 [±2]			
				r = 1/4 [6]	+1/4, −0 [+6, −0]	±1/16 [±2]			
				α = 45°	+10°, −0°	+10°, −5°			
GMAW FCAW	BC-P6-GF	1/4 [6] min.	U	R = 0	+1/16, −0 [+2, −0]	+1/8, −1/16 [+3, −2]	All	D	a, c, i
				f = 1/8 [3] min.	Unlimited	±1/16 [±2]			
				r = 1/4 [6]	+1/4, −0 [+6, −0]	±1/16 [±2]			
				α = 20°	+10°, −0°	+10°, −5°			
SAW	BC-P6-S	7/16 [11] min.	U	R = 0	±0	+1/16, −0 [+2, −0]	F	D	i
				f = 1/8 [3] min.	Unlimited	±1/16 [±2]			
				r = 1/4 [6]	+1/4, −0 [+6, −0]	±1/16 [±2]			
				α = 20°	+10°, −0°	+10°, −5°			

Figure 7.2G—Prequalified Partial Joint Penetration (PJP) Groove Welded Joint Details

See Notes on Page 36

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

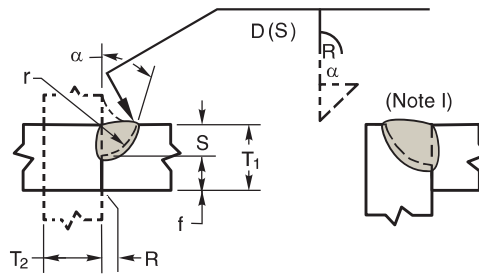
All dimensions: in [mm]

Welding Process	Joint Designation	Base Metal Thickness (U = Unlimited)		Groove Preparation			Permitted Welding Positions	Weld Size (S)	Notes
		T ₁	T ₂	Root Opening Root Face Groove Radius Groove Angle	Tolerances				
					As Detailed (see 7.6.2)	As Fit-Up (see 6.3)			
SMAW	B-P7	1/2 [13] min.	—	R = 0	+1/16, −0 [+2, −0]	+1/8, −1/16 [+3, −2]	All	D ₁ + D ₂	c, f, i
				f = 1/8 [3] min.	Unlimited	±1/16 [±2]			
				r = 1/4 [6] min.	+1/4, −0 [+6, −0]	±1/16 [±2]			
				α = 45°	+10°, −0°	+10°, −5°			
GMAW FCAW	B-P7-GF	1/2 [13] min.	—	R = 0	+1/16, −0 [+2, −0]	+1/8, −1/16 [+3, −2]	All	D ₁ + D ₂	a, c, f, i
				f = 1/8 [3] min.	Unlimited	±1/16 [±2]			
				r = 1/4 [6]	+1/4, −0 [+6, −0]	±1/16 [±2]			
				α = 20°	+10°, −0°	+10°, −5°			
SAW	B-P7-S	3/4 [19] min.	—	R = 0	±0	+1/16, −0 [+2, −0]	F	D ₁ + D ₂	c, f, i
				f = 1/4 [6] min.	Unlimited	±1/16 [±2]			
				r = 1/4 [6]	+1/4, −0 [+6, −0]	±1/16 [±2]			
				α = 20°	+10°, −0°	+10°, −5°			

Figure 7.2H—Prequalified Partial Joint Penetration (PJP) Groove Welded Joint Details

See Notes on Page 36

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



All dimensions: in [mm]

Welding Process	Joint Designation	Base Metal Thickness (U = Unlimited)		Groove Preparation			Permitted Welding Positions	Weld Size (S)	Notes
		T ₁	T ₂	Root Opening Root Face Groove Radius Groove Angle	Tolerances				
					As Detailed (see 7.6.2)	As Fit-Up (see 6.3)			
SMAW	TC-P8*	1/4 [6] min.	U	R = 0	+1/16, −0 [+2, −0]	+1/8, −1/16 [+3, −2]	All	D	c, i, k
				f = 1/8 [3] min.	Not Limited	±1/16 [±2]			
				r = 3/8 [10]	+1/4, −0 [+6, −0]	±1/16 [±2]			
				α = 45°	+10°, −0°	+10°, −5°			
SMAW	BC-P8**	1/4 [6] min.	U	R = 0	+1/16, −0 [+2, −0]	+1/8, −1/16 [+3, −2]	All	D	c, i, k
				f = 1/8 [3] min.	Not Limited	±1/16 [±2]			
				r = 3/8 [10]	+1/4, −0 [+6, −0]	±1/16 [±2]			
				α = 30°	+10°, −0°	+10°, −5°			
GMAW FCAW	TC-P8-GF*	1/4 [6] min.	U	R = 0	+1/16, −0 [+2, −0]	+1/8, −1/16 [+3, −2]	All	D	a, c, i, k
				f = 1/8 [3] min.	Not Limited	±1/16 [±2]			
				r = 3/8 [10]	+1/4, −0 [+6, −0]	±1/16 [±2]			
				α = 45°	+10°, −0°	+10°, −5°			
GMAW FCAW	BC-P8-GF**	1/4 [6] min.	U	R = 0	+1/16, −0 [+2, −0]	+1/8, −1/16 [+3, −2]	All	D	a, c, i, k
				f = 1/8 [3] min.	Not Limited	±1/16 [±2]			
				r = 3/8 [10]	+1/4, −0 [+6, −0]	±1/16 [±2]			
				α = 30°	+10°, −0°	+10°, −5°			
SAW	TC-P8-S*	7/16 [11] min.	U	R = 0	±0	+1/16, −0 [+2, −0]	F	D	c, i, k
				f = 1/4 [6] min.	Not Limited	±1/16 [±2]			
				r = 1/2 [13]	+1/4, −0 [+6, −0]	±1/16 [±2]			
				α = 45°	+10°, −0°	+10°, −5°			
SAW	C-P8-S**	7/16 [11] min.	U	R = 0	±0	+1/16, −0 [+2, −0]	F	D	c, i, k
				f = 1/4 [6] min.	Not Limited	±1/16 [±2]			
				r = 1/2 [13]	+1/4, −0 [+6, −0]	±1/16 [±2]			
				α = 20°	+10°, −0°	+10°, −5°			

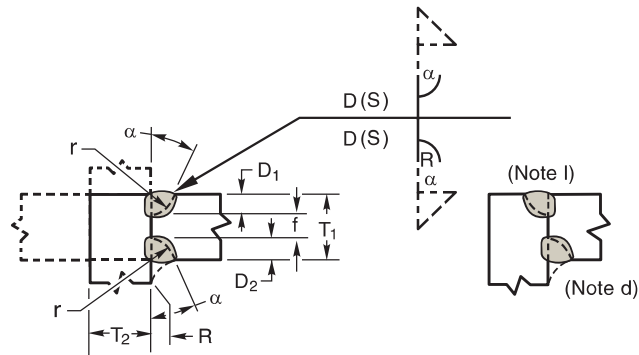
*Applies to inside corner joints.

**Applies to outside corner joints.

Figure 7.2I—Prequalified Partial Joint Penetration (PJP) Groove Welded Joint Details

See Notes on Page 36

Double-J-groove weld (9)
Butt joint (B)
T-joint (T)
Corner joint (C)



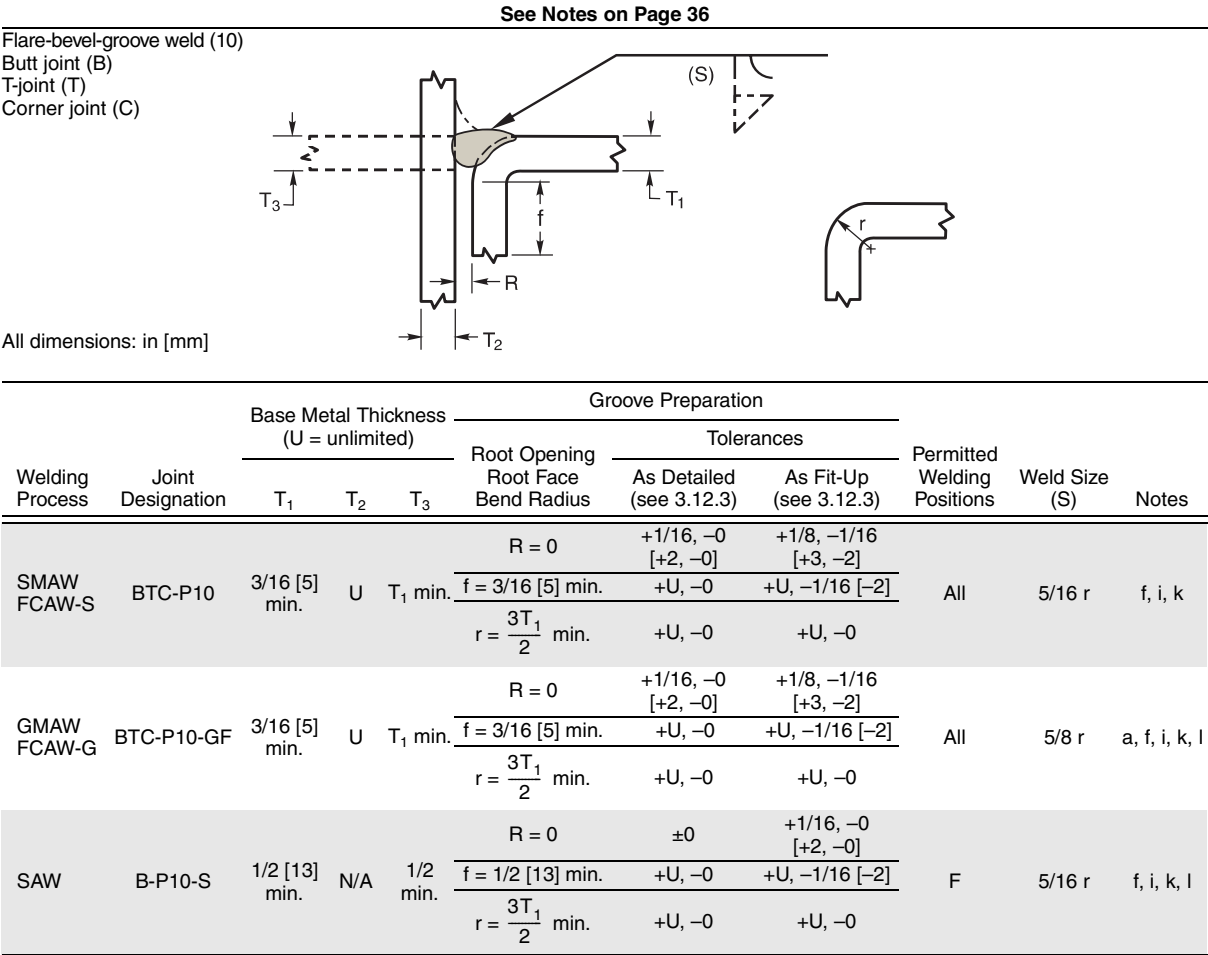
All dimensions: in [mm]

Welding Process	Joint Designation	Base Metal Thickness (U = Unlimited)		Groove Preparation			Permitted Welding Positions	Weld Size (S)	Notes
		T ₁	T ₂	Root Opening Root Face Groove Radius Groove Angle	Tolerances				
					As Detailed (see 7.6.2)	As Fit-Up (see 6.3)			
SMAW	BTC-P9*	1/2 [13] min.	U	R = 0	+1/16, -0 [+2, -0]	+1/8, -1/16 [+3, -2]	All	D ₁ + D ₂	c, f, i, k
				f = 1/8 [3] min.	-0	±1/16 [±2]			
				r = 3/8 [10]	+1/4, -0 [+6, -0]	±1/16 [±2]			
				α = 45°	+10°, -0°	+10°, -5°			
GMAW FCAW	BTC-P9-GF**	1/2 [13] min.	U	R = 0	+1/16, -0 [+2, -0]	+1/8, -1/16 [+3, -2]	All	D ₁ + D ₂	a, f, i, k
				f = 1/8 [3] min.	Not Limited	±1/16 [±2]			
				r = 3/8 [10]	+1/4, -0 [+6, -0]	±1/16 [±2]			
				α = 30°	+10°, -0°	+10°, -5°			
SAW	C-P9-S*	3/4 [19] min.	U	R = 0	±0	+1/16, -0 [+2, -0]	F	D ₁ + D ₂	c, f, i, k
				f = 1/4 [6] min.	Not Limited	±1/16 [±2]			
				r = 1/2 [13]	+1/4, -0 [+6, -0]	±1/16 [±2]			
				α = 45°	+10°, -0°	+10°, -5°			
SAW	C-P9-S**	3/4 [19] min.	U	R = 0	±0	+1/16, -0 [+2, -0]	F	D ₁ + D ₂	c, f, i, k
				f = 1/4 [6] min.	Not Limited	±1/16 [±2]			
				r = 1/2 [13]	+1/4, -0 [+6, -0]	±1/16 [±2]			
				α = 20°	+10°, -0°	+10°, -5°			
SAW	T-P9-S	3/4 [19] min.	U	R = 0	±0	+1/16, -0 [+2, -0]	F	D ₁ + D ₂	c, f, i
				f = 1/4 [6] min.	Not Limited	±1/16 [±2]			
				r = 1/2 [13]	+1/4, -0 [+6, -0]	±1/16 [±2]			
				α = 45°	+10°, -0°	+10°, -5°			

*Applies to inside corner joints.

**Applies to outside corner joints.

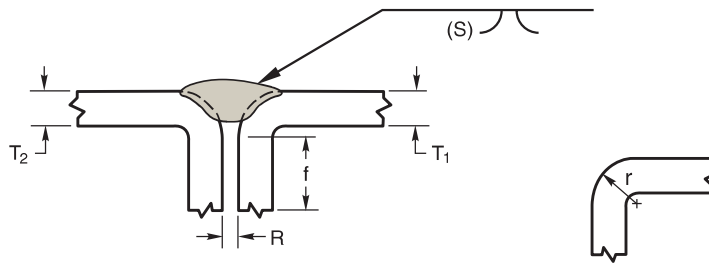
Figure 7.2J—Prequalified Partial Joint Penetration (PJP) Groove Welded Joint Details



Source: Adapted from AWS D1.1/D1.1M:2006, *Structural Welding Code—Steel*, Figure 3.3, American Welding Society.

Figure 7.2K—Prequalified Partial Joint Penetration (PJP) Groove Welded Joint Details

See Notes on Page 36

Flare-V-groove weld (11)
Butt joint (B)

All dimensions: in [mm]

Welding Process	Joint Designation	Base Metal Thickness		Groove Preparation			Permitted Welding Positions	Weld Size (S)	Notes
		(U = unlimited)		Root Opening Root Face Bend Radius	Tolerances				
		T ₁	T ₂		As Detailed (see 3.12.3)	As Fit-Up (see 3.12.3)			
SMAW FCAW-S	B-P11	3/16 [5] min.	T ₁ min.	R = 0	+1/16, -0 [+2, -0]	+1/8, -1/16 [+3, -2]	All	5/8 r	i, k, l, m
				f = 3/16 [5] min.	+U, -0	+U, -1/16 [-2]			
				$r = \frac{3T_1}{2}$ min.	+U, -0	+U, -0			
GMAW FCAW-G	B-P11-GF	3/16 [5] min.	T ₁ min.	R = 0	+1/16, -0 [+2, -0]	+1/8, -1/16 [+3, -2]	All	3/4 r	a, i, k, l, m
				f = 3/16 [5] min.	+U, -0	+U, -1/16 [-2]			
				$r = \frac{3T_1}{2}$ min.	+U, -0	+U, -0			
SAW	B-P11-S	1/2 [13] min.	T ₁ min.	R = 0	±0	+1/16, -0 [+2, -0]	F	1/2 r	i, k, l, m
				f = 1/2 [13] min.	+U, -0	+U, -1/16 [-2]			
				$r = \frac{3T_1}{2}$ min.	+U, -0	+U, -0			

**Figure 7.2K (Continued)—Prequalified Partial Joint Penetration (PJP)
Groove Welded Joint Details**

8. Technique for Prequalified Welding Procedure Specifications

8.1 Base Metal, Filler Metal, and Related Metal Requirements

8.1.1 Listed Base Metals and Filler Metals. Base metals and filler metals listed in Table 8.1 are the only materials that may be used in prequalified welding procedure specifications.

8.1.2 Unlisted Base Metals and Filler Metals. Other materials shall be qualified by test as described in Clause 10.

8.1.3 Matching Filler Metals Strength. When matching filler metal strength is required, welding shall be done using one of the filler metals within the matching specific class listed in Table 8.1.

8.1.4 Chromium-Molybdenum Filler Metals. The use of chromium-molybdenum filler metals is not permitted for a prequalified welding procedure specification. These filler metals have classifications ending in “-Bxx” (e.g., E8018-B2; ER90S-B3).

8.1.5 G-Series Filler Metals. The use of “G-Series” filler metals as defined in the applicable AWS A5 filler metal specification is not permitted for a prequalified welding procedure specification.

8.1.6 Other Material Requirements. Run-off tabs, fillers, spacer strips, and fused metallic backing shall be either a material listed in AWS B2.1/B2.1M, *Specification for Welding Procedure and Performance Qualification*, or Annex A with the same “M” number as the base metal, or the material specifically qualified.

8.2 Preheat, Interpass, and Postweld Heat Treatment (PWHT) Requirements

8.2.1 Preheated Area. When the base metal temperature is below the temperature listed in Table 8.2 for the welding process being used and the thickness of material being welded, it shall be preheated except as otherwise provided or as qualified in accordance with Clause 10. Preheating shall be in such manner that the parts on which the weld metal is being deposited are above the specified minimum temperature for a distance equal to the thickness of the part being welded, but not less than 3 in [76 mm], in all directions from the point of welding.

8.2.2 Preheat and Interpass Temperatures. Preheat and interpass temperatures shall be sufficient to prevent crack formation, and temperatures above the specified minimum may be required for highly restrained welds. In joints involving combinations of base metals, preheat shall be the highest specified for the steels being welded.

8.2.3 Thermal Stress Relief. If the weldment is to be thermally stress relieved, the welding procedure specification is not prequalified.

8.3 Shielded Metal Arc Welding (SMAW)

8.3.1 Electrodes for Shielded Metal Arc Welding. Electrodes shall conform to the requirements of the latest edition of AWS A5.1/A5.1M, *Specification for Carbon Steel Electrodes for Shielded Metal Arc Welding*, or to the requirements of AWS A5.5/A5.5M, *Specification for Low-Alloy Steel Electrodes for Shielded Metal Arc Welding*.

8.3.2 Procedures for Shielded Metal Arc Welding

8.3.2.1 Position. The work shall be in a flat position for welding whenever practical.

8.3.2.2 Welding Parameters. The classification and size of electrode, arc length, voltage, and amperage shall be suited to the thickness of the material, type of groove, welding positions, and other circumstances attending the work. Welding current shall be within the range recommended by the electrode manufacturer.

8.3.2.3 Maximum Electrode Diameter. The maximum diameter of electrodes shall be as follows:

- (1) 5/16 in [8 mm] for all welds made in the flat position, except root passes
- (2) 1/4 in [6 mm] for horizontal fillet welds
- (3) 1/4 in [6 mm] for root passes of fillet welds made in the flat position and groove welds made in the flat position with backing and a root opening of 1/4 in [6 mm] or more
- (4) 5/32 in [4 mm] for welds made with AWS A5.1/A5.1M Class EXX14 and low hydrogen electrodes in the vertical and overhead positions
- (5) 3/16 in [5 mm] for root passes of groove welds and for all other welds not included under (1) to (4)

8.3.2.4 Minimum Root Pass Weld Size. The minimum size of a root pass shall be sufficient to prevent cracking.

8.3.2.5 Maximum Root Pass Weld Size. The maximum thickness of root passes in groove welds shall be 1/4 in [6 mm].

8.3.2.6 Maximum Weld Size—Fillet Welds. The maximum size of single-pass fillet welds and root passes of multiple pass fillet welds shall be the following:

- (1) 3/8 in [10 mm] in the flat position
- (2) 5/16 in [8 mm] in the horizontal or overhead positions
- (3) 1/2 in [13 mm] in the vertical position

8.3.2.7 Maximum Weld Size—Intermediate Layers. The maximum thickness of layers subsequent to root passes of groove and fillet welds shall be the following:

- (1) 1/8 in [3 mm] for subsequent layers of welds made in the flat position
- (2) 3/16 in [5 mm] for subsequent layers of welds made in the vertical, overhead, or horizontal positions

8.3.2.8 Progression for Vertical Welds. The progression for all passes in vertical position welding shall be upward, except that undercut may be repaired vertically downwards when preheat is in accordance with Table 8.2, but not lower than 70°F [21°C]. However, when tubular products are welded, the progression of vertical welding may be upwards or downwards (see 11.2.7 for welder qualification requirements for vertical welding progression).

8.3.2.9 Complete Joint Penetration Groove Welds Without Backing. Complete joint penetration groove welds made without the use of steel backing shall have the root gouged to sound metal before welding is started from the second side.

8.4 Submerged Arc Welding (SAW)

8.4.1 General Requirements

8.4.1.1 SAW Electrode Spacing. SAW may be performed with one or more single electrodes, one or more parallel electrodes, or combinations of single and parallel electrodes. The spacing between arcs shall be such that the slag cover over the weld metal produced by a leading arc does not cool sufficiently to prevent the proper weld deposit of a following electrode. SAW with multiple electrodes may be used for any groove or fillet weld pass.

8.4.1.2 Electrode Diameter. The diameter of electrodes shall not exceed 1/4 in [6 mm].

8.4.1.3 Joint Penetration Testing Requirements. When the joint to be welded requires specific root penetration and is not backgouged, the company shall prepare a sample joint and macroetched cross section to demonstrate that the proposed welding procedure specification will attain the required root penetration. The Fabricator's Engineer may also accept properly documented evidence of previous qualification tests.

8.4.1.4 Backing. Roots of groove or fillet welds may be backed by copper, flux, glass tape, iron powder, or similar materials to prevent excessive melt-through. They may also be sealed by root passes using low hydrogen electrodes if SMAW is used, or by other arc welding processes.

8.4.1.5 Maximum Depth and Width. 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 8.1). This requirement may be waived only if the testing of a welding procedure specification (to the satisfaction of the Fabricator's Engineer) has demonstrated that such welds exhibit freedom from cracks and that the same welding procedure specification and flux-electrode classification are used in construction.

8.4.1.6 Requirements for Tack Welds. Tack welds (in the form of fillet welds 3/8 in [10 mm] or smaller, or in the roots of joints requiring specific root penetration) shall not produce objectionable changes in the appearance of the weld surface or result in decreased penetration. Tack welds not conforming to the preceding requirements shall be removed or reduced in size by any suitable means before welding. Tack welds in the root of a joint with steel backing less than 5/16 in [8 mm] thick shall be removed or replaced by a continuous weld.

8.4.2 Electrodes and Fluxes for Submerged Arc Welding. The bare electrodes and fluxes used in combination for SAW of steels shall conform to the latest edition of AWS A5.17/A5.17M, *Specification for Carbon Steel Electrodes and*

Fluxes for Submerged Arc Welding, or to the requirements of AWS A5.23/A5.23M, *Specification for Low-Alloy Steel Electrodes and Fluxes for Submerged Arc Welding*.

8.4.2.1 Active and Alloy Fluxes. The following limitations shall apply to prequalified procedures utilizing active or alloy fluxes:

(1) The maximum base metal thickness for multiple pass welds utilizing active or alloy flux shall be 1 in [25 mm], or that recommended by the flux manufacturer, whichever is less.

(2) Arc voltage for procedures utilizing active or alloy flux shall not exceed the manufacturer's recommended maximum value.

8.4.3 Procedures for Submerged Arc Welding (SAW) with a Single Electrode

8.4.3.1 Single Electrode. A single electrode is one electrode connected exclusively to one power source consisting of one or more power units.

8.4.3.2 Welding Position. All submerged arc welds, except fillet welds, shall be made in the flat position. Fillet welds are made in either the flat or horizontal position. Single-pass fillet welds made in the horizontal position shall not exceed 5/16 in [8 mm].

8.4.3.3 Maximum Weld Layer Thickness. The thickness of weld layers, except root and surface layers, shall not exceed 1/4 in [6 mm]. When the root opening is 1/2 in [13 mm] or greater, a multipass, split-layer technique shall be used. When the width of a layer of a multiple pass groove weld is 5/8 in [16 mm] or greater, a split layer technique shall be used for the next layer.

8.4.3.4 Maximum Welding Current. The welding current, arc voltage, and speed of travel shall be such that each pass shall have complete fusion with the adjacent base metal and weld metal and there shall be no overlap or undue undercutting. The maximum welding current used in making a groove weld for any pass that has fusion to both faces of the groove shall be 600 amperes (A), except that the final layer may be made using a higher current. The maximum current used for making fillet welds in the flat position shall be 1000 A.

8.4.4 Procedures for SAW with Parallel Electrodes

8.4.4.1 Parallel Electrodes. Parallel electrodes are two electrodes connected in a parallel circuit to the same power source. Both electrodes usually are fed by means of a single electrode feeder. Welding current, when specified, is the total for the two electrodes.

8.4.4.2 Welding Positions. Submerged arc welds with parallel electrodes, except fillet welds, shall be made in the flat position. Fillet welds may be made in either the flat or horizontal position, except that single-pass parallel electrode fillet welds made in the horizontal position shall not exceed 5/16 in [8 mm].

8.4.4.3 Split-Layer Technique. The thickness of weld layers is not limited. In making the root pass of a groove weld, single or parallel electrodes may be used. Steel backing bars or root faces shall be of adequate thickness to prevent excessive melt-through. When the width of a surface in a groove on which a layer of weld metal is to be deposited exceeds 1/2 in [13 mm], parallel electrodes shall be displaced laterally or a split-layer technique shall be used to assure adequate corner fusion. When the width of a previously deposited layer exceeds 5/8 in [16 mm], a split-layer technique with electrodes in tandem shall be used for the next layer.

8.4.4.4 Welding Parameters. The welding current, arc voltage, speed of travel, and relative location of electrodes shall be such that each pass shall have complete fusion with the adjacent base metal, and such that there shall be no depressions or undue undercutting at the toe of the weld. Excessive concavity of initial passes shall be avoided to prevent cracking in the roots of joints under restraint.

8.4.4.5 Maximum Welding Current—Groove Welds. The maximum welding current in making a groove weld shall be the following:

(1) 700 A for parallel electrodes when making the root pass in a groove having no root opening when the pass does not fill the groove

(2) 900 A for parallel electrodes when making the root pass in a groove having steel backing or a spacer strip

(3) 1200 A for parallel electrodes for all passes except the final layer

- (4) For the final layer, there is no restriction on welding current

8.4.4.6 Maximum Welding Current—Fillet Welds. The maximum welding current to be used in making a fillet weld shall be 1200 A for parallel electrodes.

8.4.4.7 Root Pass. Welds may also be made in the root of groove or fillet welds using gas metal arc welding (GMAW), followed by parallel submerged arcs, provided that the GMAW conforms to the requirements and providing the spacing between the gas shielded arc and the following submerged arc does not exceed 15 in [380 mm].

8.4.5 Procedures for SAW with Multiple Electrodes

8.4.5.1 Multiple Electrodes. Multiple electrodes are 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.

8.4.5.2 Welding Positions. Submerged arc welds made using multiple electrodes, except fillet welds, shall be in the flat position. Fillet welds may be in either the flat or horizontal position, except that single-pass, multiple-electrode fillet welds in the horizontal position shall not exceed 1/2 in [13 mm].

8.4.5.3 Weld Layer Limitations. The thickness of weld layers is not limited. In making the root pass of a groove weld, a single or multiple electrode may be used. Backing bars or root faces shall be of adequate thickness to prevent melt-through. When the width of a surface in a groove on which a layer of weld metal is to be deposited exceeds 1/2 in [13 mm], a split-layer technique shall be used to assure adequate corner fusion. When the width of a previously deposited layer exceeds 1 in [25 mm], and two electrodes only are used, a split-layer technique with electrodes in tandem shall be used for the next layer.

8.4.5.4 Welding Parameters. The welding current, arc voltage, speed of travel, and relative location of electrodes shall be such that each pass shall have complete fusion with the adjacent base metal and weld metal and such that there shall be no depressions or undue undercutting at the toe of the weld. Excessive concavity of initial passes shall be avoided to prevent cracking in roots of joints under restraint.

8.4.5.5 Maximum Welding Current—Groove Welds. The maximum welding current in making a groove weld shall be the following:

- (1) 700 A for any single electrode or for parallel electrodes when making the root pass in a groove having no root opening when the pass does not fill the groove
- (2) 750 A for any single electrode or 900 A for parallel electrodes when making the root pass in a groove having steel backing or a spacer strip
- (3) 1000 A for any single electrode or 1200 A for parallel electrodes for all other passes except the final layer
- (4) For the final layer, there is no restriction on welding current

8.4.5.6 Maximum Welding Current—Fillet Welds. The maximum welding current to be used in making a fillet weld is 1000 A for any single electrode or 1200 A for parallel electrodes.

8.4.5.7 Root Pass. Multiple electrode welds may also be made in the root of groove or fillet welds using GMAW followed by multiple submerged arcs, provided that the GMAW conforms to the requirements, and provided the spacing between the gas shielded arc and the first following submerged arc does not exceed 15 in [380 mm].

8.5 Gas Metal Arc and Flux Cored Arc Welding (GMAW and FCAW)

8.5.1 Welding Electrodes. The electrodes and shielding for GMAW or FCAW shall conform to the latest edition of AWS A5.18/A5.18M, *Specification for Carbon Steel Filler Metals for Gas Shielded Arc Welding*, AWS A5.20/A5.20M, *Specification for Carbon Steel Electrodes for Flux Cored Arc Welding*, AWS A5.28/A5.28M, *Specification for Low Alloy Steel Filler Metals for Gas Shielded Arc Welding*, or AWS A5.29/A5.29M, *Specification for Low Alloy Steel Electrodes for Flux Cored Arc Welding*, as applicable.

8.5.2 The following are required for prequalified procedures that are exempt from qualification testing:

- (1) Electrodes shall be dry and in suitable condition for use.
- (2) The maximum electrode diameter shall be 5/32 in [4 mm] for the flat and horizontal positions, 3/32 in [2 mm] for the vertical position, and 5/64 in [2 mm] for the overhead position.

(3) The maximum size of a fillet weld made in one pass shall be 1/2 in [13 mm] for the flat and vertical positions, 3/8 in [10 mm] for the horizontal position, and 5/16 in [8 mm] for the overhead position.

8.5.2.1 Weld Layer Thickness—Gas Metal Arc Welding. The thickness of weld layers, except root and surface layers, shall not exceed 1/4 in [6 mm]. When the root opening is 1/2 in [13 mm] or greater, a multiple-pass, split-layer technique shall be used for the next layer. When the width of a layer of a groove weld in the flat, horizontal, or overhead position is 5/8 in [16 mm] or greater, a split-layer technique shall be used for the next layer.

8.5.2.2 Weld Layer Thickness—Flux Cored Arc Welding. The thickness of the weld layers, except root and surface layers, shall not exceed 1/4 in [6 mm]. When the root opening is 1/2 in [13 mm] or greater, a split-layer technique shall be used. When the width of a layer of a groove weld in the flat, horizontal, or overhead position is 5/8 in [16 mm] or greater, a split-layer technique shall be used for the next layer. When welding in the vertical position, a split-layer technique shall be used when the width of the layer exceeds 1 in [25 mm]. When welding circular tubular joints in the 5G or 6G positions, progress of welding upwards, a split-layer technique shall be used when the width of the layer exceeds 1 in [25 mm].

8.5.2.3 Welding Parameters. The welding current, arc voltage, gas flow, mode of metal transfer, and speed of travel shall be such that each pass shall have complete fusion with adjacent base metal and weld metal. There shall be no overlap, excessive porosity, or undercutting.

8.5.2.4 Progression of Vertical Welds. The progressions for all passes of vertical position welding shall be upwards except that undercut may be repaired vertically downwards when preheat is in accordance with Table 8.2 but no lower than 70°F [21°C]. In tubular structures, the progression of vertical welding may be upwards or downwards (see 11.2.7 for welder qualification requirements for vertical progression welding).

8.5.2.5 Complete Joint Penetration Groove Welds Without Backing. Complete joint penetration groove welds made without the use of backing shall have the root of the initial weld gouged to sound metal before welding is started from the second side.

8.5.2.6 Maximum Wind Velocity. GMAW or FCAW with external gas shielding shall not be done in a draft or wind unless protected by a shelter. Such shelter shall be of material and shape appropriate to reduce wind velocity in the vicinity of the weld to a maximum of five miles [8 kilometers] per hour.

8.5.2.7 Unfused Backing. To prevent melt-through, the root of a groove or fillet weld may be backed by copper, flux, glass tape, iron powder, or similar materials, or sealed by means of root passes deposited by SMAW with low hydrogen electrodes or other arc welding processes.

8.6 Plug and Slot Welds

8.6.1 Plug Welds. The technique used to make plug welds, when using SMAW, GMAW (except short circuiting transfer), and FCAW processes shall be as follows:

8.6.1.1 Flat Position. For welds to be made in the flat position, each pass shall be deposited around the root of the joint and then deposited along a spiral path to the center of the hole, fusing and depositing a layer of weld metal in the root and bottom of the joint. The arc is then carried to the periphery of the hole and the procedure repeated, fusing and depositing successive layers to fill the hole to the required depth. The slag covering the weld metal should be kept molten until the weld is finished. If the arc is broken or the slag is allowed to cool, the slag shall be completely removed before restarting the weld.

8.6.1.2 Vertical Position. For welds to be made in the vertical position, the arc is started at the root of the joint at the lower side of the hole and is carried upward, fusing into the face of the inner plate and to the side of the hole. The arc is stopped at the top of the hole, the slag is cleaned off, and the process is repeated on the opposite side of the hole. After cleaning slag from the weld, other layers should be similarly deposited to fill the hole to the required depth.

8.6.1.3 Overhead Position. For welds to be made in the overhead position, the procedure is the same as for the flat position, except that the slag should be allowed to cool and should be completely removed after depositing each successive bead until the hole is filled to the required depth.

8.6.2 Slot Welds. Slot welds shall be made using techniques similar to those specified in 8.6.1.1 for plug welds, except that if the length of the slot exceeds three times the width, or if the slot extends to the edge of the part, the technique requirements of 8.6.1.3 shall apply.

8.7 Welding Wear Plates and Wear Liners. Welding procedure specifications for wear plates or liners that meet all of the requirements defined in 8.7.1 through 8.7.4 do not need to be qualified. Procedure qualification per Clause 10 is required for welding wear plates that also function as structural members.

8.7.1 Column Guide Wear Plates on Side Frames. Welding of column guide wear plates (typically constructed of AISI 1095 steel) shall be in accordance with the latest edition of AAR S-320, *Specification for the Application of Side Frame Column Friction Wear Plates*, and the side frame manufacturer's requirements. In applications where the welds are in addition to mechanical fasteners and primarily stabilize the wear plate, the acceptance criteria of 17.2.1 do not apply.

8.7.2 Bolster Bowl Wear Liners. Welding of bolster bowl wear liners shall be in accordance with the latest edition of AAR RP-301, AAR S-305, AAR S-308, as applicable, and the manufacturer's requirements.

8.7.3 Coupler Shank Wear Plates. Welding of coupler shank wear plates shall be in accordance with the latest edition of AAR S-137 and the manufacturer's requirements. It is permissible to apply manganese and stainless steel wear plates by welding using E309-XX/E309L-XX or equivalent FCAW or GMAW (except short circuited transfer) electrodes. It is permissible to apply nonmetallic wear plates mounted on mild steel plate by welding using E7015, E7016, E7018, or equivalent FCAW or GMAW (except short circuited transfer) electrodes.

8.7.4 Coupler Carrier Wear Plates. Welding may be used to secure manganese coupler carrier wear plates manufactured in accordance with the latest addition of AAR S-269, *Coupler Carrier Wear Plate*. Welding may be performed using E309-XX/E309L-XX electrodes or equivalent FCAW or GMAW (except short circuited transfer) wire, or AWS EFeMn electrodes per the latest edition of AAR *Field Manual Rule 16*.

8.7.5 Bolster Pocket Wear Plates. The welding of bolster pocket wear plates shall be in accordance with the bolster manufacturer's requirements.

8.7.6 Pedestal Roof Liners. The welding of pedestal roof liners shall be in accordance with AAR S-327, *Side Frame Roof Repair*, and the side frame manufacturer's requirements.

Table 8.1
Prequalified Base Metal—Filler Metal Combinations for Matching Strength

Steel Specification Requirements					Filler Metal Requirements ^j			
Steel Specification ^{a,b,c}	Minimum Yield Point/Strength		Tensile Range		Process	AWS Electrode Specification	Electrode Classification ^{e,h}	
	ksi	MPa	ksi	MPa				
Class 1								
ASTM A27	Grade U	30	207	60 min.	414 min.	SMAW	A5.1/A5.1M	E60XX, E70XX
ASTM A36 ^d		36	248	58/80	400/552		A5.5/A5.5M	E70XX-XX
ASTM A53	Type S or E Grade B	35	241	60 min.	414 min.	SAW	A5.17/A5.17M	F6AX-EXXX
	Type S or E Grade A	30	207	48 min.	331 min.			F7AX-EXXX
	Type F	25	172	45 min.	310 min.		A5.23/A5.23M	F7AX-EXX-XX
ASTM A106	Grade B	35	241	60 min.	414 min.		A5.18/A5.18M	ER70S-X
ASTM A131	Grades A, B, CS, D, DS, E	32	221	58/71	400/490			E70C-6X
ASTM A139	Grade B	35	241	60 min.	414 min.			E70C-3X
ASTM A216	Grade WCA	30	207	60 min.	414 min.	FCAW	A5.20/A5.20M	E6XT-X
ASTM A283	Grades A, B, C, D	25/32	172/221	45/60	310/414			E7XT-X
ASTM A381	Grade Y35	35	241	60 min.	414 min.			(Except -2, -3, -10, -GS)
ASTM A500	Grade A	33/39	228/269	45 min.	310 min.		A5.29/A5.29M	E7XTX-XX
	Grade B	42/46	290/317	58 min.	400 min.			
ASTM A501		36	248	58 min.	400 min.			
ASTM A515	Grade 55	30	207	55/75	379/517			
	Grade 60	32	221	60/80	414/552			
ASTM A516	Grade 55	30	207	55/65	379/448			
	Grade 60	32	221	60/72	414/496			
ASTM A524	Grade 1	35	241	60/85	414/586			
	Grade 11	30	207	55/60	379/414			
ASTM A529		42	290	60/85	414/586			
ASTM A569		(Note g)		(Note g)				
ASTM A570	Grade 30	30	207	49 min.	340 min.			
	Grade 33	33	228	52 min.	359 min.			
	Grade 36	36	248	53 min.	365 min.			
	Grade 40	40	276	55 min.	379 min.			
	Grade 45	45	310	60 min.	414 min.			
	Grade 50	50	345	65 min.	448 min.			
ASTM A573	Grade 65	35	241	65/77	448/531			
ASTM A656	Grade 50	50	345	60 min.	414 min.			
ASTM A709	Grade 36(4)	36	348	58/60	400/414			

(Continued)

Table 8.1 (Continued)
Prequalified Base Metal—Filler Metal Combinations for Matching Strength

Steel Specification Requirements				Filler Metal Requirements ^j		
Steel Specification ^{a,b,c}	Minimum Yield Point/Strength		Tensile Range		AWS Electrode Specification	Electrode Classification ^{e,h}
	ksi	MPa	ksi	MPa		
Class 1 (Continued)						
ASTM A808	42	290	60 min.	414 min.		
ASTM A1008		(Note g)		(Note g)		
	CS Type A, B, C	(Note g)		(Note g)		
	DS Type A, B	(Note g)		(Note g)		
	SS Grade 25	25	172	42	290	
	SS Grade 30	30	207	49	340	
	SS Grade 33 Types 1, 2	33	228	48	330	
	SS Grade 40 Types 1, 2	40	276	52	360	
	HSLAS Grade 45 Class 1	45	310	60	414	
	HSLAS Grade 45 Class 2	45	310	55	380	
	HSLAS Grade 50 Class 2	50	345	60	414	
	HSLAS-F Grade 50	50	345	60	414	
ASTM A1011	CS Types A, B, and C	(Note g)		(Note g)		
	DS Types A, B	(Note g)		(Note g)		
	SS Grade 30	30	207	49	340	
	SS Grade 33	33	228	52	360	
	SS Grade 36 Type 1	36	248	53	365	
	SS Grade 36 Type 2	36	248	58–80	400–550	
	SS Grade 40	40	276	55	380	
	SS Grade 45	45	310	60	414	
	HSLAS Grade 45 Class 1	45	310	60	414	
	HSLAS Grade 45 Class 2	45	310	55	380	
	HSLAS Grade 50 Class 2	50	345	60	414	
	HSLAS-F Grade 50	50	345	60	414	
ASTM A1018	CS (All grades except 1524)	(Note g)		(Note g)		
	DS	(Note g)		(Note g)		
	SS Grade 30	30	207	49	340	
	SS Grade 33	33	228	52	360	
	SS Grade 36 Type 1	36	250	53	365	
	SS Grade 36 Type 2	36	250	58–80	400–550	
	SS Grade 40	40	275	55	380	
	HSLAS Grade 45 Class 1	45	310	60	414	

(Continued)

Table 8.1 (Continued)
Prequalified Base Metal—Filler Metal Combinations for Matching Strength

Steel Specification Requirements					Filler Metal Requirements ^j		
Steel Specification ^{a,b,c}	Minimum Yield Point/Strength		Tensile Range		Process	AWS Electrode Specification	Electrode Classification ^{d,h}
	ksi	MPa	ksi	MPa			
Class 1 (Continued)							
API 5L	HSLAS Grade 45 Class 2	45	310	55	380		
	HSLAS Grade 50 Class 2	50	345	60	414		
	HSLAS-F Grade 50	50	345	60	414		
	Grade B	35	241	60 min.	414 min.		
	Grade X42	42	290	60 min.	414 min.		
AAR M201	Grade A	30	207	60 min.	414 min.		
	Hot rolled, annealed, or normalized weldable steel grades purchased to max. limits of C 0.28, Mn 1.00, P 0.04, S 0.05		(Note g)		(Note g)		
ABS	Grades A, B, CS, D, DS, and E	—		58/71	400/490		
Class II							
ASTM A27	Grade 65-35	35	241	65 min.	448 min.	SMAW	E7015
	Grade 70-36	36	248	70 min.	483 min.		E7016
	Grade 70-40	40	276	70 min.	483 min.		E7018
ASTM A131	Grades AH32, DH32, EH32	45.5	314	68/85	469/586		E7028
	Grades AH36, DH36, EH36	51	352	71/90	490/621	A5.5/A5.5M	E7015-XX
ASTM A216	Grade WCB	36	248	70 min.	483 min.		E7016-XX
	Grade WCC	40	276	70 min.	483 min.		E7018-XX
ASTM A242 ^e	Type 2	42/50	290/345	63/70	434/483	SAW	F7AX-EXXX
ASTM A441		42/50	290/345	63/70	434/483	A5.23/A5.23M	F7AX-EXX-XX
ASTM A500	Grade C	46	317	62 min.	427 min.	GMAW	A5.18/A5.18M
ASTM A515	Grade 65	35	241	64/85	441/586		ER70S-X
	Grade 70	38	262	70/90	482/621		E70C-3X
ASTM A516	Grade 65	35	241	65/77	448/531	FCAW	E70C-6X
	Grade 70	38	262	70/85	483/586		E7XT-X
ASTM A537	Class 1	50	345	70/90	483/621		(Except -2, -3, -10, -GS)
ASTM A572	Grade 42	42	290	60 min.	414 min.	A5.29/A5.29M	E7XTX-XX
ASTM A588 ^e	Grade 50	50	345	65 min.	448 min.		
	(4 in [102 mm] and under)	50	345	70 min.	483 min.		
ASTM A595	Grade A	55	379	65 min.	448 min.		

(Continued)

Table 8.1 (Continued)
Prequalified Base Metal—Filler Metal Combinations for Matching Strength

Steel Specification Requirements					Filler Metal Requirements ^j		
Steel Specification ^{a,b,c}	Minimum Yield Point/Strength		Tensile Range		AWS Electrode Specification	Electrode Classification ^{c,h}	
	ksi	MPa	ksi	MPa			
Class II (Continued)							
ASTM A606 ^e	Grades B and C	60	414	70 min.	483 min.		
		45	310	65 min.	448 min.		
ASTM A607	Grade 45	45	310	60 min.	414 min.		
		50	345	65 min.	448 min.		
ASTM A618	Grade 55	55	379	70 min.	483 min.		
		50	345	70 min.	483 min.		
ASTM A633	Grades A, B ^e	42	290	63/83	434/572		
		50	345	70/90	483/621		
(2-1/2 in [64 mm] and under)							
ASTM A656	Grade 60	60	414	70 min.	483 min.		
ASTM A709	Grade 50	50	345	65 min.	448 min.		
	Grade 50W	50	345	70 min.	483 min.		
ASTM A1008	SS Grade 50	50	340	65	410		
	HSLAS Grade 50 Class 1	50	340	65	450		
	HSLAS Grade 55 Class 1	55	380	70	480		
	HSLAS Grade 55 Class 2	55	380	65	448		
	HSLAS Grade 60 Class 2	60	410	70	480		
	HSLAS-F Grade 60	60	410	70	480		
ASTM A1011	SS Grade 50	50	345	65	448		
	HSLAS Grade 50 Class 1	50	345	65	448		
	SS Grade 55	55	379	70	483		
	HSLAS Grade 55 Class 1	55	379	70	483		
	HSLAS Grade 55 Class 2	55	379	65	448		
	HSLAS Grade 60 Class 2	60	414	70	483		
ASTM A1018	HSLAS-F Grade 60	60	414	70	483		
	HSLAS Grade 50 Class 1	50	340	65	448		
	HSLAS Grade 55 Class 1	55	379	70	483		
	HSLAS Grade 55 Class 2	55	379	65	448		
	HSLAS Grade 60 Class 2	60	414	70	483		
	HSLAS-F Grade 60	60	414	70	483		
API 2N(5)		42	290	62/80	427/552		

(Continued)

Table 8.1 (Continued)
Prequalified Base Metal—Filler Metal Combinations for Matching Strength

Steel Specification Requirements					Filler Metal Requirements ^j		
Steel Specification ^{a,b,c}	Minimum Yield Point/Strength		Tensile Range		Process	AWS Electrode Specification	Electrode Classification ^{e,h}
	ksi	MPa	ksi	MPa			
Class II (Continued)							
API 5LX	Grade X52	52	359	66/72	455/496		
ABS	Grades AH32, DH32, EH32	45.5	313	71/90	490/621		
	Grades AH32, DH32, EH36(5)	51	352	71/90	490/620		
AAR M201	Grade B	38	262	70 min.	483 min.		
	Hot rolled, annealed, or normalized weldable grades of carbon steel purchased to max. limits of C 0.34, Mn 1.00, P 0.04, S 0.05	(Note g)	(Note g)	(Note g)	(Note g)		
Class III							
ASTM A537	Class 2(5)	60	414	80/100	552/689	SMAW	A5.5/A5.5M E8015-XX
ASTM A572	Grade 60	60	414	75 min.	517 min.		E8016-XX
	Grade 65	65	448	80 min.	552 min.		E8018-XX
ASTM A633	Grade E(5)	60	414	80/100	552/689	SAW	A5.23/A5.23M F8AX-EXX-XX
ASTM A1008	SS Grade 60	60	414	75	517	GMAW	A5.28/A5.28M ER80S-XX
	HSLAS Grade 60 Class 1	60	414	75	517		E80C-XX
	HSLAS Grade 65 Class 1	65	448	80	552		E80TX-XX
	HSLAS Grade 65 Class 2	65	448	75	517		
	HSLAS Grade 70 Class 2	70	483	80	552		
	HSLAS-F Grade 70	70	483	80	552		
ASTM A1011	SS Grade 60	60	414	75	517		
	HSLAS Grade 60 Class 1	60	414	75	517		
	HSLAS Grade 65 Class 1	65	448	80	552		
	HSLAS Grade 65 Class 2	65	448	75	517		
	HSLAS Grade 70 Class 2	70	483	80	552		
	HSLAS-F Grade 70	70	483	80	552		
ASTM A1018	HSALS Grade 60 Class 1	60	414	75	517		
	HSLAS Grade 65 Class 1	65	448	80	552		
	HSLAS Grade 65 Class 2	65	448	75	517		
	HSLAS Grade 70 Class 2	70	483	80	552		
	HSLAS-F Grade 70	70	483	80	552		
	Grade B	50	345	81/101	558/696		
AAR M201	Grade B+	50	345	80 min.	552 min.		

(Continued)

Table 8.1 (Continued)
Prequalified Base Metal—Filler Metal Combinations for Matching Strength

Steel Specification ^{a, b, c}		Steel Specification Requirements		Filler Metal Requirements ^j		
		Minimum Yield Point/Strength	Tensile Range	Process	AWS Electrode Specification	Electrode Classification ^{t, h}
		ksi	MPa	ksi	MPa	
Class IV						
ASTM A514	(Over 2-1/2 in [64 mm])	90	621	100/130	689/896	E10015-XX
ASTM A709	Grades 100, 100W (2-1/2 in to 4 in [64 mm to 102 mm])	90	621	100/130	689/896	E10016-XX E10018-XX F10AX-EXX-XX F10AX-E(C)XX-XX
					SAW	A5.23/A5.23M
					GMAW	A5.5/A5.5M
					FCAW	A5.29/A5.29M
						ER100S-XX E10XTX-XX
Class V						
ASTM A514	(2-1/2 in [64 mm] and under)	100	689	110/130	758/896	E11015-XX
ASTM A517		100	689	115/135	792/931	E11016-XX E11018-XX
ASTM A709	Grades 100, 100W (2-1/2 in [64 mm] and under)	100	689	100/130	689/896	F11AX-EXX-XX F11AX-E(C)XX-XX
					SAW	A5.23/A5.23M
					GMAW	A5.28/A5.28M
					FCAW	A5.29/A5.29M
						ER110S-XX E11XTX-XX

^a In joints involving base metals of different classes, low hydrogen filler metal requirements applicable to the lower strength class may be used. The low hydrogen processes shall be subject to the technique requirements applicable to the higher strength class.

^b Match API Standard 2B (fabricated tubes) according to the steel use.

^c The addition of 0.2% min. copper is permitted.

^d Only low hydrogen electrodes shall be used when welding steel more than 1 in [25 mm] thick.

^e Special welding materials and procedures (e.g., E80XX-XX low hydrogen electrodes) may be required to match the notch toughness of base metal (for applications involving impacting or low temperature), or for atmospheric corrosion and weathering characteristics.

^f The use of chromium-molybdenum alloys (B-series filler metals) is not permitted.

^g Mechanical properties generally are not specified.

^h Deposited weld metal shall have a minimum impact strength of 20 ft-lb [27 Joules] at 0°F [-18°C] when Charpy V-notch specimens are required.

ⁱ When welding ASTM A514, A517, and A709 Grade 100 and 100W, the heat input shall not exceed the manufacturer's recommendation. This includes control of preheat and interpass temperatures, as well as arc energy (joules/inch).

^j AWS A5M (SI Units) electrodes of the same classification may be used in lieu of the AWS A5 (U.S. Customary Units) electrode classification.

Table 8.2
Prequalified Minimum Preheat and Interpass Temperature (Steel)^{a, b}

Preheat Category	Steel Specification ^c	Steel Specification ^c	Welding Process	Thickness of Thickest Part at Point of Welding		Minimum Temperature	
				in	mm	°F	°C
A	ASTM A27	Grade U60-30	Shielded metal arc welding with other than low hydrogen electrodes. For other processes, see Category B instructions.	≤3/4	≤20	32	0
	ASTM A36 ^d	Grade 60-30					
	ASTM A53	Types S or E Grades A and B, Type F		Over 3/4 through 1-1/2	Over 0 through 38	150	65
	ASTM A106	Grade B					
	ASTM A313	Grades A, B, CS, D, DS, E					
	ASTM A139	Grade B					
	ASTM A216	Grade WCA					
	ASTM A283	Grades A, B, C, D					
				Over 1-1/2 through 2-1/2	Over 38 through 63	225	104
	ASTM A381	Grade Y35					
	ASTM A500	Grade A					
	ASTM A501	Grade B					
				Over 2-1/2	Over 63	300	149

(Continued)

Table 8.2 (Continued)
Prequalified Minimum Preheat and Interpass Temperature (Steel)^{a, b}

Preheat Category	Steel Specification ^c	Steel Specification ^c	Welding Process	Thickness of Thickest Part at Point of Welding		Minimum Temperature	
				in	mm	°F	°C
B	ASTM A27	Grades 65-35, 70-36, 70-40	Shielded, metal arc welding with low hydrogen electrodes, submerged arc welding, gas metal arc welding, flux cored arc welding	≤3/4	≤19	32	0
	ASTM A36						
	ASTM A53	All grades					
	ASTM A106	Grade B					
	ASTM A131	Grades A, B, CS, D, DS, E					
		AH 32 and 36					
		DH 32 and 36					
		EH 32 and 36					
	ASTM A139	Grade B					
	ASTM A216	Grade WCB, WCC					
	ASTM A242	Grade 2					
	ASTM A283	Grades A, B, C, and D					
	ASTM A381	Grade Y35	Shielded, metal arc welding with low hydrogen electrodes, submerged arc welding, gas metal arc welding, flux cored arc welding	Over 3/4 through 1-1/2	Over 19 through 38	50	10
	ASTM A441						
	ASTM A500	Grades A, B					
	ASTM A501						
			Shielded, metal arc welding with low hydrogen electrodes, submerged arc welding, gas metal arc welding, flux cored arc welding	Over 1-1/2 through 2-1/2	Over 38 through 64	150	65
			Shielded, metal arc welding with low hydrogen electrodes, submerged arc welding, gas metal arc welding, flux cored arc welding	Over 1-1/2 through 2-1/2	Over 38 through 64	150	65

(Continued)

Table 8.2 (Continued)
Prequalified Minimum Preheat and Interpass Temperature (Steel)^{a, b}

Preheat Category	Steel Specification ^c	Steel Specification ^c	Welding Process	Thickness of Thickest Part at Point of Welding		Minimum Temperature
				in	mm	
B (Cont'd)	ASTM A516	Grades 65 and 70	Shielded, metal arc welding with low hydrogen electrodes, submerged arc welding, gas metal arc welding, flux cored arc welding	Over 2-1/2	Over 64	225 107
	ASTM A524	Grades 1 and 11				
	ASTM A529					
	ASTM A537	Classes 1 and 2				
C	ASTM A572	Grade 60 and 65	Shielded, metal arc welding with low hydrogen electrodes, submerged arc welding, gas metal arc welding, flux cored arc welding	≤3/4	≤19	50 10
	ASTM A633	Grade E				
	API 5 L X	Grade X52				
	AAR TC128 AAR M201	Grade B Grade B+				
D	ASTM A514		Shielded metal arc welding with low hydrogen electrodes, submerged arc welding with carbon or alloy steel wire or neutral flux, gas metal arc welding, or flux cored arc welding	≤3/4	≤19	50 10
	ASTM A517					
	ASTM A709	Grades 100 and 100W				

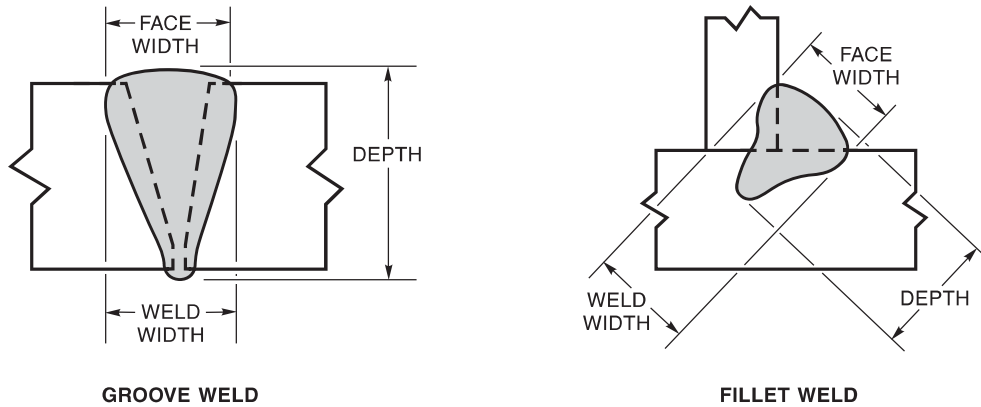
^a When the base metal is below the temperature listed for the welding process being used and the thickness of the base metal being welded, it shall be preheated (except as otherwise provided or as qualified in accordance with Clauses 9 through 13) in such manner that the surfaces of the base metal in which weld metal is being deposited are at or above the specified minimum temperature for a distance equal to the thickness of the members being welded, but not less than 3 in [76 mm] in all directions from the point of welding. Preheat and interpass temperatures must be sufficient to prevent crack formation. Temperature above the minimum shown may be required for highly restrained welds.

^b In joints involving combination of base metals, preheat shall be as specified for the higher strength steel being welded.

^c The addition of 0.2% min. copper is permitted.

^d Only low hydrogen electrodes shall be used when welding A36 or A709 Grade 36 steel more than 1 in [25 mm].

^e When welding ASTM A514, A517, and A709 Grade 100 and 100W, the heat input shall not exceed the manufacturer's recommendation. This includes control of preheat and interpass temperatures, as well as, arc energy (joules/inch).



Note: The details shown are examples only; they are applicable to all weld and groove types.

Figure 8.1—Weld Pass in Which Depth and Width Exceed the Width of the Weld Face

9. General Requirements for Qualification

9.1 Prequalified Procedures

9.1.1 Exemption from Testing. Welding procedure specifications that conform in all respects to the provisions of Clauses 5 through 8 shall be deemed as prequalified and shall be exempt from tests or qualification.

9.1.2 Engineering Judgment. The use of a prequalified joint welding procedure specification is not intended as a substitute for engineering judgment in the suitability of application of these welding procedure specifications to a welded assembly or connection.

9.1.3 Requirement for Written Welding Procedure Specifications. All prequalified joint welding procedure specifications to be used shall be prepared by the company as written welding procedure specifications and shall be available to those authorized to examine them. A suggested form showing the information required in the welding procedure specification is given in Annex D.

9.1.4 Combination of Qualified and Prequalified Welding Procedure Specifications. For base metal 1/8 in [3 mm] or greater in thickness, a combination of qualified or prequalified joint welding procedure specifications may be used without qualification, provided the limits of essential variables applicable to each procedure are observed.

9.1.5 Materials Less than 1/8 in [3 mm] Thick. There are no prequalified joints for welds made on base metal less than 1/8 in [3 mm] thick. Welding procedure specifications for these materials shall be qualified in accordance with 18.2.

9.2 Qualified Procedures. Except for the procedures exempted in 9.1.1, joint welding procedure specifications that are to be employed in executing work under this specification shall be qualified prior to use (to the satisfaction of the Fabricator's Engineer) by tests as prescribed in 10.1 through 10.11, as applicable. A welding procedure specification qualified by a company shall be considered qualified for use indefinitely. However, any change in the essential variables outside the limits provided for the specific base metal being welded shall require requalification.

9.3 Welders, Welding Operators, and Tack Welders

9.3.1 Testing Requirements. All welders, welding operators, and tack welders shall be qualified by tests prescribed in 5.3.1, as well as Clauses 11, 12, and 13.

9.4 Qualification Responsibility

9.4.1 Each company shall be responsible for welding procedure qualifications used by the company and their subcontractors. When a facility changes ownership, the new Owner shall review the procedure qualification records to determine whether they conform to the requirements of this specification. Properly documented WPSs that do conform to the provisions of this specification may be used without requalification provided that the new Owner accepts responsibility for them and that the WPSs reflect the name of the new Owner. The term "company" as used in this clause, in 5.2.3 and in 9.4.2 includes all companies under common ownership that utilize the same program of welding standards and documentation.

9.4.2 Each company shall be responsible for performance qualifications of welders, welding operators, and tack welders used by the company and their subcontractors. When a facility changes ownership, the new Owner shall review the performance qualification test records to determine whether they conform to the requirements of this specification. Welders, welding operators, and tack welders whose qualification records do conform to the provisions of this specification may continue to weld without requalification provided that the new Owner accepts responsibility for their qualification and that their qualification records reflect the name of the new Owner.

9.4.3 Qualifications that were performed to and met the requirements of earlier editions of AWS D15.1 while those editions were in effect are valid and may be used. It is not acceptable to use an earlier edition for new qualifications in lieu of the current edition, unless the specific early edition is a contractual requirement.

10. Procedure Qualification

10.1 Limitation of Essential Variables. Essential variables are as listed in Table 10.1. When Notch Toughness is a requirement, the “Supplemental Essential Variables” shall also apply.

10.2 Types of Tests and Purposes

10.2.1 Groove Welds. The types of tests outlined below are to determine the mechanical properties and soundness of welded joints made under a given procedure. The tests used are as follows:

- (1) Transverse reduced-section tension test (for tensile strength)
- (2) Transverse root-bend test (for soundness)
- (3) Transverse face-bend test (for soundness)
- (4) Side-bend test (for soundness)
- (5) Longitudinal face- and root-bend tests (for soundness)
- (6) All-weld-metal tension test (for mechanical properties)
- (7) Impact test (when specified for toughness—see 10.1.6)
- (8) Macroetch test for soundness and weld size measurements in partial penetration groove welds
- (9) Radiographic or ultrasonic testing (for soundness)

10.2.2 Fillet Welds. A macroetch test is required to determine the soundness of welded joints made under a given procedure.

10.2.3 Plug Welds. Three sample welds shall be made and each one sectioned through the center line of the weld. Each section shall be prepared per 10.8.2.

If the welding consumables and base metal combination do not conform to Table 8.1, and if the welding procedure specification has not been qualified for groove welds by the manufacturer in accordance with 10.6.1 or 10.6.2, then a complete joint penetration groove weld test plate shall be welded to qualify the proposed combination of base metal and consumables.

10.2.4 Slot Welds. Two slot welds shall be made. One shall be sectioned longitudinally through the center of the weld. The other shall be sectioned in three places transverse to the weld. Sections shall be at the center of the weld length and at a distance from the weld ends equal to weld length divided by four. Each section shall be prepared per 10.8.2.

If the welding consumables and base metal combination do not conform to Table 8.1, and if the welding procedure specification has not been qualified for groove welds by the manufacturer in accordance with 10.6.1 or 10.6.2, then a complete joint penetration groove weld test plate shall be welded to qualify the proposed combination of base metal and consumables.

10.2.5 Buildup Welds. Buildup welds shall be qualified using the complete joint penetration groove weld test.

10.3 Base Metal and Its Preparation. The base metal and its preparation for welding shall comply with the welding procedure specification. For all types of welded joints, the length of the weld and dimensions of the base metal shall provide sufficient material for test specimens required by this specification.

10.4 Position of Test Welds. All welds used in actual construction shall be classified as: (1) flat, (2) horizontal, (3) vertical, or (4) overhead in accordance with the definitions of welding positions given in Figures 10.1 and 10.2. Each procedure shall be tested in the manner stated below for each position for which it is to be qualified (see also Table 10.4).

10.4.1 Groove Plate Test Welds (Figure 10.3). In making the tests to qualify groove welds, test plates shall be welded in the following positions:

10.4.1.1 Position 1G (Flat). The test plate shall be placed in an approximately horizontal plane and the weld metal deposited from the upper side [see Figure 10.3(A)].

10.4.1.2 Position 2G (Horizontal). The test plates shall be placed in an approximately vertical plane with the groove approximately horizontal [see Figure 10.3(B)].

10.4.1.3 Position 3G (Vertical). The test plates shall be placed with the groove approximately vertical [see Figure 10.3(C)].

10.4.1.4 Position 4G (Overhead). The test plates shall be placed in an approximately horizontal plane and the weld metal shall be deposited from the underside [see Figure 10.3(D)].

10.4.1.5 A manufacturer who does production welding in a special orientation may make a groove plate test weld for procedure qualification in that specific orientation. Such qualifications are valid only for the positions actually tested, except for the following:

(1) For other than vertical position test welds (Figure 10.1) an angular deviation of $\pm 15^\circ$ is permitted in the inclination of the weld axis and the rotation of the weld face.

(2) Vertical position test welds qualify all vertical positions of lesser inclination.

10.4.2 Groove Pipe Test Welds (Figure 10.4). In making the tests to qualify groove welds, test pipe shall be welded in the following positions:

10.4.2.1 Position 1G (Pipe Horizontal Rolled). The test pipe shall be placed with its axis horizontal and the groove approximately vertical. The pipe shall be rotated during welding so the weld metal is deposited from the upper side [see Figure 10.4(A)].

10.4.2.2 Position 2G (Pipe Vertical Fixed). The test pipe shall be placed with its axis vertical and the welding groove approximately horizontal. The pipe shall not be rotated during welding [see Figure 10.4(B)].

10.4.2.3 Position 5G (Pipe Horizontal Fixed). The test pipe shall be placed with its axis horizontal and the groove approximately vertical. The pipe is not rotated during welding [see Figure 10.4(C)].

10.4.2.4 Position 6G (Pipe Inclined Fixed). The test pipe shall be inclined at 45° with the horizontal. The pipe is not rotated during welding [see Figure 10.4(D)].

10.4.2.5 A manufacturer who does production welding in a special orientation may make groove pipe test weld for procedure qualification in that specific orientation. Such qualifications are valid only for the position actually tested, except that an angular deviation of $\pm 15^\circ$ is permitted in the inclination of the pipe axis.

10.4.3 Fillet Welds in Plate (Figure 10.5). In making the tests to qualify fillet welds, test plates shall be welded in the position outlined below:

10.4.3.1 Position 1F (Flat). The test plates shall be so placed that each fillet weld is deposited with its axis approximately horizontal and its throat approximately vertical [see Figure 10.5(A)].

10.4.3.2 Position 2F (Horizontal). The test plates shall be so placed that each fillet weld is deposited on the upper side of the horizontal surface and against the vertical surface [see Figure 10.5(B)].

10.4.3.3 Position 3F (Vertical). The test plates shall be so placed that each fillet weld is deposited with its axis approximately vertical [see Figure 10.5(C)].

10.4.3.4 Position 4F (Overhead). The test plates shall be so placed that each fillet weld is deposited on the underside of the horizontal surface and against the vertical surface [see Figure D5(D)].

10.4.3.5 A manufacturer who does production welding in a special orientation may make fillet plate test welds for procedure qualification in that specific orientation. Such qualifications are valid only for the positions actually tested, except for the following:

(1) For other than vertical position test welds (see Figure 10.2), an angular deviation of $\pm 15^\circ$ is permitted in the inclination of the weld axis and rotation of the weld face.

(2) Vertical position test welds qualify all vertical position fillet welds of lesser inclination.

10.4.4 Fillet Welds in Pipe (Figure 10.6)

10.4.4.1 Flat Position 1F. The test pipe shall be placed with its axis inclined at 45° to the horizontal and rotated during welding. The weld metal is deposited from above so that at the point of deposition, the axis of the weld is horizontal and the weld size vertical [see Figure 10.6(A)].

10.4.4.2 Horizontal Positions 2F and 2FR

(1) The position 2F test pipe shall be placed with its axis vertical so that the weld is deposited on the upper side of the horizontal surface and against the vertical surface. The axis of the weld shall be horizontal and the pipe is not rotated during welding [see Figure 10.6(B)].

(2) The position 2FR test pipe shall be placed with its axis horizontal and the axis of the deposited weld in the vertical plane. The pipe is rotated during welding [see Figure 10.6(C)].

10.4.4.3 Overhead Position 4F. The test pipe shall be placed with its axis vertical so that the weld is deposited on the underside of the horizontal surface and against the vertical surface. The axis of the weld shall be horizontal and the pipe is not rotated during welding [see Figure 10.6(D)].

10.4.4.4 Multiple Position 5F. The test pipe shall be placed with its axis horizontal and the axis of the deposited weld in the vertical plane. The pipe is not rotated during welding [see Figure 10.6(E)].

10.4.4.5 A manufacturer who does production welding in a special orientation may make fillet pipe test welds for procedure qualification in that orientation. Such qualifications are valid only for the position tested, except that an angular deviation of $\pm 15^\circ$ is permitted in the inclination of the pipe axis.

10.5 Joint Welding Procedure Specification

10.5.1 The procedure used shall comply in all respects with the welding procedure specifications.

10.5.2 Weld cleaning shall be done with the weld in the same position as the welding position being qualified.

10.6 Test Specimens: Number, Type, and Preparation

10.6.1 Complete Joint Penetration Groove Welds

10.6.1.1 The type and number of specimens that shall be tested to qualify a welding procedure specification are shown in Table 10.1, together with the range of thickness that is qualified for use in construction. The range is based on the thickness of the test plate, pipe, or tubing used in making the qualification.

10.6.1.2 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 during construction, except the depth of groove need not exceed 1 in [25 mm].

10.6.1.3 Nondestructive Testing. Before preparing mechanical test specimens, the qualification test plate, pipe, or tubing shall be nondestructively tested for soundness as follows:

(1) Either radiographic or ultrasonic testing shall be used. For test plates, a minimum of 6 in [150 mm] of effective weld length between the discard strips shall be tested. For pipe or tubing, the full circumference of the completed weld shall be tested.

(2) For acceptable qualification, the weld, as revealed by radiographic or ultrasonic testing, shall conform to the requirements of 17.3 and 17.4.

10.6.1.4 Mechanical Testing. The welded test assemblies conforming to 10.6.1.3 shall have test specimens prepared by cutting the test plate, pipe, or tubing as shown in Figures 10.7 through 10.10, as applicable. The test specimens shall be prepared for testing in accordance with Figures 10.11 through 10.14, as applicable.

10.6.1.5 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 10.6.1.3 shall have test specimens prepared by cutting the test plate as shown in Figures 10.9 or 10.10, whichever is applicable. The test specimens for the longitudinal bend test shall be prepared for testing as shown in Figure 10.14.

10.6.2 Partial Joint Penetration Groove Welds. The type and number of specimens that shall be tested to qualify a welding procedure specification are shown in Table 10.2. A sample weld shall be made using the type of groove design and joint welding procedure specification to be used in construction, except the depth of groove need not exceed 1 in [25 mm]. For the macroetch test required in Table 10.2, any M1 steel of group 1, 2, or 3 (refer to AWS B2.1/B2.1M, Annex A for the M number) may be used to qualify any steel or combination of steels in those groups.

10.6.2.1 For joint welding procedure specifications that conform in all respects to 5.4, 5.5, Clause 6, and Clause 8, three macroetch cross-sectional specimens shall be prepared to demonstrate that the designated effective weld size (obtained from the requirements of the welding procedure specification) is met.

10.6.2.2 When a joint welding procedure specification has been qualified for a complete joint penetration groove weld and is applied to the welding conditions of a partial joint penetration groove weld, three macroetch cross-sectional test specimens are required.

10.6.2.3 If a joint welding procedure specification is not covered by either 10.6.2.1 or 10.6.2.2, or if the welding conditions do not meet the prequalified status, or if they have not been used and tested for a complete joint penetration weld in a butt joint, then a sample joint shall be prepared, and a macroetch test specimen shall be made to determine the effective weld size of the joint. Then, the excess material shall be machined off on the bottom side of the joint to the thickness of the effective throat. Tension and bend test specimens shall be prepared and tests performed as required for complete joint penetration groove welds (see 10.6.1).

10.6.2.4 Flare-Groove Welds. The effective weld sizes for qualified flare-groove welds shall be determined by the following:

- (1) Test sections shall be used to verify that the effective weld size is consistently obtained.
- (2) For a given set of WPS conditions, if the manufacturer has demonstrated consistent production of larger effective weld sizes than those shown in Table 7.1, the manufacturer may establish such larger effective weld sizes by qualification.
- (3) Qualification required by (2) shall consist of sectioning the radiused member, normal to its axis, at midlength and ends of the weld. Such sectioning shall be made on a number of combinations of material sizes representative of the range used by the manufacturer in construction.

10.6.3 Fillet Welds. The type and number of specimens that shall be tested to qualify a welding procedure specification are shown in Table 10.3.

10.6.3.1 Fillet Welds. A T-joint fillet weld test for plate as shown in Figure 10.15, or pipe weld test as shown in Figure 10.17, shall be made for each procedure and position to be used in construction.

10.6.3.2 One test weld shall be the maximum size single-pass fillet weld, and one test weld shall be 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. The weldment shall be cut perpendicular to the direction of welding, as shown in Figure 10.15 or 10.17. Specimens representing one face of each of three cuts shall constitute a macroetch test specimen and shall be tested in accordance with 10.8.2.

10.6.4 Consumables Verification Test

10.6.4.1 If both the proposed welding consumables and the proposed welding procedure specification for welding the fillet weld test plate prescribed in 10.6.3.1 are neither prequalified nor otherwise qualified by 9.2; that is, (1) if the welding consumables used do not conform to Table 8.1 and also (2) if the welding procedure specification using the proposed consumables has not been established by the manufacturer in accordance with either 10.6.1 or 10.6.2, then a complete joint penetration groove weld test plate shall be welded to qualify the proposed combination.

10.6.4.2 The test plate shall be welded as follows:

- (1) The test plate shall have the groove configuration shown in Figures 11.2 or 12.1 with metal 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 below, oriented as shown in Figure 10.16.

(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 welding procedure specification from which, when production fillet weld are made, changes in essential variables shall be measured in accordance with 10.1.3 through 10.1.17.

(5) The test plate shall be tested as follows:

(a) Two side-bend (see Figure 10.13) and one all-weld-metal-tension (see Figure 10.12) test specimens shall be removed from the test plate, as shown in Figure 10.16.

(b) The bend test specimens shall be tested in accordance with 10.8.3. Those test results shall conform to the requirements of 10.9.2.

(c) The tension test specimen shall be tested in accordance with 10.8.4. The test results shall determine the strength level of the welding consumables, which shall conform to the requirements of the welding process being used and the base metal strength level being welded.

10.6.5 Pipe and Tubing Qualification. A joint welding procedure specification for the groove welding of pipe or tubing qualified in accordance with 10.6.1 shall also constitute procedure qualification for fillet welding plate, pipe, or tubing.

10.6.6 Pipe Welding Positions Qualified. Qualification on pipe or tubing shall also qualify for plate, but not vice versa, except that qualification on plate in the 1G (flat) or 2G (horizontal) positions shall qualify for welding pipe or tubing over 24 in [610 mm] in diameter. Welding position limitations for procedure qualification are shown in Table 10.4.

10.6.6.1 Procedure qualification of pipe or tubing in the 5G (pipe horizontal fixed) position qualifies the procedure for flat, vertical, and overhead position groove and fillet welding of pipe, tubing, and plate.

10.6.6.2 Procedure qualification of pipe or tubing in the 6G (inclined fixed) position qualifies the procedure for all position groove and fillet welding of pipe, tubing, and plate.

10.6.6.3 A joint welding procedure specification for welding plate shall also constitute procedure qualification for fillet welding plate and pipe within the limitations shown in Table 10.5.

10.7 Special Test Conditions

10.7.1 For aluminum alloy castings guided-bend tests are not required. Macroetch tests may be substituted for the bend tests to evaluate soundness.

10.7.2 Wear-resistant base and weld metals, as well as cast iron, generally cannot meet the bend test requirements of 10.8.3 and 10.9.2. Such materials at the discretion of the Fabricator's Engineer, shall, in lieu of the bend test, be qualified by a macroetch test (see 10.8.2 and 10.9.3.4).

10.7.3 Test Specimen Aging. When required by the filler metal specification applicable to weld metal being tested, fully welded qualification test specimen may be aged at 200°F to 220°F [93°C to 104°C] for 48 hours ± 2 hours.

10.8 Method of Testing Specimens

10.8.1 Reduced Section Tension Specimens. Before testing, the **least** width and corresponding thickness of the reduced section shall be measured in inches [mm]. The specimen shall be ruptured under tensile load, f , 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.

10.8.2 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 (see Annex F).

10.8.3 Root-, Face-, and Side-Bend Specimens. Each specimen shall be bent in a fixture having the contour shown in Figure 11.11, 11.12, or 11.13. Other parts of the fixture should be substantially in accordance with these figures. Any convenient means may be used to move the plunger member with relation to the die member.

10.8.3.1 The specimen shall be placed on the die member of the fixture 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 speci-

mens 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.

10.8.3.2 The plunger shall force the specimen into the die until the specimen becomes U-shaped. The weld and heat-affected zones shall be centered and completely within the bent portion of the specimen after testing.

10.8.3.3 When using the wraparound fixture, the specimen shall be firmly clamped on one end so that there is no sliding of the specimen during the bending operation. The weld and heat-affected zones shall be completely in the bent portion of the specimen after testing. Test specimens shall be removed from the fixture when the outer roll has been moved 180° from the starting point.

10.8.4 All-Weld-Metal Tension Test. The test specimen shall be tested in accordance with the latest edition of AWS B4.0, *Standard Methods for Mechanical Testing of Welds*.

10.8.5 The radiographic procedure and technique shall be in accordance with the requirements of Clause 15.

10.8.6 The ultrasonic procedure and technique shall be in accordance with the requirements of Clause 16.

10.9 Test Results Required. The requirements for the test results shall be as follows:

10.9.1 Reduced Section Tension Test

10.9.1.1 If base metals of different minimum tensile strengths are used, the requirements for the weaker (or unspecified strength) apply.

10.9.1.2 For aluminum alloy base metals, the tensile strength shall meet the requirements of Table 10.5.

10.9.1.3 When the base metal has no specified minimum tensile strength (see 10.9.1.5), the test results are acceptable if the following apply:

- (1) Failure occurs in the base metal outside of the weld or fusion line
- (2) Failure occurs at a strength equal to or greater than the specified minimum strength of the weld metal

10.9.1.4 For all other base metals, the tensile strength shall not be less than the following:

(1) The specified minimum tensile strength of the base metal (base metal specification). However, if the specimen breaks in the base metal outside of the weld or fusion line, the test shall be accepted as meeting the requirements provided the strength is not more than 5% below the specified minimum tensile strength of the base metal.

(2) The specified minimum tensile strength of the filler metal when a lower strength weld metal is permitted by the design.

10.9.1.5 When a procedure is qualified using a base metal with no specified minimum tensile strength, the test will not qualify the welding of any other base metal.

10.9.2 Root, Face, and Side 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:

10.9.2.1 1/8 in [3 mm] measured in any direction on the surface.

10.9.2.2 3/8 in [10 mm]—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].

10.9.2.3 1/4 in [6 mm]—maximum corner crack, except when that corner crack resulted from visible slag inclusion or other fusion type discontinuities, then the 1/8 in [3 mm] maximum shall apply.

10.9.2.4 Specimens with corner cracks exceeding 1/4 in [6 mm] with no evidence of slag inclusions or other fusion-type discontinuities may be disregarded and a replacement test specimen from the original weldment tested.

10.9.3 Macroetch Test. For acceptable qualification, the macroetch test specimen, when inspected visually, shall conform to the following requirements:

10.9.3.1 Partial joint penetration groove welds shall have the designated weld size.

10.9.3.2 Fillet welds shall have fusion to the root of the joint, but not necessarily beyond.

10.9.3.3 Minimum leg size shall meet the specified fillet weld size.

10.9.3.4 The partial joint penetration groove welds and fillet welds shall have the following:

- (1) No cracks
- (2) Complete fusion between adjacent layers of weld metal and between weld metal and base metal
- (3) Weld profiles conforming to intended detail, but with none of the variations prohibited in Figure 6.2
- (4) No undercut exceeding the values permitted in Class 1, Table 17.1

10.9.3.5 For plug welds, fusion shall be complete to the surfaces of the hole and fusion to the backing base metal shall be at least equal to the hole diameter.

10.9.3.6 For slot welds, fusion to the slot surfaces shall be complete and fusion to the backing base metal shall be at least equal to the slot dimensions.

10.9.4 Nondestructive Testing. For acceptable qualification, the weld, as revealed by radiographic or ultrasonic testing, shall conform to the requirements of Clause 17.

10.9.5 Visual Inspection of Pipe and Tubing. For acceptable qualification, a pipe weld, when inspected visually, shall conform to the following requirements:

10.9.5.1 The weld shall be free of cracks.

10.9.5.2 All craters shall be filled to the full cross section of the weld.

10.9.5.3 The face of the weld shall be at least flush with the outside surface of the pipe, and the weld shall merge smoothly with the base metal. Undercut shall not exceed 1/64 in [0.4 mm]. Maximum weld reinforcement is shown in Table 11.5.

10.9.5.4 The root of the weld shall be inspected, and there shall be no evidence of cracks, incomplete fusion, or inadequate joint penetration. A concave root surface is permitted within the limits shown below, provided the total weld thickness is equal to or greater than that of the base metal.

10.9.5.5 The maximum root surface concavity shall be 1/16 in [2 mm] and the maximum melt-through shall be 1/8 in [3 mm].

10.9.6 Visual Inspection Plate. For acceptable qualification, the welded test plate, when inspected visually, shall conform to the requirements for visual inspection in 17.2.

10.10 Records. Records of the test results shall be kept by the manufacturer and shall be available to those authorized to examine them.

10.11 Retests. If any one specimen of all those tested fails to meet the test requirements, two retests for that particular type of test specimen may be performed with specimens cut from the same procedure qualification material. The results of both test specimens shall meet the test requirements. For material over 1-1/2 in [38 mm] thick, failure of a specimen shall require testing of all specimens of the same type from two additional locations in the test material.

Table 10.1
PQR Essential Variable Changes Requiring WPS Requalification for SMAW, SAW, GMAW, FCAW, and GTAW (See 10.1)

Essential Variable Changes to PQR Requiring Requalification:	Process				
	SMAW	SAW	GMAW	FCAW	GTAW
Joint Design					
(1) A change in joint design type from one of the below to another type except that backgouging may be added:					
(a) Square groove	X	X	X	X	X
(b) Single- or double-bevel or J groove					
(c) Single- or double U or V groove					
(2) A change in groove joint design that results in:					
(a) A decrease in the groove angle					
(b) A decrease in root opening					
(c) An increase in root face for CJP welds	X	X	X	X	X
(d) The omission, but not addition, of backing material					
(e) The addition or omission of consumable inserts					
(3) For plug and slot welds:					
(a) A change in the specified slot width or hole diameter					
(b) A change in the depth of the slot or hole of more than 1/16 in [2 mm]	X	X	X	X	X
(c) A decrease in thickness of the specified backing base metal of more than 1/16 in [2 mm]					
Base Metal, Backing Bar, Filler, Spacer Strips, and Run-off Tabs					
(4) For M1 material, a change to a higher group number (see AWS B2.1/B2.1M and/or Annex A for M number classifications)	X	X	X	X	X
(5) A change from one "M" number to another "M" number or to an unlisted base metal, unless the unlisted base metal can be shown to have mechanical properties in the same range and a similar chemical composition within the same range as verified by the Fabricator's Engineer	X	X	X	X	X
(6) For joints between base metals of different M numbers, requalification is required except for M1, M3, M4, and M5 (of 3% maximum nominal chromium content); a procedure with one M number shall also qualify for that metal welded to each of the lower M number.	X	X	X	X	X
(7) For M11 material, a change of group number	X	X	X	X	X

(Continued)

Table 10.1 (Continued)
PQR Essential Variable Changes Requiring WPS Requalification for SMAW, SAW, GMAW, FCAW, and GTAW (See 10.1)

Essential Variable Changes to PQR Requiring Requalification:	Process				
	SMAW	SAW	GMAW	FCAW	GTAW
Base Metal, Backing Bar, Filler, Spacer Strips, and Run-off Tabs (Continued)					
(8) When welding quenched and tempered steel, any change within the limitation of variables shall not increase the heat input beyond the steel producer's recommendations	X	X	X	X	X
(9) A change in the "M" number of the backing material, if the backing material alters the composition of the weld metal	X	X	X	X	X
Filler Metals					
(10) A change from one AWS "F" number to another AWS "F" number or to any filler metal not listed in Annex B	X	X	X	X	X
(11) For Carbon Steel and Low Alloy Steel welding, a change in electrode classification not covered in:	AWS A5.1/A5.1M or A5.5/A5.5M	AWS A5.17/A5.17 or A5.23/A5.23M	AWS A5.18/A5.18M or A5.28/A5.28M	AWS A5.20/A5.20M or A5.29/A5.29M	AWS A5.18/A5.18M or A5.28/A5.28M
(12) For Stainless Steel welding, a change in electrode classification not covered in:	AWS A5.4/A5.4M	AWS A5.9/A5.9M	AWS A5.9/A5.9M	AWS A5.22/A5.22M	AWS A5.9/A5.9M
(13) For Aluminum welding, a change in electrode classification not covered in:		AWS A5.10/A5.10M	AWS A5.10/A5.10M		AWS A5.10/A5.10M
(14) A change in brands of electrodes with a "G" classification	X		X	X	
(15) A change in nominal electrode diameter by:	> 1/32 in [0.8 mm] increase	Any increase	Any increase or decrease	Any increase	
(16) The addition or deletion of filler metal					X
Process Parameters					
(17) A change in amperage or voltage that is not within a range recommended by the electrode supplier	X		X (for other than aluminum)	X	
(18) For aluminum, a change of more than $\pm 15\%$ in amperage, voltage, or both			X		
(19) A change in the type of welding current (ac or dc), or polarity (DCEP or DCEP)		X	X	X	X
(20) A change in mode of metal transfer			X		
Shielding Gas					
(21) A change from a single gas to any other gas or to a mixture of gases or a change in the specified percentage composition of gas mixture			X	X	X

(Continued)

Table 10.1 (Continued)
PQR Essential Variable Changes Requiring WPS Requalification for SMAW, SAW, GMAW, FCAW, and GTAW (See 10.1)

Essential Variable Changes to PQR Requiring Requalification:	Process				
	SMAW	SAW	GMAW	FCAW	GTAW
SAW Parameters					
For Procedures utilizing a powdered filler metal, active flux, or an alloy flux #23 through #29 apply					
(22) A change of more than 10% in the amperage		X			
(23) A change of more than 7% in the arc voltage		X			
(24) An increase of less than 7% in the arc voltage but exceeding the flux manufacturer's recommended maximum		X			
(25) A change of more than 15% in the arc travel speed		X			
(26) A change of more than 10% or 1/8 in [3 mm], whichever is greater, in the longitudinal spacing of the arcs		X			
(27) A change of more than 10% or 1/16 in [2 mm], whichever is greater, in the lateral spacing of the arcs		X			
(28) Any change in the nominal electrode diameter		X			
(29) In machine or automatic SAW, an increase or decrease in the angle of electrodes of more than 10° in the direction of travel		X			
(30) In machine or automatic SAW, an increase or decrease in the angle of electrodes of more than 10° normal to the direction of travel		X			
(31) If supplemental powdered or granular filler metal or cut wire is to be fused, the maximum and minimum additions should be qualified		X			
(32) When utilizing active or alloy SAW flux the maximum base metal thickness for multiple pass welds shall be 1 in [25 mm], or that recommended by the flux manufacturer, whichever is less.		X			
Preheat and Interpass Temperature and Specified Postweld Heat Treatment					
(33) The addition, deletion, or change in the specified postweld heat treatment	X	X	X	X	X
(34) Except for steel with a preheat and interpass temperatures in accordance with Table 8.2, a decrease of more than 50°F [28°C] in the minimum metal temperature	X	X	X	X	X

(Continued)

Table 10.1 (Continued)
PQR Essential Variable Changes Requiring WPS Requalification for SMAW, SAW, GMAW, FCAW, and GTAW (See 10.1)

Essential Variable Changes to PQR Requiring Requalification:	Process				
	SMAW	SAW	GMAW	FCAW	GTAW
Preheat and Interpass Temperature and Specified Postweld Heat Treatment (Continued)					
(35) Except for steel with preheat and interpass temperatures in accordance with Table 8.2; an increase of more than 100°F [56°C] in the maximum specified temperature of the qualification test	X	X	X	X	X
(36) For a preheat temperature of 32°F [0°C], or lower, the test temperature is the minimum	X	X	X	X	X
General					
(37) A change in welding process to one not qualified	X	X	X	X	X
(38) In vertical welding a change in progression for any pass from upward to downward or vice versa. Vertical down welding of aluminum is not recommended except to fill undercut	X	X	X	X	X
(39) The omission but not inclusion of backgouging	X	X	X	X	X
(40) A change in contact-tip-to-work distance to a value outside the range recommended by the electrode supplier		X	X	X	
(41) A change in base metal thickness, pipe/tube diameter, or both, as defined in 10.6, beyond that shown in Table 10.1, 10.2, or 10.3	X	X	X	X	X
Supplemental Essential Variables					
(42) Except when the WPS is qualified with a grain-refining austenitizing heat treatment after welding, an increase in heat input or volume of weld metal deposited per unit length of weld, over that qualified. It is recommended that the welding procedure specification be qualified at both the maximum and minimum heat inputs. The inputs may be measured by either of the following:					
(a) Heat Input (J/in) = $\frac{\text{Volts} \times \text{Amps} \times 60}{\text{Travel Speed (in/mm)}}$					
Heat Input (J/in) = $\frac{\text{Volts} \times \text{Amps} \times 60}{\text{Travel Speed (mm/min)}}$					

(Continued)

Table 10.1 (Continued)
PQR Essential Variable Changes Requiring WPS Requalification for SMAW, SAW, GMAW, FCAW, and GTAW (See 10.1)

Essential Variable Changes to PQR Requiring Requalification:	Process				
	SMAW	SAW	GMAW	FCAW	GTAW
Supplemental Essential Variables (Continued)					
<i>NOTE: For closely spaced multiple arcs, the heat input is the sum of the heat input of the individual arcs.</i>					
(b) Weld metal volume—An increase in weld bead size, a decrease in length of weld bead per unit length of electrode, or a decrease with a constant burn-off in travel speed	X	X	X	X	X
(43) A change in the group number	X	X	X	X	X
(44) The 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
(45) A change in the manufacturer's brand name or type of electrode				X	
(46) A change in position as defined in Table 10.5 except that a 3G vertical up test qualifies for all positions. A change in the position of welding, as defined in Figures 10.1 and 10.2, except as permitted by Table 10.5	X		X	X	X
(47) A change from single electrode to multiple electrodes in the same weld pool, and vice versa		X	X		X
(48) In the 3G position, a change from stringer to weave	X		X	X	X
(49) A change from multipass per side to single pass per side	X	X	X	X	X
(50) A change exceeding $\pm 20\%$ in the oscillation variables for mechanized or automatic welding		X	X	X	X

Table 10.2
Procedure Qualification—Number and Type of Specimens and
Range of Thickness Qualified—Complete Joint Penetration Groove Weld^{a, b, e, f, g}

1. Tests on Plate

Nominal Plate Thickness (T) Tested, in [mm]	Number of Specimens				Nominal Plate, Pipe, or Tube Thickness ^c Qualified, in [mm]	
	Reduced Section Tension (see Fig. 10.11)	Root Bend (see Fig. 10.14)	Face Bend (see Fig. 10.14)	Side Bend (see Fig. 10.13)	Min.	Max.
$1/8 \leq T \leq 3/8$ [3 ≤ T ≤ 10]	2	2	2	(Note f)	1/8 [3]	2T
$3/8 < T < 3/4$ [10 < T < 20]	2	—	—	4	3/16 [5]	2T
3/4 [20] and over	2	—	—	4	3/16 [5]	Unlimited

2. Tests on Pipe or Tubing^d

								Nominal Plate, Pipe, or Tube Wall Thickness ^c Qualified, in [mm]	
		Number of Specimens					Nominal Diameter of Pipe or Tube Size Qualified, in [mm]		
Nominal Pipe Size or Diam, in [mm]	Nominal Wall Thickness, T, in [mm]	Reduced Section Tension (see Fig. 10.11)	Root Bend (see Fig. 10.14)	Face Bend (see Fig. 10.14)	Side Bend (see Fig. 10.13)	Min.		Max.	
Job Size Test Pipes	<24 [600]	1/8 ≤ T ≤ 3/8 [3 ≤ T ≤ 10]	2	2	2	(Note f)	Test diam. and over	1/8 [3]	2T
		3/8 < T < 3/4 [10 < T < 20]	2	—	—	4	Test diam. and over	3/16 [5]	2T
		3/4 [20] and over	2	—	—	4	Test diam. and over	3/16 [5]	Unlimited
	≥24 [600]	1/8 ≤ T ≤ 3/8 [3 ≤ T ≤ 10]	2	2	2	(Note f)	Test diam. and over	1/8 [5]	2T
		3/8 < T < 3/4 [10 < T < 20]	2	—	—	4	24 [600] and over	3/16 [5]	2T
		3/4 [20] and over	2	—	—	4	24 [600] and over	3/16 [5]	Unlimited
Standard Test Pipes	2 [50] in Sch 80 or 3 [75] in Sch 40	2	2	2	—	3/4 through 4 [20–100]	1/8 [3]	7/16 [11]	
	6 [150] in Sch 120 or 8 [200] in Sch 80	2	—	—	4	4 [100] and over	3/16 [5]	Unlimited	

^a All welded test plates shall be inspected (see 10.9.6).^b A minimum of 6 in [150 mm] effective weld length shall be tested by radiographic or ultrasonic testing prior to mechanical testing (see 10.6.1.3).^c For square groove welds, the maximum thickness qualified shall be the test plate thickness.^d All welded test pipes or tubing shall be visually inspected (see 10.9.5).^e For pipe or tubing, the full circumference of the completed weld shall be tested by RT or UT prior to mechanical testing (see 10.6.1.3).^f For 3/8 in [10 mm] plate or wall thickness, a side bend test may be substituted for each of the required face- and root-bend tests.^g All groove welds qualify fillet welds on base metal 1/8 in [3 mm] and thicker.

Table 10.3
Procedure Qualification—Number and Type of Specimens and
Range of Thickness Qualified—Partial Joint Penetration Groove Weld^a

Groove Type	Groove Depth, Maximum, in [mm]	Number of Sample Welds	Test Specimens Required			
			Macroetch for Effective Throat (E) (10.6.2.1) (10.6.2.2) (10.6.2.3)	Tension and Bend Tests		Plate Thickness Qualified, Maximum
				Reduced-Section Tension (see Figure 10.11)	Side-Bend (see Figure 10.13)	
Same as used in construction ^b	1 [25]	1	3	2	4	Unlimited

^a All partial welded test plates shall be visually inspected (see 10.9.6).

^b If a partial joint penetration bevel- or J-groove weld is to be used for T-joints or a double-bevel- or double-J-groove weld is to be used for corner joints, the butt joint shall have a temporary restrictive plate in the plane of the square face to simulate a T-joint configuration.

Note: See Table 10.2 for pipe diameter qualification.

Table 10.4
Procedure Qualification—Number and Type of
Specimens and Range of Thickness Qualified—Fillet Weld^a

Test Specimen	Fillet Size	Number of Welds per Procedure	Test Specimens			Size Qualified	
			Macroetch (10.6.3) (10.8.2)	All-Weld-Metal Tension (see Figure 10.12)	Side-Bend (see Figure 10.13)	Plate Thickness	Fillet Size
Plate T-Joint ^a (Figure 10.15)	Single-pass, max. size to be used in construction	1 in each position	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
Pipe T-Joint ^b (Figure 10.17)	Single-pass, max. size to be used in construction	1 in each position to be used (see Table 10.4)	3 faces (except for 4F and 5F, 4 faces required)	—	—	Unlimited	Max. tested single-pass and smaller
	Multiple-pass, min. size to be used in construction	1 in each position to be used (see Table 10.4)	3 faces (except for 4F and 5F, 4 faces required)	—	—	Unlimited	Min. tested multiple-pass and larger
Groove Weld ^c (Figure 10.16) (with fused metallic backing)		1 in 1G position	—	1	2	Qualifies welding consumables to be used in T-tests above	

^a All welded test specimens shall be visually inspected (see 10.9.5 and 10.9.6).

^b See Table 10.2 for pipe diameter qualification.

^c When the welding consumables used do not conform to the prequalified provisions of 8.1.1 and a welding procedure using the proposed welding consumables has not been established in accordance with either 10.6.1 or 10.6.2, a complete joint penetration groove weld test plate shall be welded in accordance with 10.6.1.

Table 10.5
Procedure Qualification Type and Position Limitations

Qualification Test		Type of Weld and Position of Welding Qualified ^a			
		Plate		Pipe	
Weld	Plate or Pipe Positions ^b	Groove	Fillet	Groove	Fillet
Plate-Groove Complete Joint Penetration	1G	F	F	F ^c	F ^c
	2G	F, H	F, H	F, H ^c	F, H ^c
	3G ^c	V	V		
	4G	OH	OH		
Plate-Fillet	1F		F		F ^c
	2F		F, H		F, H ^c
	3F ^c		V		V ^c
	4F		OH		OH ^c
Pipe-Groove	1G	F	F	F	F
	2G	F, H	F, H	F, H	F, H
	5G ^c	F, V, OH	F, V, OH	F, H, OH	F, V, OH
	6G ^c	All	All	All	All
Pipe-Fillet	1F		F		F
	2F		F, H		F, H
	2FR		F, H		F, H ^d
	4F		F, H, OH		F, H, OH
	5F ^c		All		All

^a Positions of welding: F = flat, H = horizontal, V = vertical, OH = overhead (see Figures 10.1 and 10.2).

^b See Figures 10.3, 10.4, 10.5, and 10.6.

^c Qualifies for welding pipe or tubing over 24 in [600 mm] in diameter.

^d Qualifies for horizontal fillet welds on rotated pipes only.

^e In vertical welding a change in progression specified for any pass from upward to downward or vice versa shall require a separate qualification test.

Table 10.6
As-Welded Strength of Aluminum Alloys (GTAW or GMAW)

Base Metal M No.	Alloy and Temper	Product	Thickness, in [mm]	Minimum Tensile Strength, ksi [MPa]
21	1060-0 H12, H14, H18, H112, H113, F	Sheet and Plate	1/8–3 [3–76]	8 [55]
		Extrusions	All	8.5 [59]
21	1100-0, H12, H14, H16, H18, H22, H24, H26, H28, H112, H113, F	All	1/8–3 [3–76]	11 [76]
21	3003-0, H12, H14, H16, H18, H22, H24, H26, H28, H112, H113, F	All	1/8–3 [3–76]	14 [97]
		Tube	All	13 [90]
21	Alclad 3003-0, H12, H14	Sheet and Plate	1/8–1/2 [3–13]	13 [90]
		Plate	1/2–3 [13–76]	14 [97]
22	3004-0, H32, H34, H36, H38, H112, F	All	1/8–3 [3–76]	22 [152]
22	Alclad 3004-0, H32, H34	Sheet and Plate	1/8–1/2 [3–13]	21 [145]
		Plate	1/2–3 [13–76]	22 [152]
21	5005-0, H12, H14, H16, H18, H32, H34, H36, H38, H112, F	All	1/8–3 [3–76]	15 [103]
21	5050-0, H32, H34, H36, H38, H112, F	All	1/8–3 [3–76]	18 [124]
22	5052-0, H22, H24, H26, H28, H32, H34, H36, H38, H112, F	All	1/8–3 [3–76]	25 [172]
	5083-0, H111, H112	Forgings	Up through 4 [102]	38 [262]
	5083-0, H111, H112, F	Extrusions	Up through 5 [127]	39 [269]
25	5083-0, H112, H116, H321F	Sheet and Plate	1/8–1-1/2 [3–38]	40 [276]
		Plate	<1-1/2–3 [38–76]	39 [269]
		Plate	<3–5 [76–127]	38 [262]
		Plate	<5–7 [127–178]	37 [255]
		Plate	<7–8 [178–203]	36 [248]
25	5086-0, H32, H34, H36, H38, H111, H112, H116, F	All	1/8–2 [3–51]	35 [241]
		Extrusions	<2–5 [51–127]	35 [241]
		Plate	<2–3 [51–76]	34 [235]
22	5154-0, H32, H34, H36, H38, H112, F	All	1/8–3 [3–76]	30 [207]
22	5254-0, H32, H34, H36, H38, H112, F	All	1/8–3 [3–76]	30 [207]
22	5454-0, H32, H34, H111, H112, F	All	1/8–3 [3–76]	31 [214]
23	6061-T4, T42, T451, T51, T6, T62, T651, F	All	1/8–3 [3–76]	24 [166]
	6061-T6, T651	Plate and Forgings	<3–4 [17–102]	24 [166]
	6061-T651	Plate	<4–6 [102–152]	24 [166]
	6061-T6	Forgings	<4–8 [102–203]	24 [166]

(Continued)

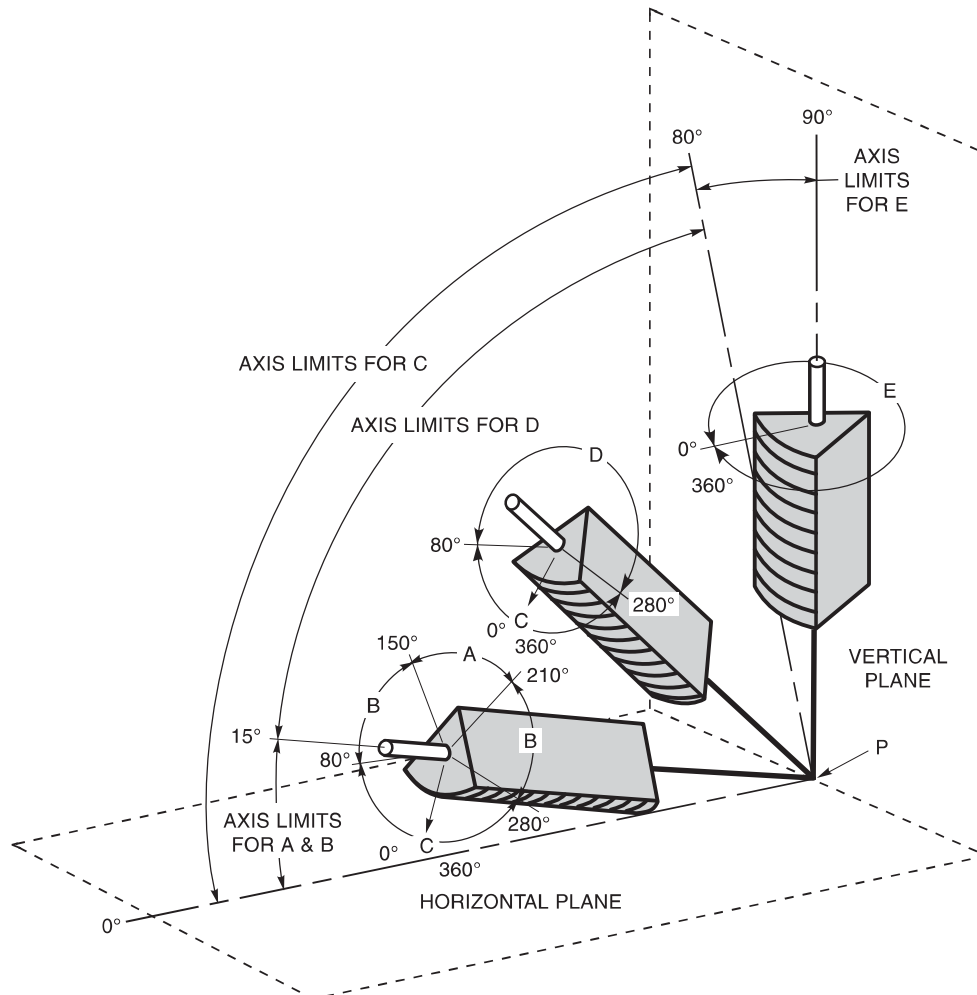
Table 10.6 (Continued)
As-Welded Strength of Aluminum Alloys (GTAW or GMAW)

Base Metal M No.	Alloy and Temper	Product	Thickness, in [mm]	Minimum Tensile Strength, ksi [MPa]
23	Alclad 6061-T4, T42, T451, T6, T62, T65, F	Sheet and Plate	1/8–3 [3–76]	24 [166]
	Alclad 6061-T62, T651	Plate	<3–5 [17–127]	24 [166]
23	6063-T4, T42, T5, T52, T6, T62, T83, T831, T832	Extrusions	Up through 1 [25]	17 [117]
23	6005-T5	Extrusions	Up through 1 [25]	24 [166]
23	6351-T4, T5, T51, T53, T54, T6	Extrusions	Up though 1 [25]	24 [166]
25	5456-0, H112, H116, H321, F	Sheet and Plate	1/8–1-1/2 [3–38]	42 [290]
		Plate	<1-1/2–3 [38–76]	41 [283]
	5456-0, H116, F	Plate	<3–5 [76–127]	40 [276]
		Plate	<5–7 [127–178]	39 [269]
26	356.0-T51, T6, T7, T71	Castings	All	23 [159]
	443.0-F	Castings	All	17 [117]
26	A444.0-T4	Castings	All	17 [117]
	514.0-F	Castings	All	22 [152]
	535.0-F	Castings	All	35 [241]
27	7005-T53	Extrusions	1/8–1 [3–25]	40 [276]

Notes:

1. Materials to be tested as M23 material.
2. Special bend test requirement.

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	15° to 80°	80° to 280°
	E	80° to 90°	0° to 360°



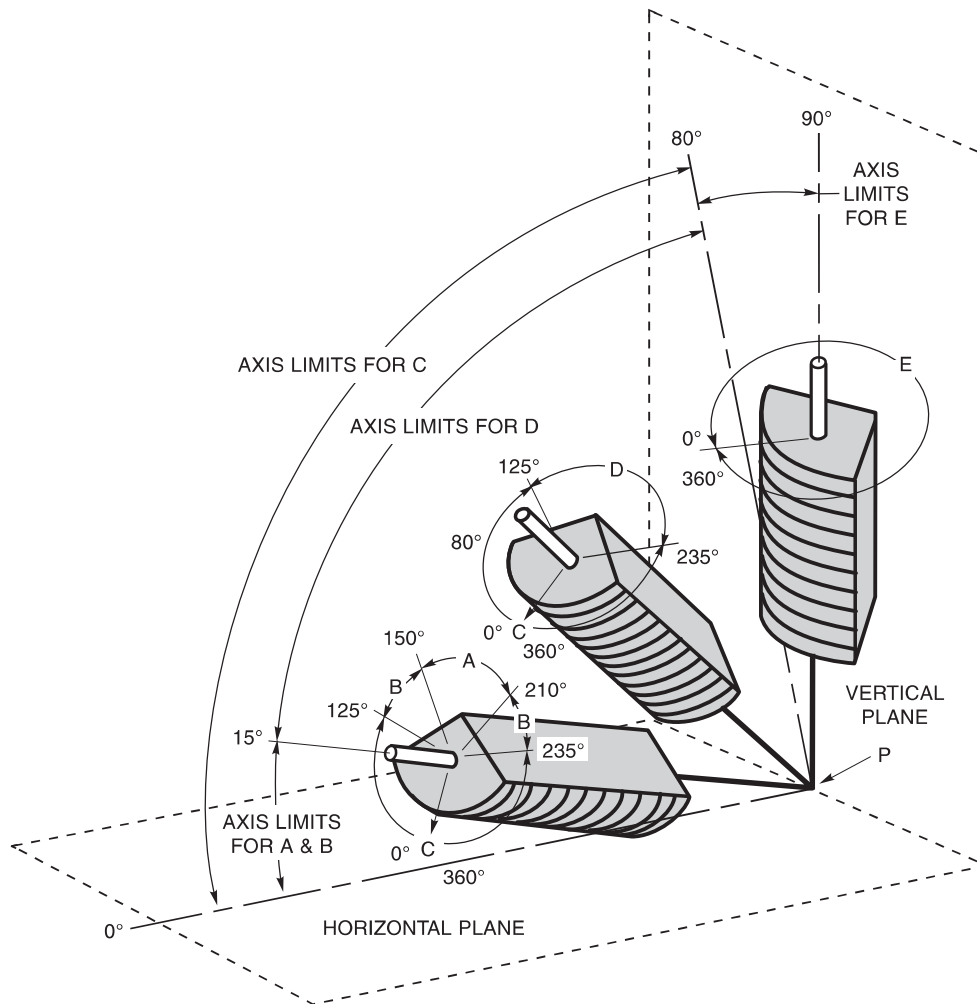
Notes:

1. The horizontal reference plane is always taken to lie below the weld under consideration.
2. The inclination of the weld axis is measured from the horizontal reference plane toward the vertical reference plane.
3. The angle of rotation of the weld face is determined by a line perpendicular to the weld face of the weld that passes through the weld axis. The reference position (0°) of rotation of the weld 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 weld face is measured in a clockwise direction from the reference position (0°).

Source: Reproduced from AWS A3.0M/A3.0:2010, *Standard Welding Terms and Definitions*, Figure B.16A, American Welding Society.

Figure 10.1—Positions of Groove Welds

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	15° to 80°	125° to 235°
	E	80° to 90°	0° to 360°



Notes:

1. The horizontal reference plane is always taken to lie below the weld under consideration.
2. The inclination of the weld axis is measured from the horizontal reference plane toward the vertical reference plane.
3. The angle of rotation of the weld face is determined by a line perpendicular to the weld face that passes through the weld axis. The reference position (0°) of rotation of the weld 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 weld face is measured in a clockwise direction from the reference position (0°).

Source: Reproduced from AWS A3.0M/A3.0:2010, *Standard Welding Terms and Definitions*, Figure B.16B, American Welding Society.

Figure 10.2—Positions of Fillet Welds

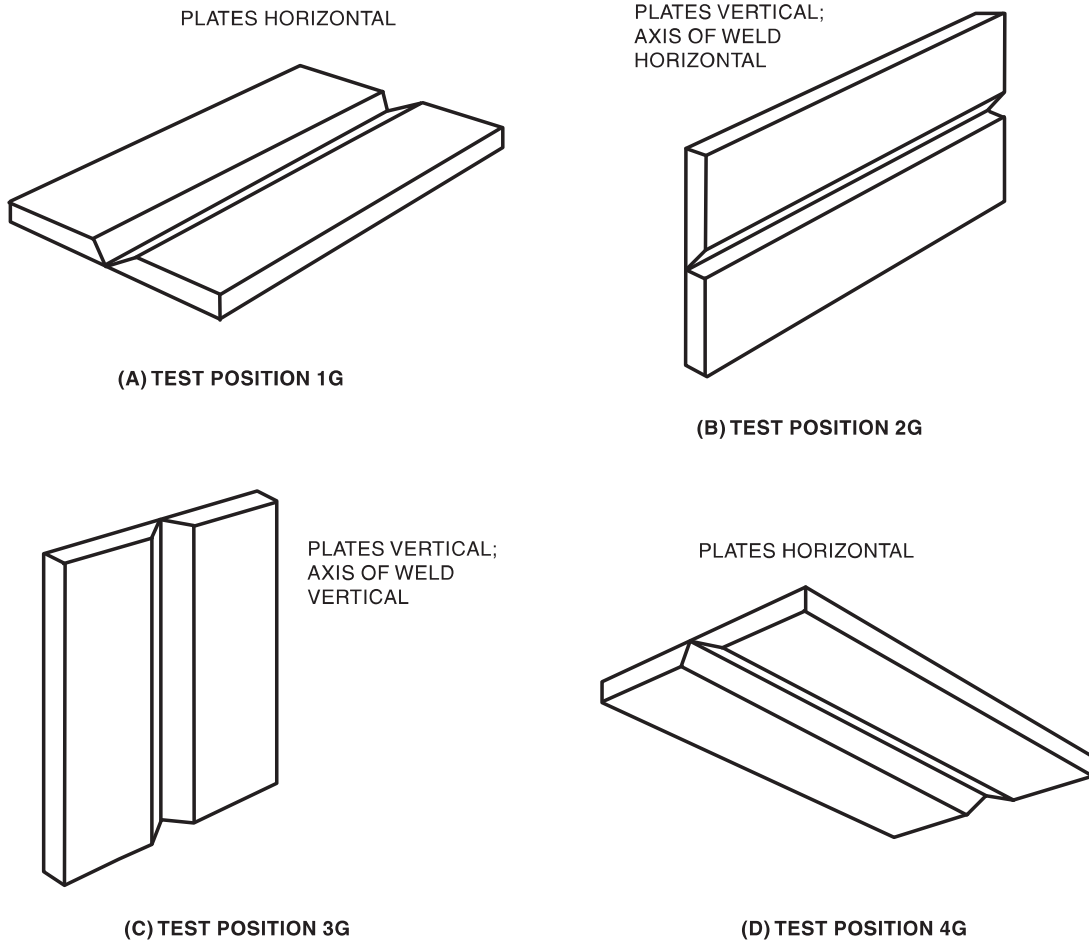


Figure 10.3—Positions of Test Plates for Groove Welds

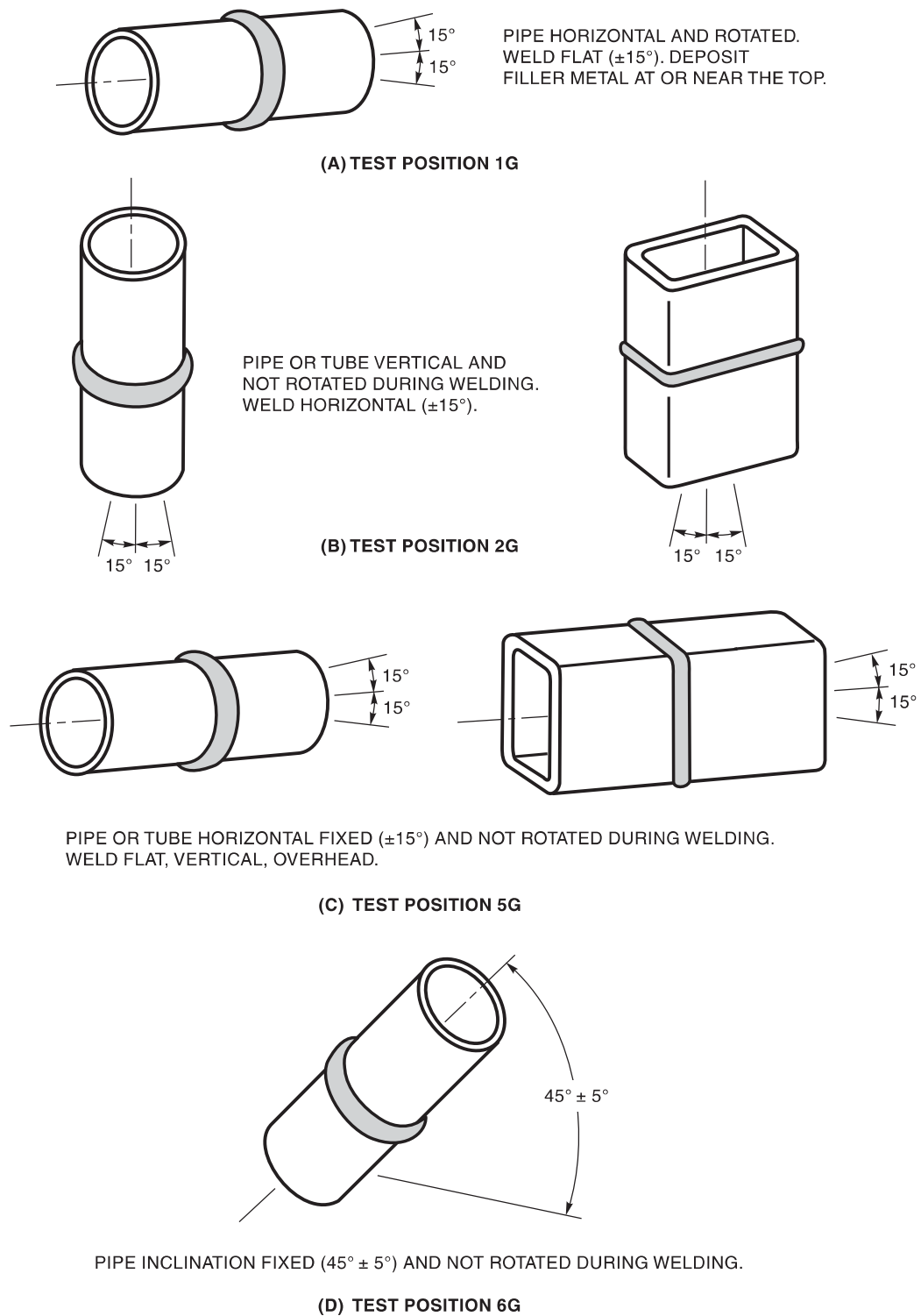
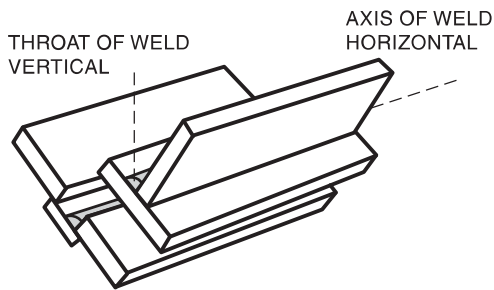
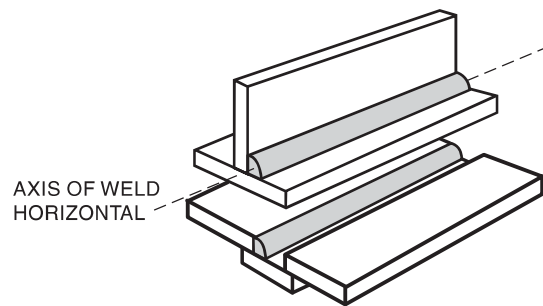


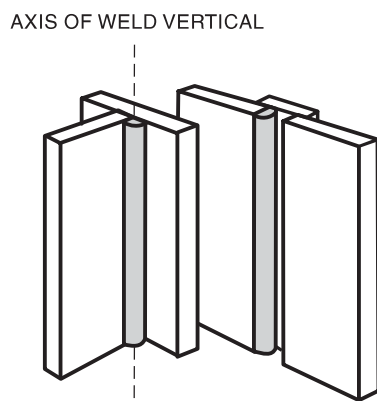
Figure 10.4—Positions of Test Pipe or Tubing for Groove Welds



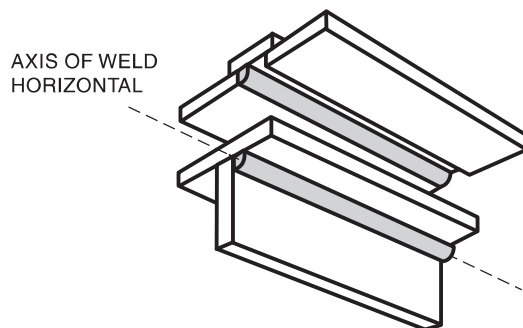
(A) FLAT POSITION 1F



(B) HORIZONTAL POSITION 2F



(C) VERTICAL POSITION 3F



(D) OVERHEAD POSITION 4F

Figure 10.5—Test Positions for Fillet Welds (for Plate)

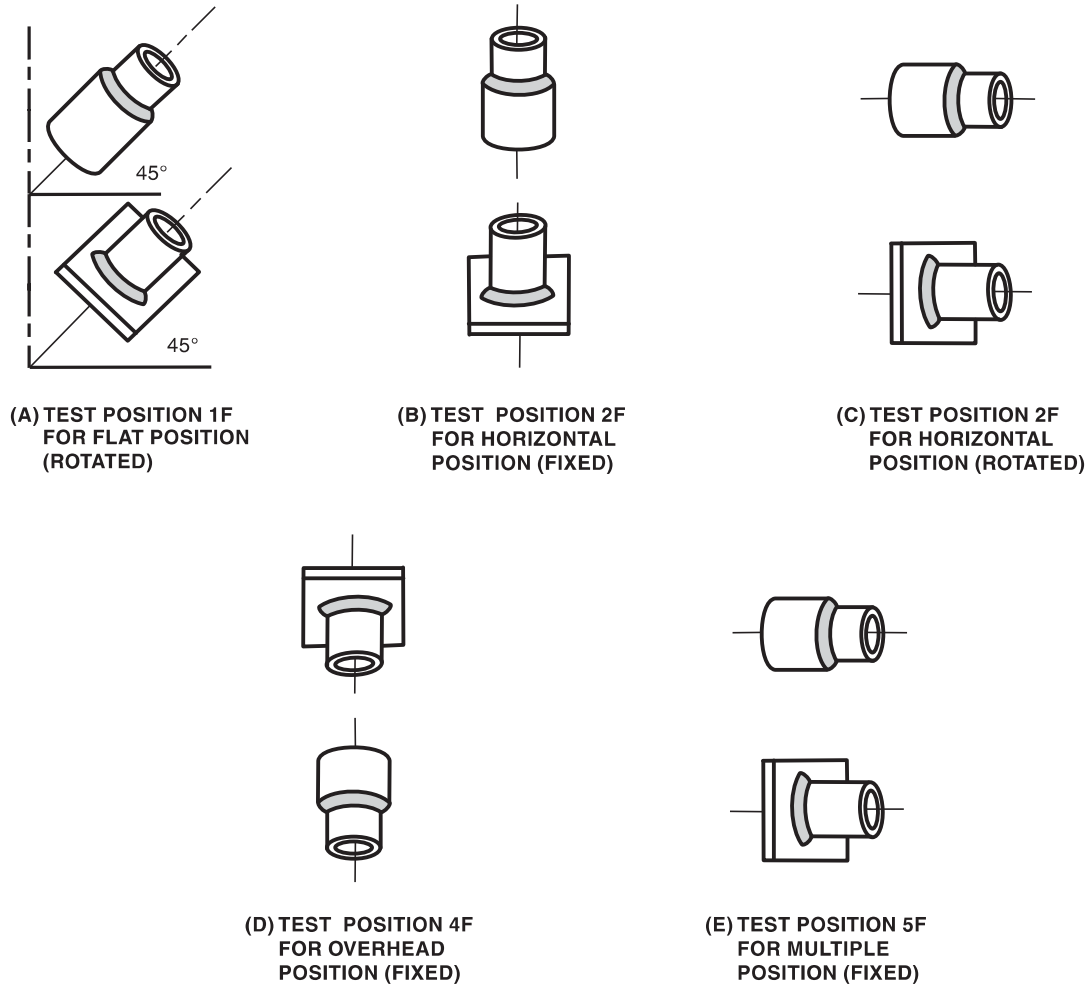


Figure 10.6—Test Positions for Fillet Welds (for Pipe and Tubing)

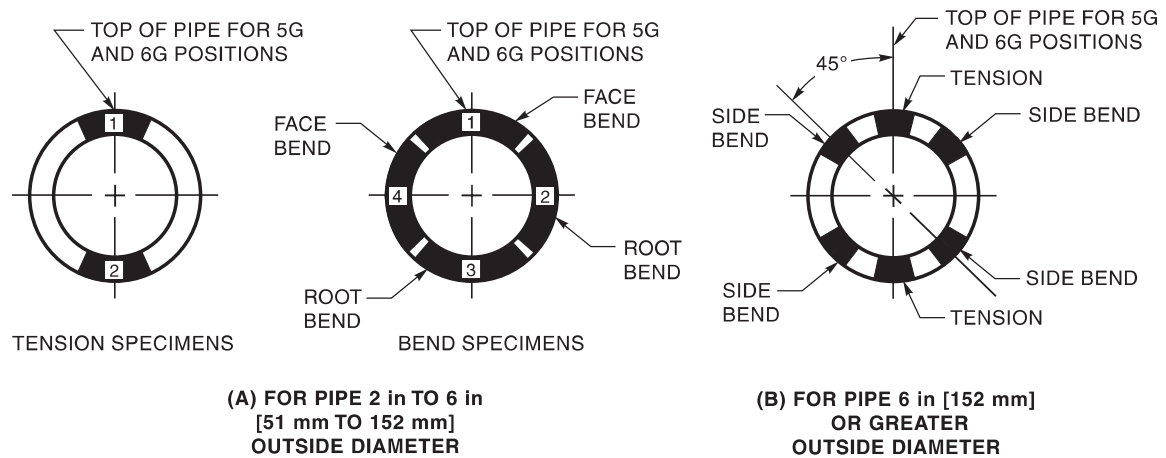


Figure 10.7—Location of Test Specimens on Welded Test Pipe

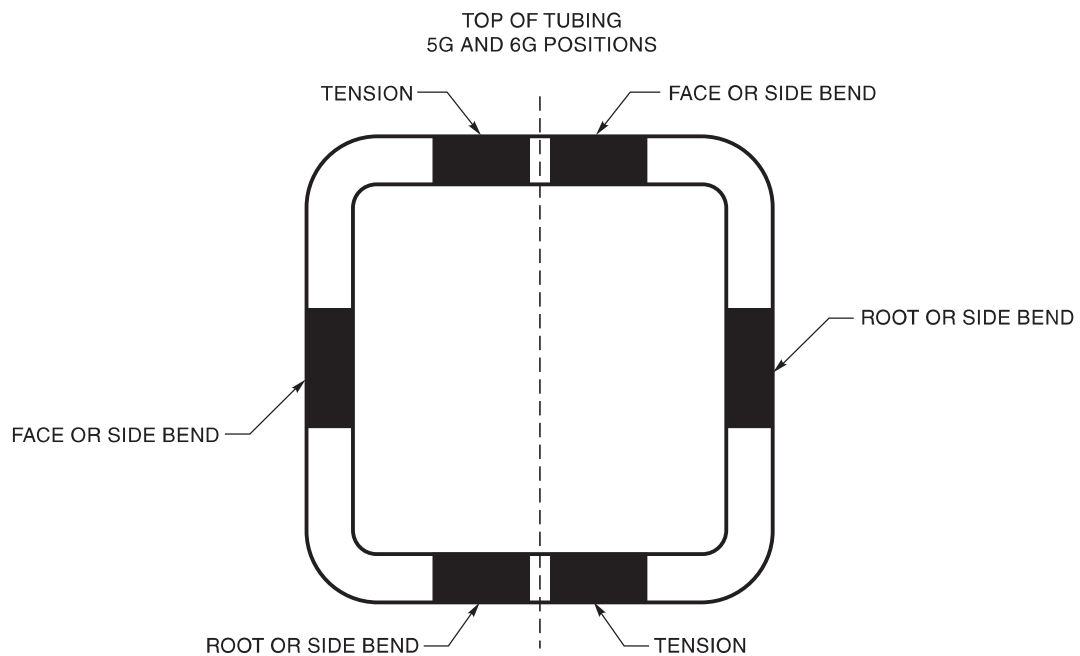
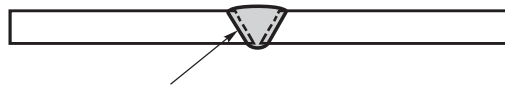
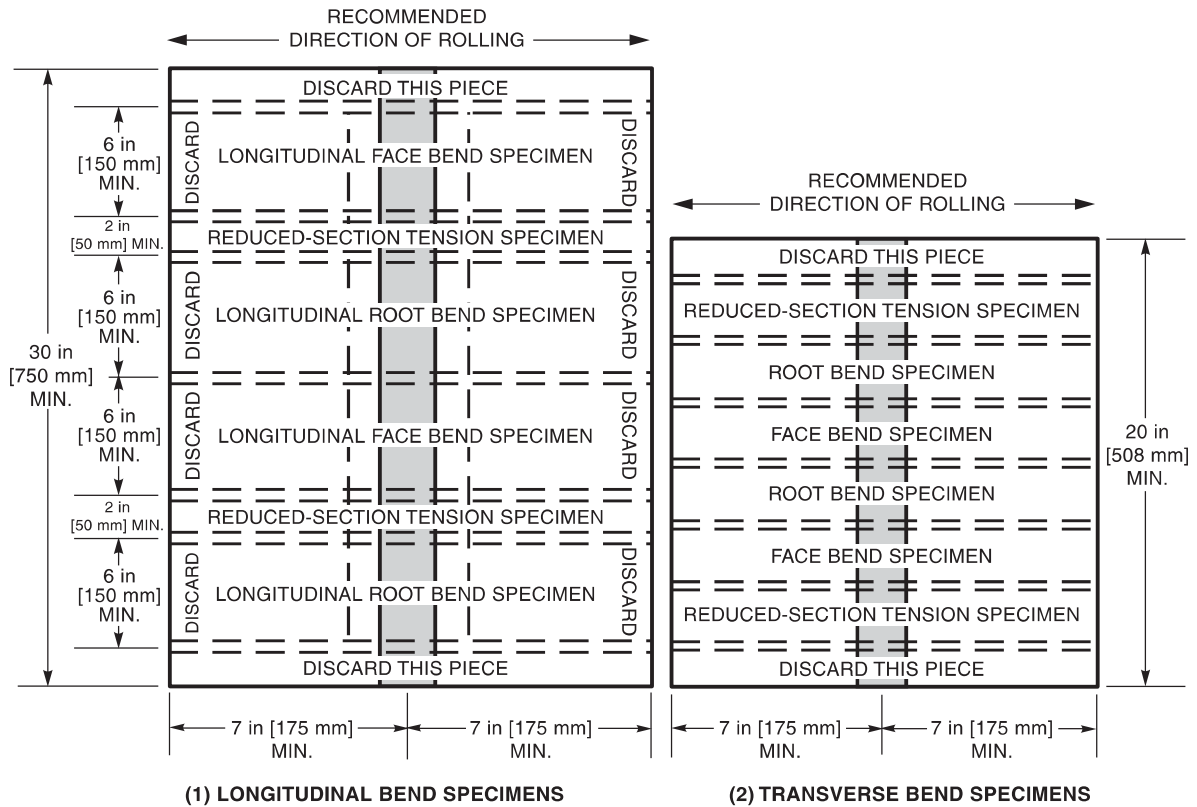
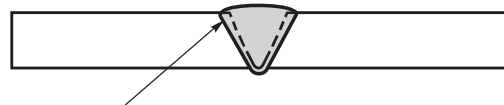


Figure 10.8—Location of Test Specimens for Welded Square and Rectangular Tubing

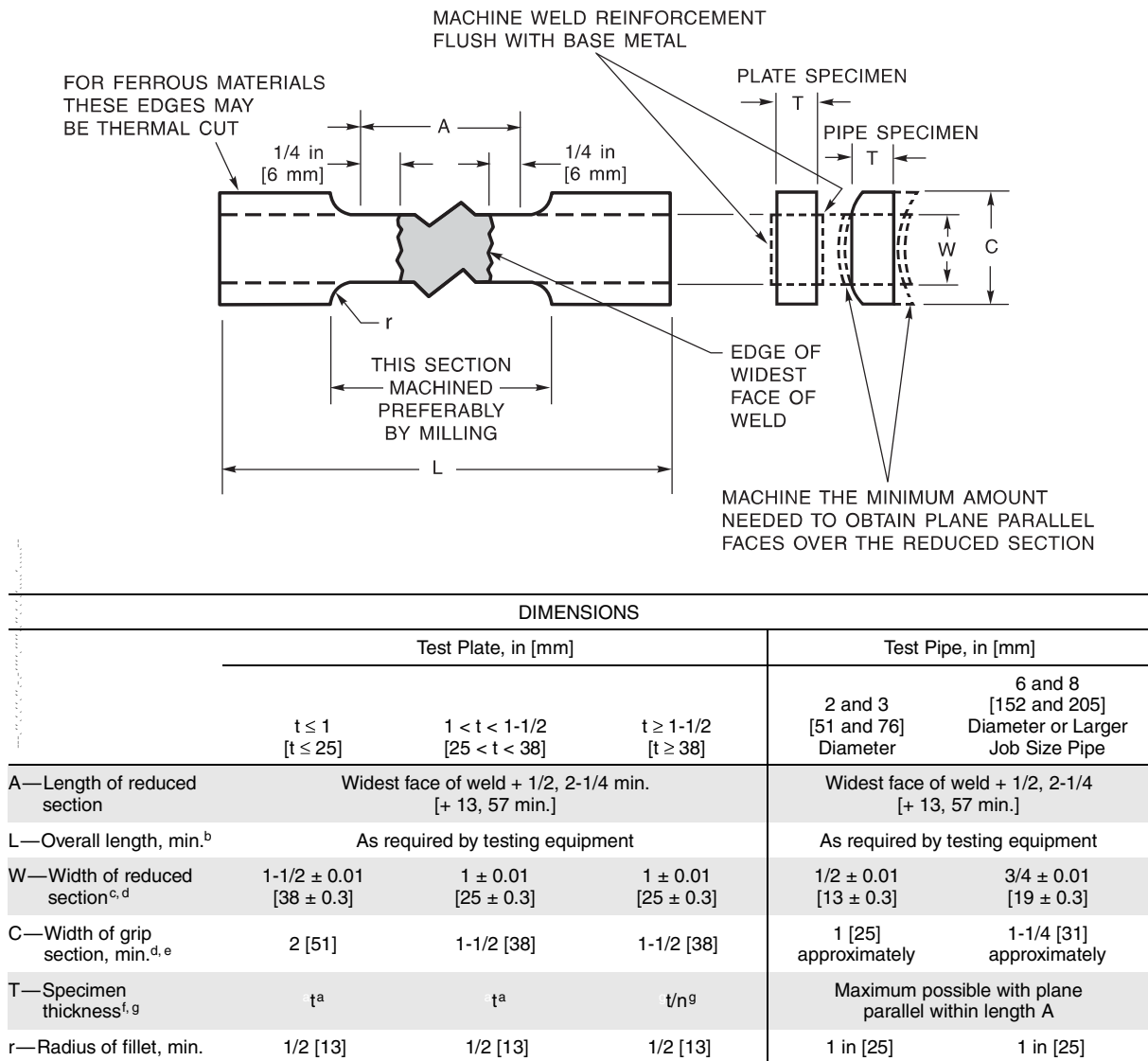


THE GROOVE CONFIGURATION SHOWN IS FOR ILLUSTRATION ONLY.
THE GROOVE SHAPE USED SHALL CONFORM TO THAT BEING QUALIFIED.

Figure 10.9—Location of Test Specimens on Welded Test Plate for 1/8 in to 3/8 in [3 mm to 10 mm] (inclusive) Thick Procedure Qualification



**Figure 10.10—Location of Test Specimens on Welded Test Plate
3/8 in [10 mm] Thick and Over Procedure Qualification**



^a t = thickness of the plate or pipe.

^b 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.

^c 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 at either end shall not be more than 0.015 in [0.4 mm] larger than the width at the center.

^d 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 permits. If the width of the material is less than W , the sides may be parallel throughout the length of the specimen.

^e For standard plate type specimens, the ends of the specimen shall be symmetrical with the center line of the reduced section within 0.25 in [6 mm] except for referee testing, in which case the ends of the specimen shall be symmetrical with the center line of the reduced section within 0.10 in [2 mm].

^f The dimension t is the thickness of the test specimen as provided for in the applicable material specifications. The minimum nominal thickness of $1\frac{1}{2}$ in [38 mm] wide specimens shall be $\frac{3}{16}$ in [5 mm] except as permitted by the product specification.

^g For plates over $1\frac{1}{2}$ in [38 mm] thick, specimens may be cut into the minimum number (n) of approximately equal strips not exceeding $1\frac{1}{2}$ in [38 mm] in thickness. Test each strip and average the results.

Figure 10.11—Reduced-Section Tension Specimen

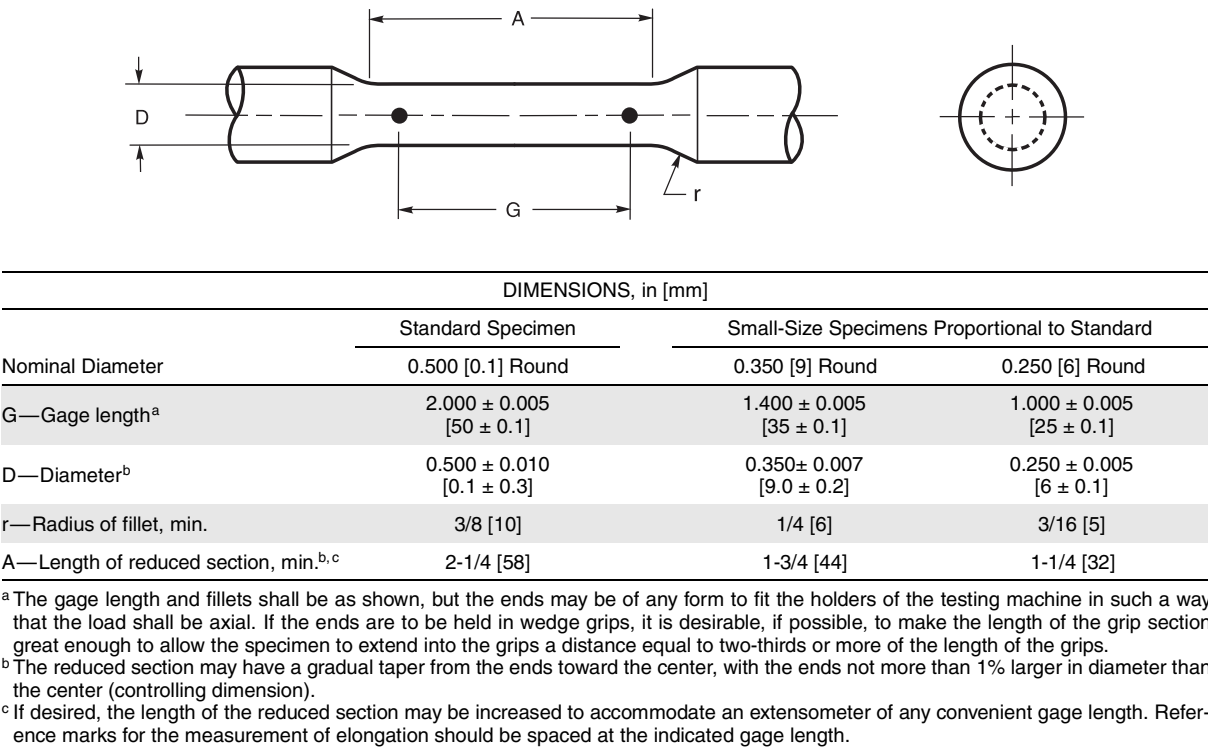
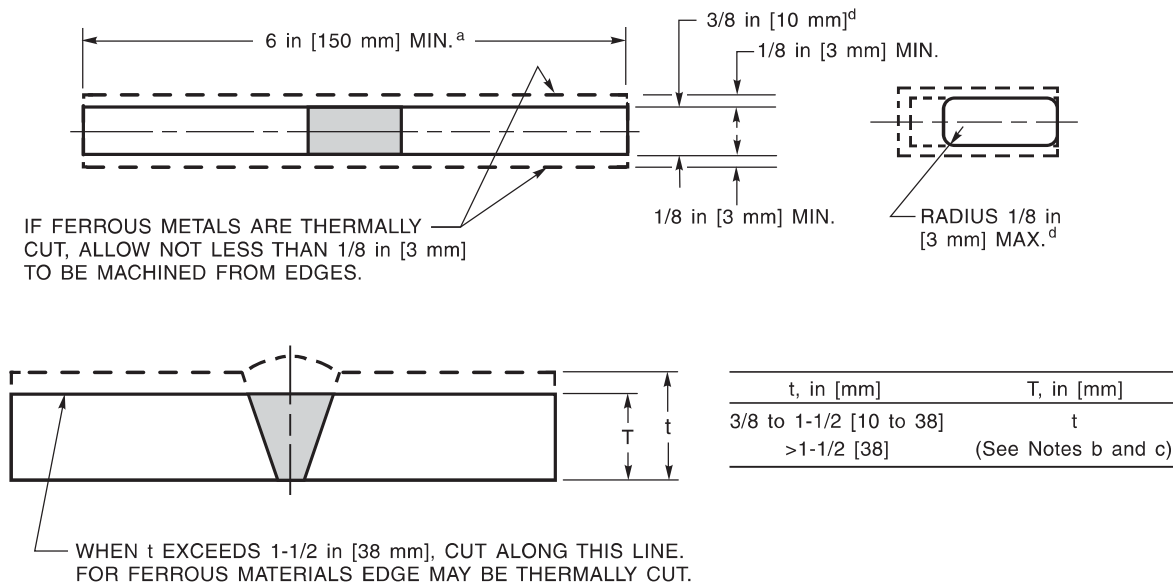


Figure 10.12—All-Weld-Metal Tension Specimen



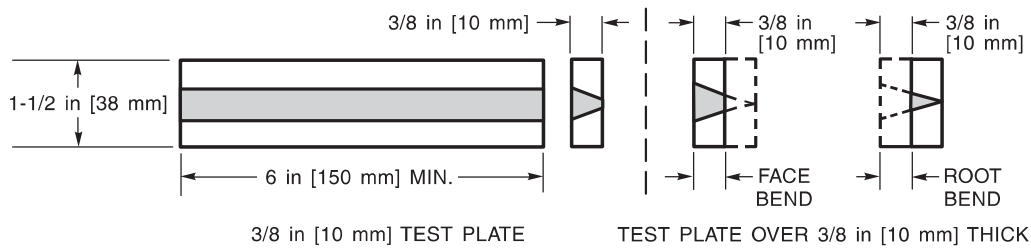
^a A longer specimen length may be necessary when using a wraparound-type bending fixture or when testing steel with a yield point of 90 ksi [620 MPa] or more.

^b For plates over 1-1/2 in [38 mm] thick, cut the specimen into approximately equal strips with T between 3/4 in and 1-1/2 in [19 mm and 38 mm] and test each strip.

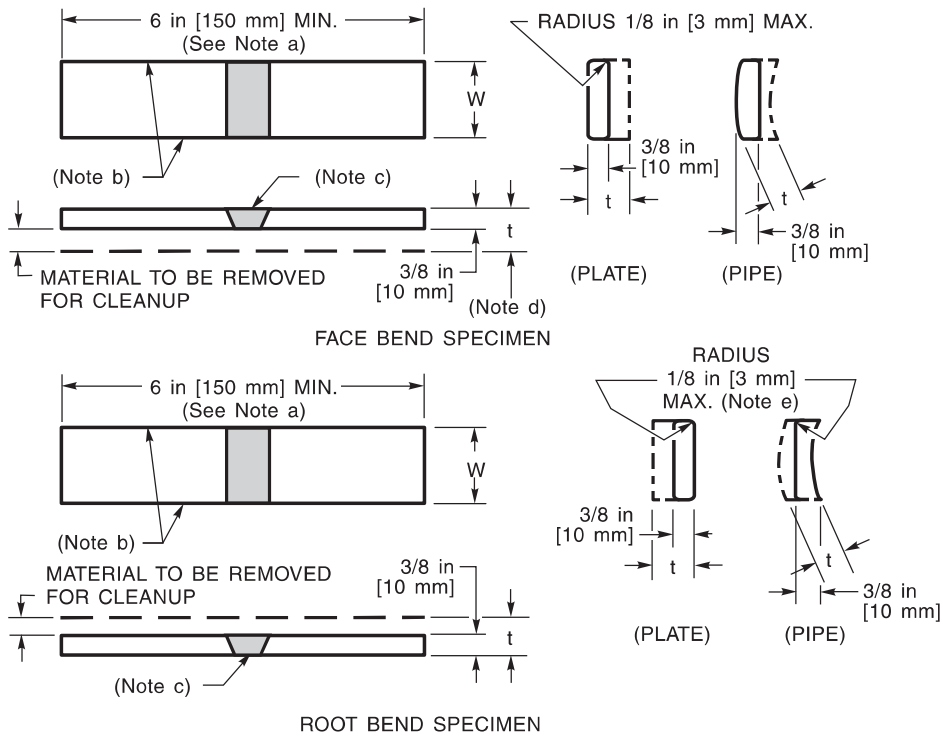
^c t = plate or pipe thickness.

^d 1/8 in [3 mm] thickness for M23 material and any welds made with F23 weld metal. Corner radius on these specimens shall be 1/16 in [2 mm] min.

Figure 10.13—Side-Bend Specimens



(A) LONGITUDINAL BEND SPECIMENS



(B) TRANSVERSE BEND SPECIMENS

DIMENSIONS	
Test Weldment	Test Specimen Width (W) in [mm]
Plate	1-1/2 [38]
Test pipe 2 in and 3 in [51 mm and 76 mm] in diameter	1 [25]
Test pipe 6 in and 8 in [152 mm and 203 mm] in diameter	1-1/2 [38]

Base Metal Thickness in [mm]	T, in [mm]	
	M -No. 23, F-No. 23	All Other Metals
1/8–3/8 [3–10]	1/8 [3]	1
>3/8 [10]	1/8 [3]	3/8 [10]

^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.

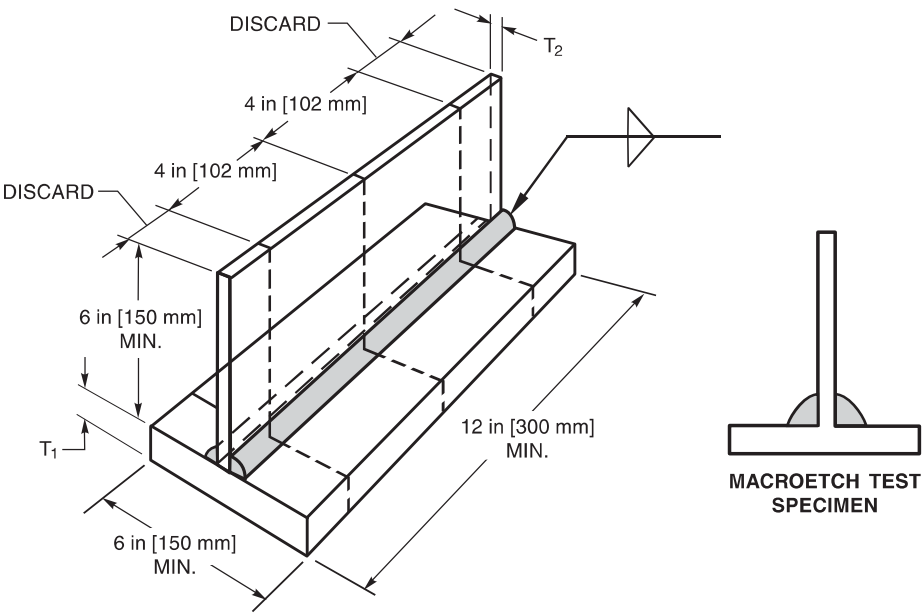
^b These edges may be oxygen-cut or plasma cut, and may or may not be machined.

^c The weld reinforcement and backing, if any, shall be removed flush with the surface of the specimen. 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 cases, the thickness of the finished specimen shall be that specified above. Cut surfaces shall be smooth and parallel.

^d t = plate or pipe thickness.

^e R = 1/2T max. for T ~ 1/4 in [6 mm].

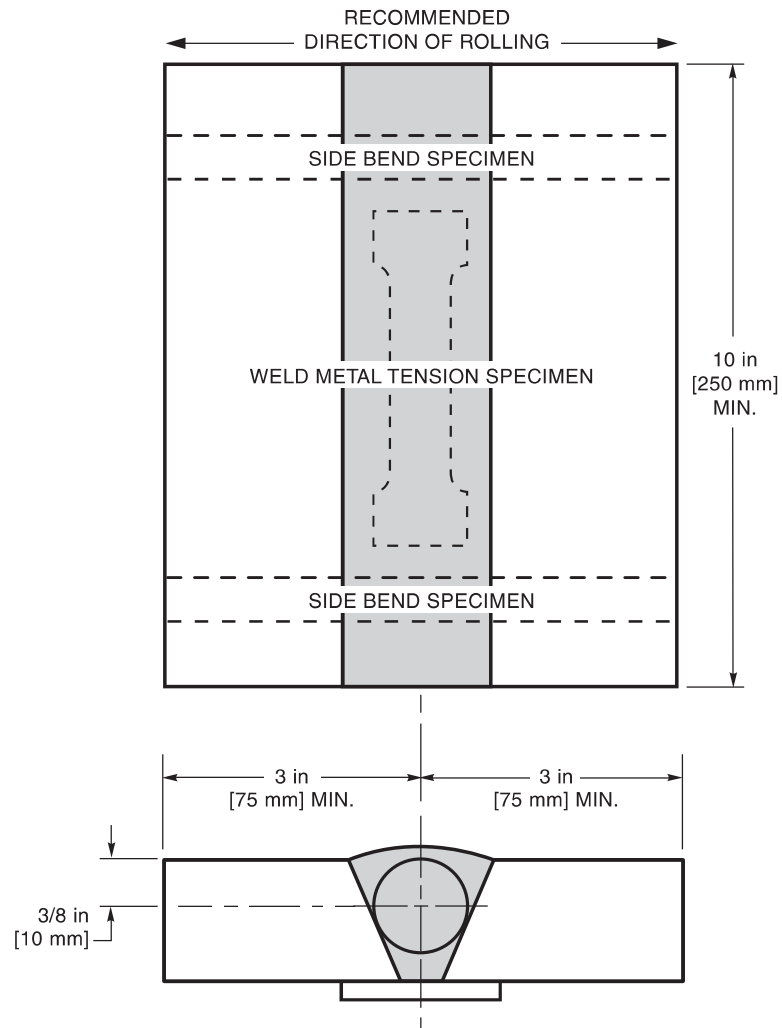
Figure 10.14—Face- and Root-Bend Specimens



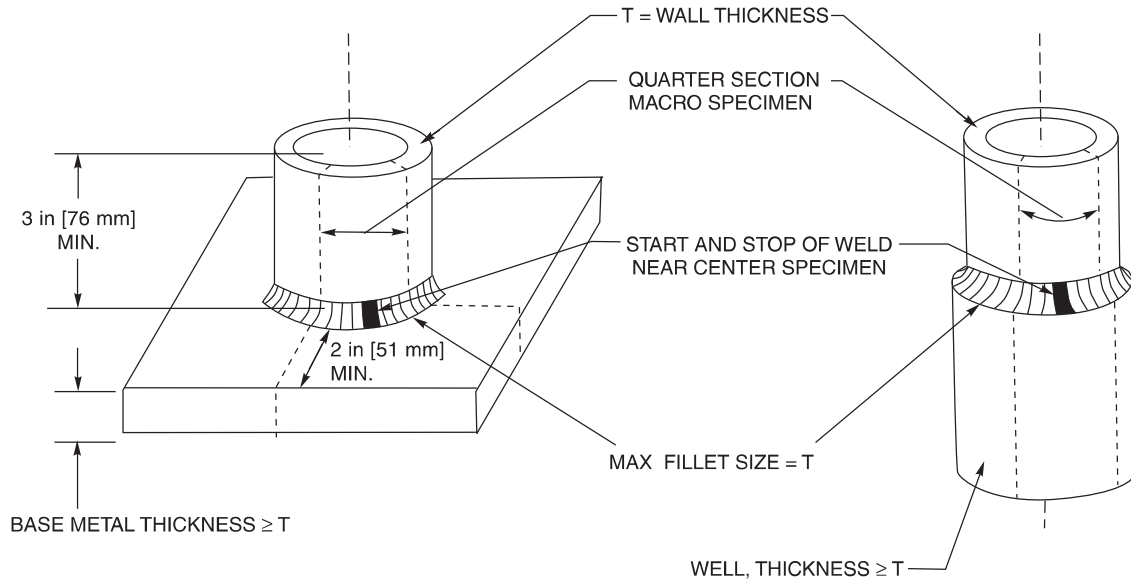
Weld Size in [mm]	T ₁ min. ^a in [mm]	T ₂ min. ^a in [mm]
3/16 [5]	1/2 [13]	3/16 [5]
1/4 [6]	3/4 [19]	1/4 [6]
5/16 [8]	1 [25]	5/16 [8]
3/8 [10]	1 [25]	3/8 [10]
1/2 [13]	1 [25]	1/2 [13]
5/8 [16]	1 [25]	5/8 [16]
3/4 [19]	1 [25]	3/4 [19]
>3/4 [19]	1 [25]	>3/4 [19]

^a Where the maximum plate thickness used in production is less than the value shown in the table, the maximum thickness of the production pieces may be substituted for T₁ and T₂.

Figure 10.15—Fillet Weld Soundness Test for Procedure Qualification



**Figure 10.16—Location of Test Specimens on Welded Test Plate 1 in [25 mm] Thick—
Consumables Verification for Fillet Weld Procedure Qualification**

**Notes:**

1. See Table 10.4 for position requirements.
2. See Table 10.3 for number and type of specimens required.
3. Pipe shall be of sufficient thickness to prevent melt-through.
4. Either pipe-to-plate or pipe-to-pipe may be used as shown.

Figure 10.17—Pipe Fillet Weld Soundness Test Procedure Qualification

11. Welder Qualification

11.1 General. The qualification tests described in this clause are specially devised tests to determine the welder's ability to produce sound welds. The qualification tests are not intended to be used as guides for welding during actual construction. The latter shall be performed in accordance with the requirements of the welding procedure specification.

11.2 Limitation of Variables. Any change from the limitations in Table 11.1 shall require separate qualification.

11.2.1 A welder shall be qualified for each process used.

11.2.1.1 GMAW-S (short circuiting mode) is considered a separate process.

11.2.1.2 Welders qualified using GMAW, FCAW, or GTAW shall be considered as qualified welding operators in the same process(es), subject to the same essential variable limitations of 12.2 and provided that there is sufficient evidence that the welders have received training and have demonstrated their ability to produce satisfactory production welds.

11.3 Qualification Tests Required

11.3.1 Plate and Structural Shapes

11.3.1.1 The welder qualification tests for manual and semiautomatic welding shall be as follows:

- (1) Groove weld qualification tests for plate in accordance with 11.4
- (2) Fillet weld qualification tests (only) in accordance with 11.6.1

11.3.1.2 A welder may also be qualified by welding a satisfactory procedure qualification test plate, as specified in 10.6.1, that meets the requirements of 10.9.

11.3.2 Pipe or Square or Rectangular Tubing

11.3.2.1 Welder qualification tests for manual and semiautomatic welding shall be as follows:

- (1) Groove weld qualification tests for butt joints on pipe, or square or rectangular tubing in accordance with 11.5
- (2) Groove weld qualification tests on plate for butt joints in accordance with 11.4
- (3) Fillet weld qualification tests for fillet welds in accordance with 11.6.2

11.3.2.2 A welder may also be qualified by welding a satisfactory procedure qualification test pipe, without backing, as specified in 10.6.1, that meets the requirements of 10.9. The welder is thereby qualified to weld pipe and tubing with the process and in the test position used for procedure qualification. The diameter and wall thickness ranges qualified for shall be as specified in Table 11.3(2).

11.4 Groove Weld Plate Qualification Test for Plate. Suggested groove weld joint designs are given in Figures 11.1 through 11.4. Other joint designs may be used.

11.5 Groove Weld Qualification Test for Pipe or Square or Rectangular Tubing. Suggested joint details are shown in Figures 11.5 and 11.6. Other joint designs may be used.

11.6 Fillet Weld Qualification Test for Fillet Welds Only

11.6.1 Plate and Structural Shapes. For fillet weld qualification only the following shall apply:

11.6.1.1 For fillet welds between members having a dihedral angle (Ψ) of less than 60°, Figure 5.4(A), the welder shall weld a groove weld test plate as required by 11.4. This qualification shall also be valid for joints having a dihedral angle (Ψ) of 60° and greater.

11.6.1.2 For joints having a dihedral angle (Ψ) of 60° or greater, but not exceeding 135°, the welder shall weld a test plate according to Option 1 or Option 2, depending upon the manufacturer's choice, as follows:

- (1) **Option 1.** Weld a test plate in accordance with Figure 11.7.
- (2) **Option 2.** Weld a soundness test plate in accordance with Figure 11.8.

11.6.2 Pipe or Tubing. For fillet weld qualification only the following shall apply:

11.6.2.1 For fillet welds in connections having a dihedral angle (Ψ) of less than 60° , qualification tests shall be as required by 11.5. The qualification shall also be valid for connections having a dihedral angle (Ψ) of 60° or greater.

11.6.2.2 For connections having a dihedral angle (Ψ) of 60° or greater, the welder shall weld test pipes in accordance with Figure 11.9.

11.7 Position of Test Welds (see Table 11.4)

11.7.1 Test Assemblies and Positions Required. Table 11.4 describes the type of test by assemblies and standard test positions that shall be taken to qualify a welder for the type of assembly and positions to be used for production welding of plate, pipe, or box tubing.

11.7.2 Standard Positions. See 10.4 for definitions.

11.7.3 Special Orientations. A manufacturer who does production welding in a special orientation may make test assemblies for performance qualification in that orientation. Such qualifications are valid only for the orientation actually tested.

11.8 Base Metal. The base metal used shall comply with the welding procedure specification.

11.9 Joint Welding Procedure Specification. The welder shall comply with the requirements of a welding procedure specification qualified in accordance with this document. Weld cleaning shall be done in the same position as the welding position being qualified.

11.10 Test Specimens

11.10.1 The type and number of test specimens that shall be tested to qualify a welder by mechanical testing are shown in Table 11.3 together with the range of thickness of the test plate, pipe, or tubing used in making the qualification assembly. Except for joints welded by GMAW short circuiting transfer mode, radiographic examination of groove welds may be used at the manufacturer's option in lieu of mechanical testing.

11.10.2 Guided-bend test specimens shall be prepared by cutting the test plate, pipe, or tubing as shown in Figures 11.1, 11.2, 11.3, 11.4, 11.8, 11.9, and 11.10, and as applicable, to form specimens approximately rectangular in cross section. The specimen shall be prepared for testing in accordance with Figure 10.13 or 10.14, as applicable, and the test method of 11.11.1 shall be followed.

11.10.3 The fillet weld break and macroetch test specimens shall be cut from the test assembly as shown in Figure 11.7.

11.10.4 If radiographic testing is used in lieu of the prescribed bend tests, the weld reinforcement need not 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 radiography, the root shall be ground flush with the base metal.

11.11 Method of Testing Specimens

11.11.1 Root, Face, or Side Bend Specimens. Each specimen shall be bent in a fixture having the contour shown in Figure 11.11, 11.12, or 11.13. Other parts should be substantially in accordance with the appropriate figure. Any convenient means may be used to move the plunger member with relation to the die member.

11.11.1.1 The specimen shall be placed on the die member of the fixture with the weld at midspan. 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.

11.11.1.2 The plunger shall force the specimen into the die until the specimen becomes U-shaped. The weld and heat-affected zones (HAZs) shall be centered and completely within the bent portion of the specimen after testing.

11.11.1.3 When using a wrap around fixture (Figure 11.12) the specimen shall be firmly clamped on one end so that the specimen does not slide during the bending operation. The weld and HAZs shall be completely within the bent portion of the specimen after testing. Test specimens shall be removed from the fixture when the outer roller has been moved 180° from the starting point.

11.11.2 Fillet Weld Break Test. The entire length of the fillet weld shall be examined visually and then the 6 in [150 mm] specimen shall be loaded in such a way that the root of the weld is in tension. At least one weld stop and start shall be located within the test section. The load shall be steadily increased or repeated until the specimen fractures or bends flat upon itself.

11.11.3 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 (see Annex F).

11.11.4 Radiographic Test. The radiographic procedure and technique shall be in accordance with the requirements of Clause 15. Exclude 1-1/4 in [32 mm] at each end of the weld from evaluation in the plate test. Welded test pipe or tubing 4 in [102 mm] in diameter or larger shall be examined for a half of the weld perimeter selected to include a sample of all positions welded. (For example, a test pipe or tube welded in the 5G or 6G position shall be radiographed from the top centerline to the bottom centerline on either side.) Welded test pipe or tubing less than 4 in [102 mm] in diameter shall require 100% radiography.

11.12 Test Results Required

11.12.1 Visual Inspection. For acceptable qualification, the welded specimens shall conform to the requirements of Table 17.1, Class 1.

11.12.2 Root, Face, and Side 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:

11.12.2.1 1/8 in [3 mm] measured in any direction on the surface.

11.12.2.2 3/8 in [10 mm]—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].

11.12.2.3 1/4 in [6 mm]—maximum corner crack, except when that corner crack resulted from visible slag inclusion or other fusion-type discontinuities, then the 1/8 in [3 mm] maximum shall apply. The specimens with corner cracks exceeding 1/4 in [6 mm] with no evidence of slag inclusions or other fusion-type discontinuities may be disregarded, and a replacement test specimen from the original weldment shall be tested.

11.12.3 Fillet Weld Break Test

11.12.3.1 To pass the visual examination, the fillet weld shall present a reasonably uniform appearance and shall be free of overlap, cracks, and excessive undercut. There shall be no porosity visible on the surface of the weld.

11.12.3.2 The specimen shall pass the test if it bends flat upon itself. If the fillet weld fractures, the fractured surface shall show complete fusion to the root of the joint and shall exhibit no inclusion or porosity larger than 3/32 in [2 mm] in greatest dimension. 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] specimen.

11.12.4 Macroetch Test. For acceptable qualification, the test specimens, when inspected visually, shall conform to the following requirements:

11.12.4.1 Partial joint penetration groove welds shall have the designated effective weld size.

11.12.4.2 Fillet welds shall have fusion to the root of the joint but not necessarily beyond.

11.12.4.3 Minimum leg size shall meet the specified fillet weld size and shall not exceed the specified size by more than 1/8 in [3 mm].

11.12.4.4 The partial joint penetration groove welds and fillet welds shall have the following:

- (1) No cracks
- (2) Complete fusion between adjacent layers of weld metal and between weld metal and base metal
- (3) Weld profiles conforming to intended detail, but with none of the variations prohibited in Figure 6.2
- (4) No undercut exceeding the values permitted in Table 17.1, Class 1

11.12.5 Radiographic Test. For acceptable qualification, the weld, as revealed by the radiograph, shall conform to the requirements of 17.3.

11.13 Retests. In a case where a welder fails to meet the requirements of one or more test welds, a retest may be allowed under the following conditions:

11.13.1 An immediate retest may be made consisting of two test welds of each type on which the welder failed. All retest specimens shall meet all the specified requirements.

11.13.2 A retest may be made, provided there is evidence that the welder has had further training or practice. In this case, a complete retest (single test welds of each type) shall be made.

11.14 Period of Effectiveness. The welder's qualification as specified in this specification shall be considered as remaining in effect indefinitely unless either of the following applies:

11.14.1 The welder has not been engaged in the process of welding for which the welder was qualified by the employer for a period exceeding six months.

11.14.1.1 In the case described in 11.14.1, the requalification test need be made only in the 3/8 in [10 mm] thickness.

11.14.2 There is some specific reason to question a welder's ability.

11.15 Records. Records of the test results shall be kept by the manufacturer and shall be available to those authorized to examine them.

Table 11.1
Performance Qualification—Limitation of Essential Variables

	Welders ^{a, b}	Welding Operators	Tack Welders
(1) To a process not qualified (GMAW-S is considered a separate process)	X	X	X
(2) A change from a ferrous to a nonferrous base metal or vice versa	X	X	
(3) A change in an “M” number of nonferrous materials (a change involving only aluminum alloys is exempt)	X	X	X
(4) To an SMAW electrode with an F-number (see Table 11.2) higher than the WPQR electrode F-number	X		X
(5) If electrode and shielding medium combination is not approved for the process used in qualification test	X	X	X
(6) To a position not qualified	X	X	X
(7) To a diameter or thickness not qualified	X	X	
(8) To a vertical welding progression not qualified (uphill or downhill)	X		
(9) The omission of backing (if used in the WPQR test)	X	X	
(10) To multiple electrodes but not vice versa.		X	

^a Welders qualified for 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 welder is qualified for plug, slot, and buildup welding by a complete penetration groove weld test.

Table 11.2
Electrode Classification Groups for Welder and Tack Welder Qualification

F Number	AWS A5.1/A5.1M, A5.4/A5.4M, and A5.5/A5.5M Electrode Classification ^a
F1	EXX20, EXX20-X, EXX24, EXX27-X, EXX28
F2	EXX12, EXX13, EXX13-X, EXX14
F3	EXX10, EXX10-X, EXX11, EXX11-X
F4	EXX15, EXX15-XX, EXX16, EXX16-XX, EXX18, EXX18-XX
F5	EXXX(X)-15, EXXX(X)-16, EXXX(X)-17

^a The letters “XX” used in the classification designation in this table for F1 through F4 electrodes stands for the various strength levels (60 ksi, 70 ksi, 80 ksi, 90 ksi, 100 ksi, and 120 ksi [414 MPa, 483 MPa, 551 MPa, 620 MPa, 690 MPa, and 827 MPa]) of deposited weld metal. AWS A5.5/A5.5M, *Specification for Low-Alloy Steel Electrodes for Shielded Metal Arc Welding*, requires composition designations such as EXX18-XX where “-XX” indicates a chemical composition.

Table 11.3
Number and Type of Specimens and Range of Thickness Qualified—
Welder and Welding Operator Qualification

1. Test on Plateⁱ

Type of Weld	Thickness of Test Plate (T) as Welded, in [mm]	Visual Screening Inspection	Number of Specimens					Qualified, in [mm]
			Bend Tests ^j			T-Joint Break	Macroetch Thickness Test	
			Face	Root	Side			
Groove ^g	T ≤ 3/8 [10]	Yes	1	1	—	—	—	1/8 [3]–2T ^c
Groove ^g	3/8 ≤ T < 3/4 [10 ≤ T < 19]	Yes	—	—	2	—	—	1/8 [3]–2T ^{c, d}
Groove ^g	3/4 [19] or over	Yes	—	—	2	—	—	1/8 [3]–Unlimited ^c
Fillet Option 1 ^{a, e}	3/16–1/2 [5–13]	Yes	—	—	—	1	1	1/8 [3]–Unlimited
Fillet Option 2 ^{b, e}	3/8 [10]	Yes	—	2	—	—	—	1/8 [3]–Unlimited

2. Test on Pipe

Type of Weld	Outside Diameter, in [mm]	Number of Specimens							Macro and Break	Outside Diameter Qualified, in [mm]	Plate, Pipe, or Tube Wall Thickness Qualified, in [mm]	
		All Positions Except 5G and 6G Only			5G and 6G Positions Only			Min.			Max.	
		Face Bend	Root Bend	Side Bend	Face Bend	Root Bend	Side Bend					
Groove	<1 [25]	1	1	—	2	2	—	—	Size welded, min.	T/2	2T ^c	
Groove	1 to ≤2-7/8 [25 to ≤73]	1	1	—	2	2	—	—	≥1 [25]	T/2	2T ^c	
Groove	2-7/8 [73] and over	1	1	—	2	2	—	—	≥2-7/8 [73]	T/2	2T ^c	
Fillet Option 3 ^f	<1 [25]	—	—	—	—	—	—	1	Size welded, min.	1/8 [3]	Unlimited	
Fillet Option 3 ^f	1 to ≤2-7/8 [25 to ≤73]	—	—	—	—	—	—	1	≥1 [25]	1/8 [3]	Unlimited	
Fillet Option 3 ^f	2-7/8 [73]	—	—	—	—	—	—	1	≥2-7/8 [73]	1/8 [3]	Unlimited	

^a See Figure 11.7.^b See Figure 11.8.^c Also qualifies for welding fillet welds of all sizes on material of 1/8 in [3 mm] to unlimited thickness for the positions qualified in Table 11.4.^d T max for welding operator qualifications.^e Also qualifies fillet welds on pipe 2-7/8 in [73 mm] outside diameter and over for the positions qualified in Table 11.4.^f See Figure 11.9.^g Qualification for butt joint groove welds in plate also qualifies for box tubing (and vice versa) for the positions qualified in Table 11.4.^h T = Thickness of test coupon.ⁱ Qualifies to weld pipe over 24 in [610 mm] in diameter.^j Radiographic examination of welder operator test plate may be made in lieu of the bend test (see 11.11.4 and 12.7).

Table 11.4
Welder and Welding Operator Qualification—Type and Position Limitation^a

Qualification Test ^b		Production Weld Type and Position Qualified ^c			
		Plate, Structural Shapes, Box Tubing, and Pipe over 24 in. [610 mm] in Diameter	Pipe 24 in. [610 mm] and Under in Diameter		
Weld Type	Position	Groove	Fillet	Groove	Fillet ^e
Plate-Groove	1G	F	F, H	—	F, H
	2G	F, H	F, H	—	F, H
	3G	F, V	F, V	—	F, V
	4G	F, OH	F, OH	—	F, OH
	2G, 3G and 4G ^d	All	All	—	All
Plate-Fillet ^d	1F	—	F	—	F
	2F	—	F, H	—	F, H
	3F	—	F, V	—	F, V
	4F	—	F, OH	—	F, OH
	2F, 3F and 4F	—	All	—	All
Pipe-Groove 24 in. [610 mm] and under in diameter	1G Rotated	F, H	F, H	F	F, H
	2G	F, H	F, H	F, H	F, H
	5G	F, V, OH	F, V, OH	F, V, OH	F, V, OH
	6G	All	All	All	All
	2G and 5G	All	All	All	All
Pipe-Fillet 24 in. [610 mm] and under in diameter	1F Rotated	—	F	—	F
	2F/2FR	—	F, H	—	F, H
	4F	—	F, OH	—	F, OH
	5F	—	All	—	All

^a For thickness and diameter range qualified, see Table 11.3.

^b For welding test positions see Figures 10.3 through 10.6.

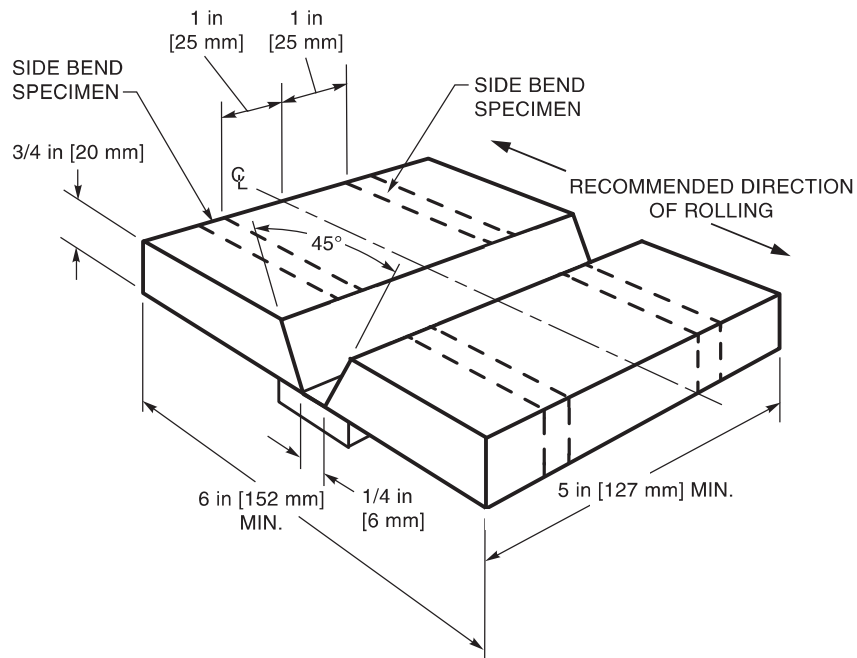
^c For production welding positions, see Figures 10.1 and 10.2; F = flat, H = horizontal, V = vertical, OH = overhead.

^d Not applicable for connections having a dihedral angle of less than 60° (see 11.6.2.1 and 12.3.5.1).

^e Includes socket welded fittings.

Table 11.5
Maximum Reinforcement—Pipe Welds

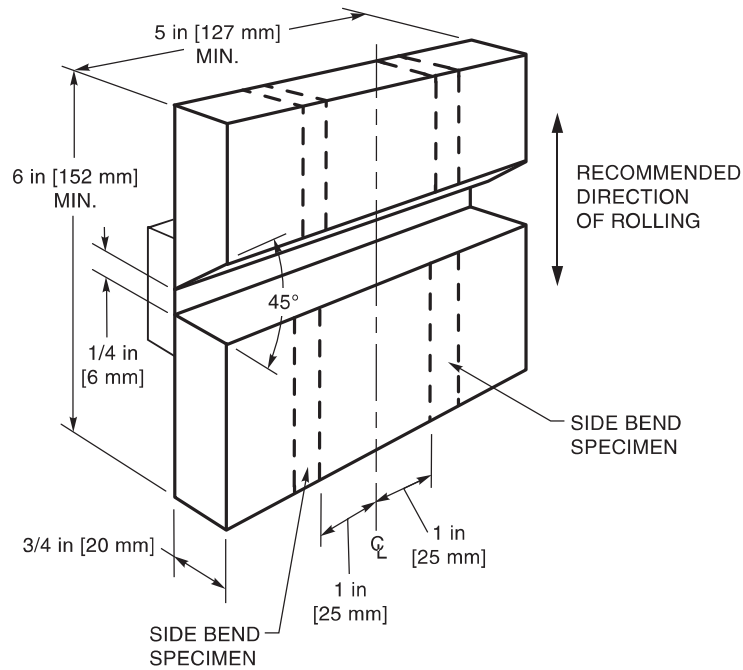
Pipe Wall Thickness, in [mm]	Reinforcement, Max., in [mm]
3/8 [10] or less	3/32 [2]
Over 3/8 to 3/4 [10 to 19] incl.	1/8 [3]
Over 3/4 [19]	3/16 [5]



Notes:

1. When radiography is used for testing, no tack welds shall be in the test area.
2. The backing thickness shall be 1/4 in [6 mm] min. to 3/8 in [10 mm] max.; width of backing shall be 3 in [75 mm] min. when not removed for radiography, otherwise 1 in [25 mm] min.

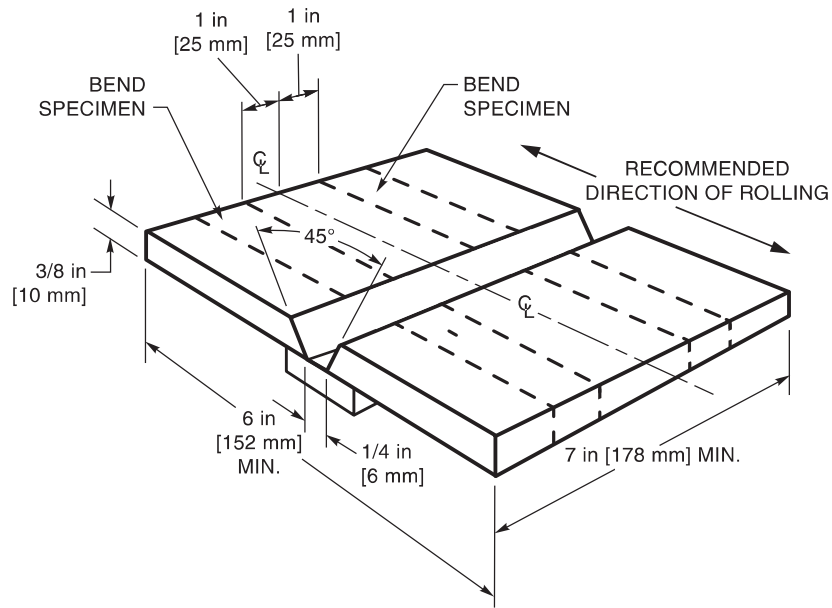
Figure 11.1—Test Plate for Unlimited Thickness Welder Qualification



Notes:

1. When radiography is used for testing, no tack welds shall be in the test area.
2. The backing bar thickness shall be 1/4 in [6 mm] min. to 3/8 in [10 mm] max.; width of backing shall be 3 in [76 mm] min. when not removed for radiography, otherwise 1 in [25 mm] min.

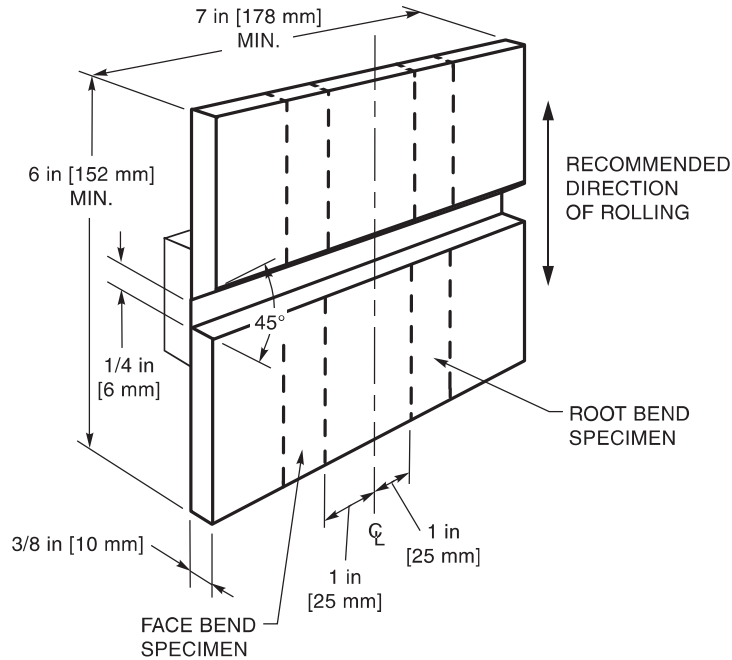
Figure 11.2—Test Plate for Unlimited Thickness Horizontal Position—Welder Qualification



Notes:

1. When radiography is used for testing, no tack welds shall be in test area.
2. The backing thickness shall be 1/4 in [6 mm] min. to 3/8 in [10 mm] max.; backing width shall be 3 in [75 mm] min. when not removed for radiography, otherwise 1 in [25 mm] min.
3. See Figure 10.13 or 10.14 for the appropriate specimen dimensions.

Figure 11.3—Test Plate for Limited Thickness—Welder Qualification



Notes:

1. When radiography is used for testing, no tack welds shall be in test area.
2. The backing thickness shall be 1/4 in [6 mm] min. to 3/8 in [10 mm] max.; backing width shall be 3 in [75 mm] min. when not removed for radiography, otherwise 1 in [25 mm] min.
3. See Figure 10.13 or 10.14 for the appropriate specimen dimensions.

Figure 11.4—Test Plate for Limited Thickness Horizontal Position—Welder Qualification

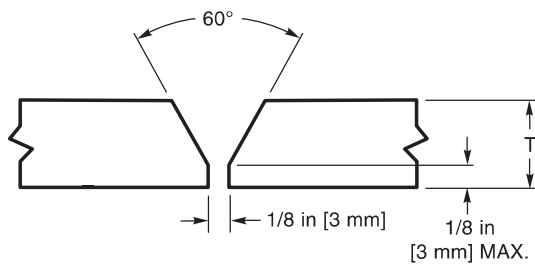


Figure 11.5—Tubular Butt Joint—Welder Qualification without Backing

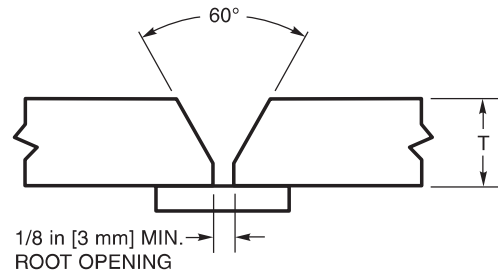
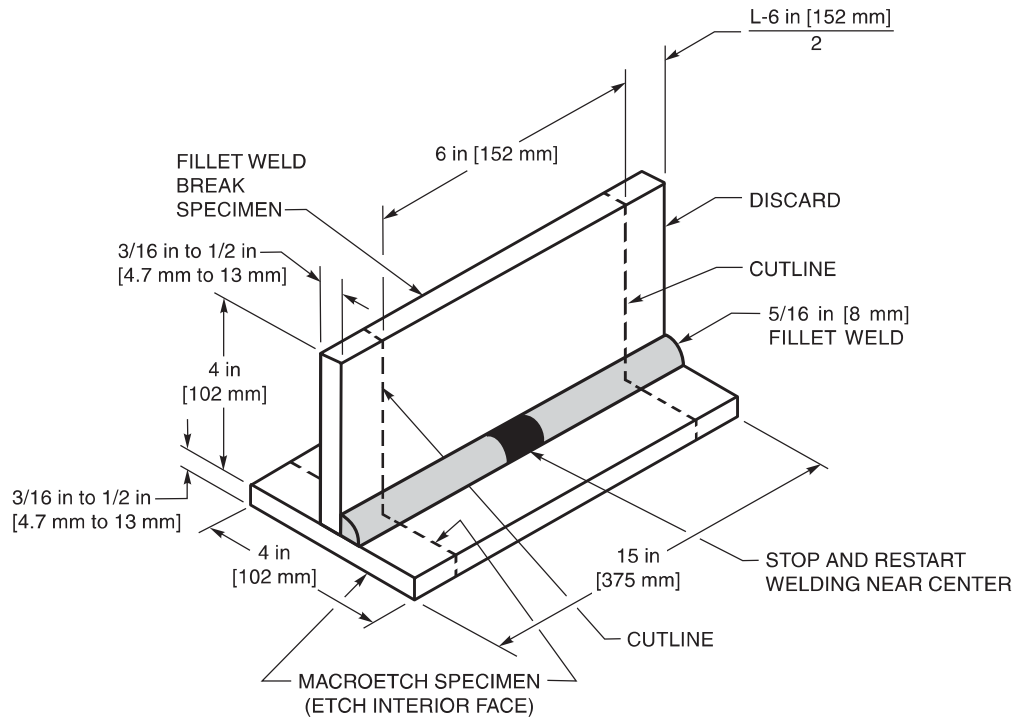


Figure 11.6—Tubular Butt Joint—Welder Qualification with Backing



Notes:

1. L = 15 in [375 mm].
2. Plate thickness and dimensions are minimum.

Figure 11.7—Fillet-Weld-Break and Macroetch Test Plate Welder and Welding Operator Qualification—Option 1

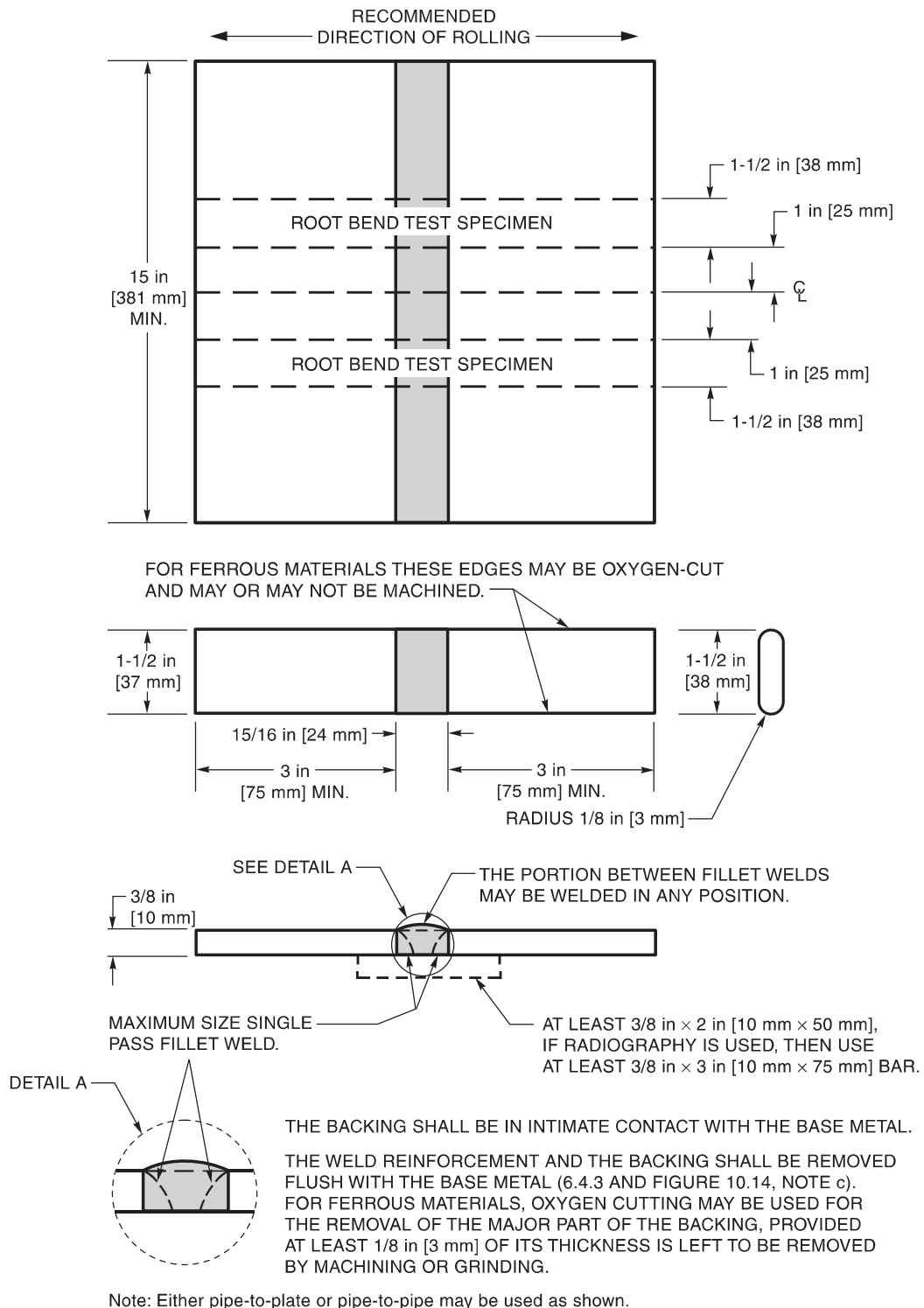
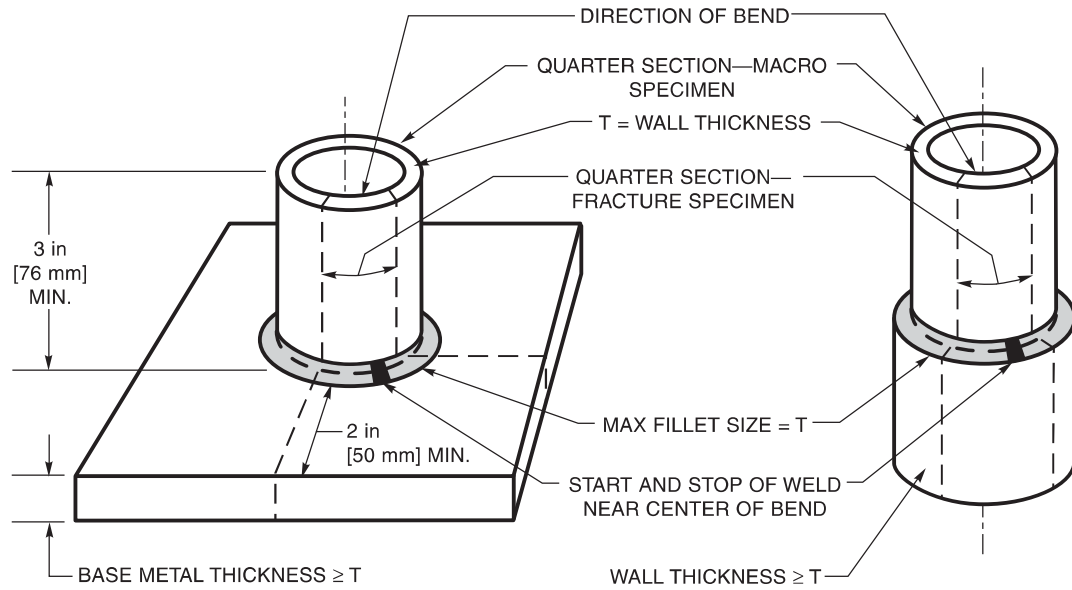
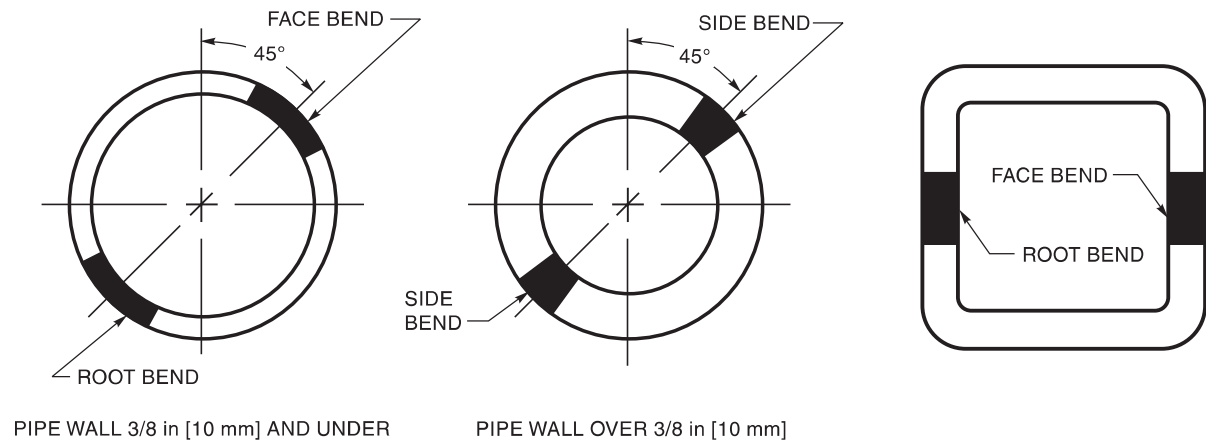


Figure 11.8—Fillet Weld Root-Bend Test Plate Welder and Welding Operator Qualification—Option 2

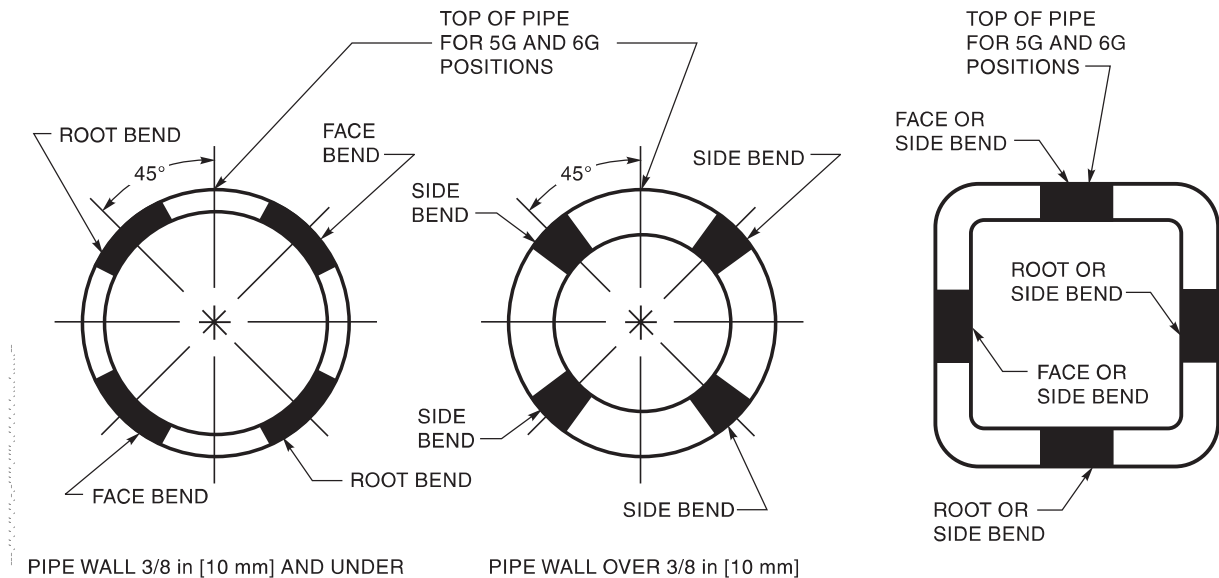


Note: Either pipe-to-plate or pipe-to-pipe may be used as shown.

Figure 11.9—Fillet Weld on Pipe—Welder and Welding Operator Qualification—Option 3

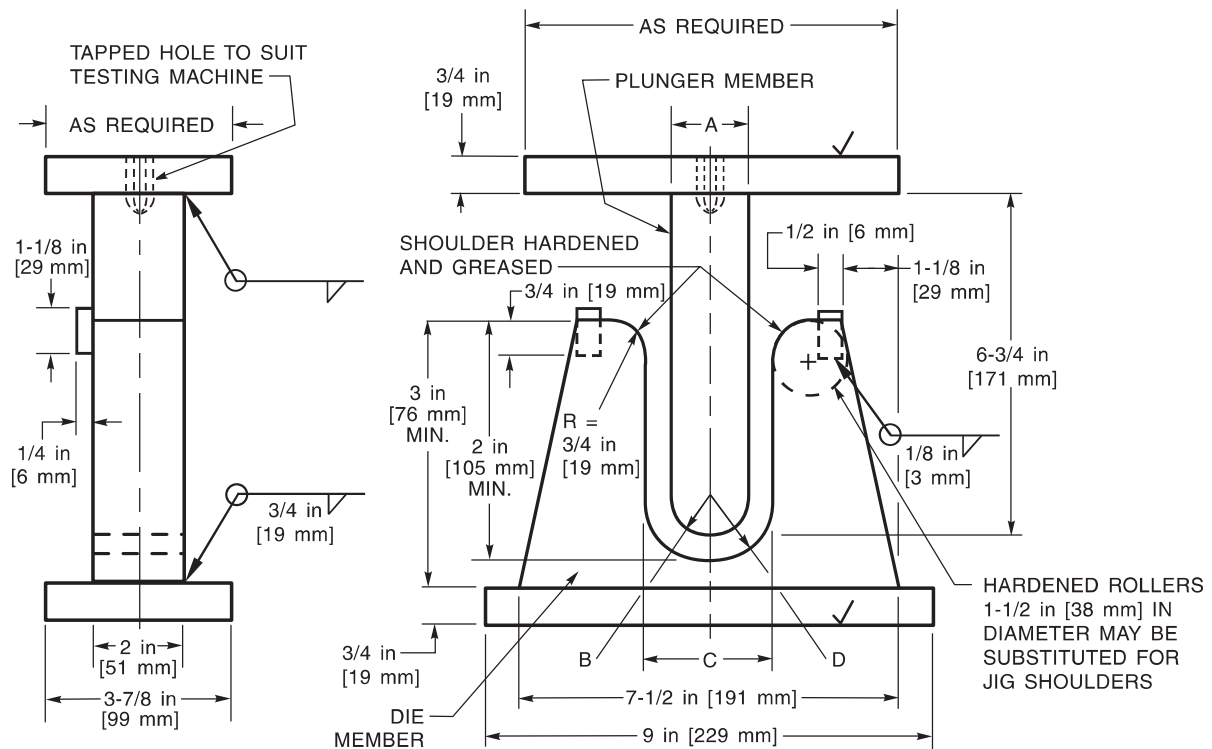


SPECIMENS FOR 1G AND 2G POSITIONS



SPECIMENS FOR 5G AND 6G POSITIONS

Figure 11.10—Location of Test Specimens on Welded Test Pipe and Square or Rectangular Tubing—Welder Qualification

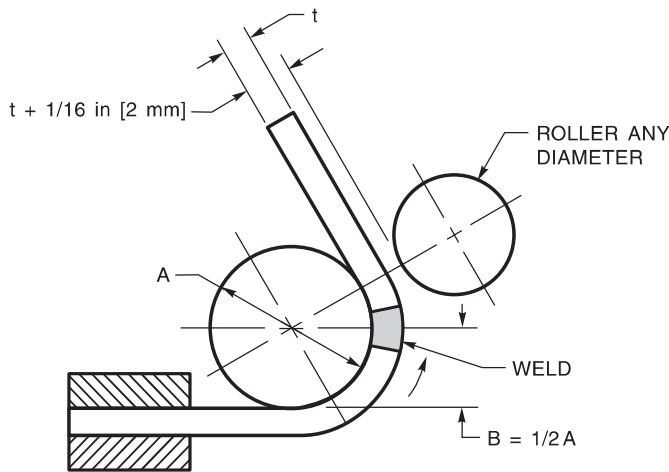


Source: Adapted from ANSI/AWS B4.0-98, *Standard Methods for Mechanical Testing of Welds*, Figure A2, American Welding Society.

Material ^a	Thickness of Specimen, in [mm]	A, in [mm]	B, in [mm]	C, in [mm]	D, in [mm]
M-No. 23 to M-No. 2X, M-No. 2X with F-No. 23	1/8 [3] $t = 1/8 [3]$ or less	2-1/16 [53] 16-1/2t	1-1/32 [26] 8-1/4t	2-3/8 [60] 18-1/2t + 1/16 [2]	1-3/16 [30] 9-1/4t + 1/32
M-No. 11; M-No. 25 welded to M-No. 21 or M-No. 22 or M-No. 25; Steel over 90 ksi [620 MPa] yield	3/8 [10] $t = 3/8 [10]$ or less	2-1/2 [64] 6-2/3t	1-1/4 [32] 3-1/3t	3-3/8 [86] 6-2/3t + 1/8 [3]	1-11/16 [43] 4-1/3t + 1/16 [2]
7005 Al alloy	3/8 [10] $t = 3/8 [10]$ or less	3 [76] 8t	1-1/2 [38] 4t	3-7/8 [98] 10t + 1/8 [3]	1-15/16 [49] 5t + 1/16 [2]
Steel from 50 ksi to 90 ksi [345 MPa to 620 MPa] yield	3/8 [10] $t = 3/8 [10]$ or less	2 [51] 5-1/3t	1 [25] 2-2/3t	2-7/8 [73] 7-2/3t	1-7/16 [37] 3-5/16t
All others	3/8 [10] $t = 3/8 [10]$ or less	1-1/2 [38] 4t	3/4 [19] 2t	2-3/8 [60] 6t + 1/8 [3]	1-3/16 [30] 3t + 1/16 [2]

^a "X" refers to 1, 2, 3, or 5, as applicable.

Figure 11.11—Guided-Bend Jig



Source: Adapted from ANSI/AWS B4.0-98, *Standard Methods for Mechanical Testing of Welds*, Figure A3, American Welding Society.

Material ⁽¹⁾	Thickness of Specimen, in [mm]	A, in [mm]	B, in [mm]
M-No. 23 to M-No. 2X, M-No. 2X with F-No. 23; Al alloy	1/8 [3] t = 1/8 [3] or less	2-1/16 [52] 16-1/2t	1-1/32 [27] 8-1/4t
M-No. 11; M-No. 25 to M-No. 21 or M-No. 22 or M-No. 25 Steel over 90 ksi [620 MPa] yield	3/8 [10] t = 3/8 [10] or less	2-1/2 [64] 6-2/3t	1-1/4 [32] 3-1/3t
7005 Al alloy	3/8 [10] t = 3/8 [10] or less	3 [77] 8t	1-1/2 [38] 4t
Steel over 50 ksi to 90 ksi [345 MPa to 620 MPa] yield	3/8 [10] t = 3/8 [10] or less	2 [51] 5-1/3t	1 [25] 2-2/3t
All others	3/8 [10] t = 3/8 [10] or less	1-1/2 [38] 4t	3/4 [19] 2t

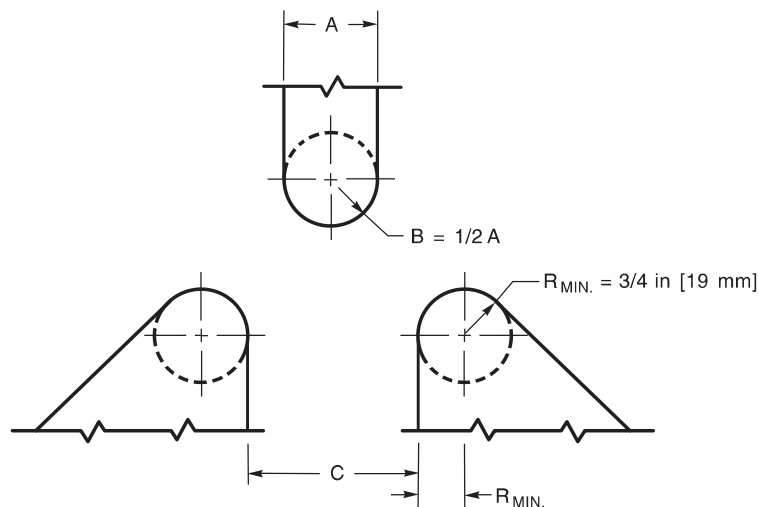
a "X" refers to 1, 2, 3, or 5, as applicable.

Notes:

1. Dimensions not shown are the option of the designer. The essential consideration is to have adequate rigidity so that the jig parts will not spring.
2. The specimen shall be firmly clamped on one end so that there is no sliding of the specimen during the bending operation.
3. Test specimens shall be removed from the jig when the outer roll has been removed 180° from the starting point.

Figure 11.12—Guided-Bend Wraparound Jig

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Source: Adapted from ANSI/AWS B4.0-98, *Standard Methods for Mechanical Testing of Welds*, Figure A1, American Welding Society.

Material ^a	Thickness of Specimen, in [mm]	A, in [mm]	B, in [mm]	C, in [mm]
M-No. 23 to M-No. 2X, M-No. 2X with F-No. 23; Al alloy	1/8 [3] $t = 1/8 [3]$ or less	2-1/16 [52] $16-1/2t$	1-1/32 [26] $8-1/4t$	2-3/8 [60] $18-1/2t + 1/16$
M-No. 11; M-No. 25 to M-No. 21 or M-No. 22 or M-No. 25 Steel over 90 ksi [620 MPa] yield	3/8 [10] $t = 3/8 [10]$ or less	2-1/2 [64] $6-2/3t$	1-1/4 [32] $3-1/3t$	3-3/8 [86] $6-2/3t + 1/8$
7005 Al alloy	3/8 [10] $t = 3/8 [10]$ or less	3 [76] $8t$	1-1/2 [38] $4t$	3-7/8 [98] $10t + 1/8$
Steel over 50 ksi to 90 ksi [345 MPa to 620 MPa] yield	3/8 [10] $t = 3/8 [10]$ or less	2 [51] $5-1/3t$	1 [25] $2-2/3t$	2-7/8 [73] $7-2/3t$
All others	3/8 [10] $t = 3/8 [10]$ or less	1-1/2 [38] $4t$	3/4 [19] $2t$	2-3/8 [60] $6t + 1/8$

^a "X" refers to 1, 2, 3, or 5, as applicable.

Notes:

1. The weld and heat affected zone in the case of a transverse-weld bend specimen shall be completely within the bend portion of the specimen after testing.
2. Either hardened and greased shoulders or hardened rollers free to rotate shall be used.
3. The shoulders or rollers shall have a minimum bearing surface of 2 in [51 mm] for placement of the specimen. The rollers shall be high enough above the bottom of the jig so that the specimens will clear the rollers when the ram is in the low position.
4. The ram shall be fitted with an appropriate base and provision made for attachment to the testing machine, and shall be a sufficiently rigid design to prevent deflection and misalignment while making the bend test. The body of the ram may be less than the dimensions shown in column A.
5. If desired, either the rollers or the roller supports may be made adjustable in the horizontal direction so that specimens of t thickness may be tested on the same jig.
6. The roller supports shall be fitted with an appropriate base designed to safeguard against deflection or misalignment and equipped with means for maintaining the rollers centered midpoint and aligned with respect to the ram.

Figure 11.13—Guided-Bend Roller Jig

12. Welding Operator Qualification

12.1 General. The qualification tests described in this section are specifically devised tests to determine a welding operator's ability to produce sound welds. The qualification tests are not intended to be used as guides for welding during actual construction. The latter shall be performed in accordance with the requirements of the welding procedure specification.

12.2 Limitation of Variables. Any change from the limitations in Table 11.2 shall require separate qualification.

12.3 Qualification Tests Required for Welding Operators

12.3.1 The welding operator qualification test shall utilize a joint design in accordance with an approved welding procedure specification. Figure 12.1 cites a suggested plate groove weld test design. Except for GMAW short circuiting transfer mode, the welding operator may instead be qualified by radiography of the initial 15 in [380 mm] of a production groove weld. The material thickness range qualified shall be that shown in Table 11.3.

12.3.2 The welding operator who makes a complete joint penetration groove weld procedure qualification test in plate that meets the requirements is thereby qualified for that process and test position for plate of thickness given in Tables 11.2 and 11.3.

12.3.3 The welding operator who makes a complete joint penetration groove weld procedure qualification test in pipe or tubing that meets the requirements is thereby qualified for that process and test position for pipe or tubing. The pipe diameter and wall thickness range qualified for shall be that shown in Table 11.3. This qualifies the welding operator for welding groove and fillet welds in plate, pipe, or tubing as shown in Table 11.4.

12.3.4 Qualification of a welding operator on plate in the 1G (flat), or 2G (horizontal) position shall qualify the welding plate operator for welding pipe or tubing over 24 in [610 mm] in diameter for the position qualified, except that qualification in the 1G position also qualifies for the fillet welding of plate in the flat and horizontal positions, and qualification in the 2G position also qualifies for groove welding of plate in the flat position, and for fillet welding of plate in the flat and horizontal positions.

12.3.5 For fillet weld qualification only the following shall apply:

12.3.5.1 For fillet welds between parts having a dihedral angle (Ψ) of less than 60°, the welding operator shall weld a groove weld test plate as required by 12.3.1.

12.3.5.2 For joints having a dihedral angle (Ψ) 60° or greater, but not exceeding 135°, the welding operator shall weld a test assembly according to Option 1, Option 2, or Option 3, depending on the manufacturer's choice, as follows:

- (1) **Option 1.** Weld a T-test plate in accordance with Figure 11.7.
- (2) **Option 2.** Weld a soundness test plate in accordance with Figure 11.8.
- (3) **Option 3.** Weld a soundness test assembly in accordance with Figure 11.9.

12.3.6 For operator qualification using pipe welds, see Clause 11.

12.4 Base Metal. The base metal used shall comply with the welding procedure specification.

12.5 Joint Welding Procedure Specification

12.5.1 The welding operator shall follow the welding procedure specified by the welding procedure specification.

12.5.2 Weld cleaning shall be done with the test weld in the same position as the welding position being qualified.

12.6 Test Specimens: Number, Type, and Preparation. For the number, type, and preparation of test specimens, see 11.10.

12.7 Method of Testing Specimens. For test specimens and methods, see 11.11.

12.8 Test Results Required. For test results required, see 11.12.

12.9 Retests. If a welding operator fails to meet the requirements of one or more test welds, a retest may be allowed under the following conditions:

12.9.1 An immediate retest may be made consisting of two test welds of each type on which the welding operator failed. All specimens shall meet all the requirements specified for such welds.

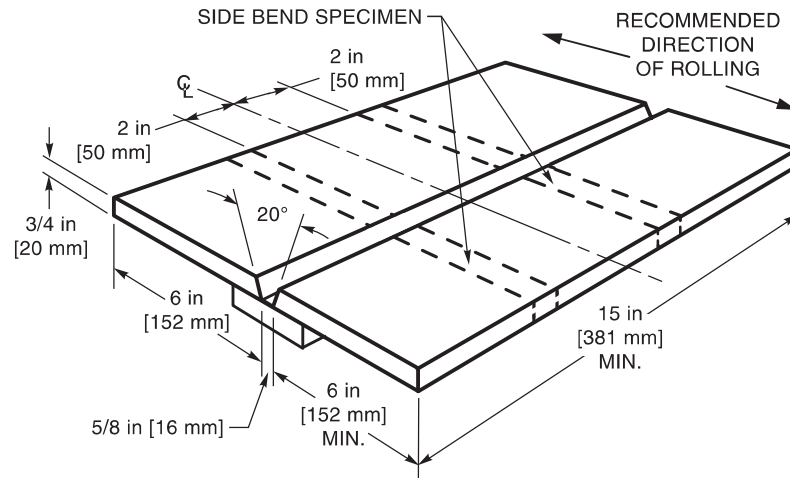
12.9.2 A retest may be made provided there is evidence that the welding operator has had further training or practice. In this case, a complete retest (single test welds of each type) shall be made.

12.10 Period of Effectiveness. The welding operator's qualification specified in Clause 12 shall be considered as remaining in effect indefinitely unless one of the following applies:

12.10.1 The welding operator is not engaged in the given process of welding for which the operator is qualified for a period exceeding six months.

12.10.2 There is some specific reason to question the welding operator's ability.

12.11 Records. Records of the test results shall be kept by the manufacturer and shall be available to those authorized to examine them.



Notes:

1. When radiography is used for testing, no tack welds shall be in test area.
2. The joint configuration of a qualified groove weld procedure may be used in lieu of the groove configuration shown here.
3. The backing bar thickness shall be 3/8 in [10 mm] min. to 1/2 in [13 mm] max.; backing bar width shall be 3 in [76 mm] min. when not removed for radiography, otherwise 1-1/2 in [38 mm].
4. See Figure 10.13 or 10.14 for the appropriate specimen dimensions.

Figure 12.1—Test Plate for Unlimited Thickness—Welding Operator Qualification

13. Tack Welder Qualification

13.1 General. The qualification tests described in 13.3 are tests specially devised to determine a tack welder's ability to produce sound welds. The qualification tests are not intended to be used as a guide for tack welding during actual construction. The latter shall be performed in accordance with the requirements of the procedure specification.

13.2 Limitation of Variables. Any change from the limitations in Table 11.2 shall require separate qualification.

13.3 Qualification Tests Required. A tack welder shall be qualified by one test plate made in each position in which he or she is to tack weld. The tack welder shall make a 1/4 in [6 mm] maximum size tack weld approximately 2 in [51 mm] long on the fillet-weld-break specimen as shown in Figure 13.1.

13.4 Base Metal. The base metal used shall comply with the procedure specification.

13.5 Test Specimens: Number, Type, and Preparation. One test specimen shall be welded as shown in Figure 13.1 with the entire welded assembly as the test specimen.

13.6 Method of Testing Specimens. A force shall be applied to the specimen as shown in Figure 13.2 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.

13.7 Test Results Required

13.7.1 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.

13.7.2 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 metal nor any inclusion or porosity larger than 3/32 in [2 mm] in greatest dimension.

13.7.3 A tack welder who passes the fillet-weld-break test shall be eligible to tack weld all types of joints for the process and in the position in which the tack welder has qualified.

13.8 Retests. In case of failure to pass the above test, the tack welder may make one retest without additional training.

13.9 Period of Effectiveness. A tack welder who passes the qualification test 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 ability of the tack welder. In such case, the tack welder shall be required to demonstrate an ability to make sound tack welds by again passing the prescribed tack welding test.

13.10 Records. Records of the test results shall be kept by the manufacturer and shall be available to those authorized to examine them.

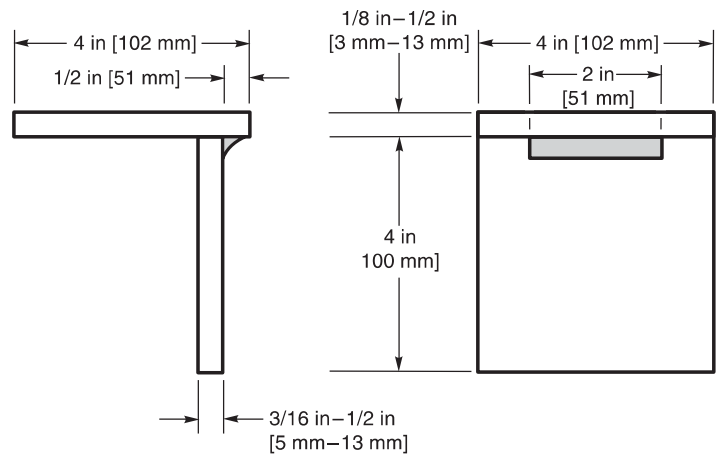


Figure 13.1—Fillet-Weld-Break Specimen—Tack Welder Qualification

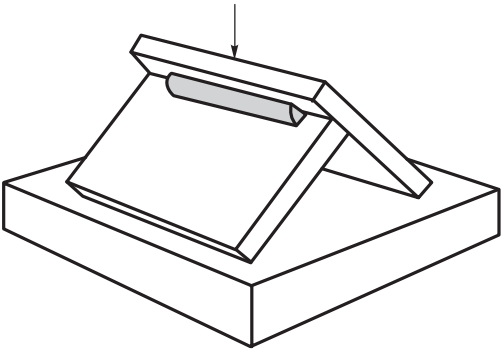


Figure 13.2—Method of Rupturing Specimen—Tack Welder Qualification

14. Inspection—General Requirements

14.1 Manufacturer's Responsibility. The company performing welding is responsible for inspection.

14.2 Designated Inspector (Fabrication Inspector)

14.2.1 The Designated Inspector is an individual who is given responsibility by the company to inspect welding operations and completed welds. Inspection may, or may not, be this person's sole responsibility and when so assigned by the company, the welder or welding operator may function as the designated inspector.

14.2.2 The Designated Inspector shall be adequately trained and qualified to perform all of the assigned duties. There shall be documented evidence of training received. For other than visual inspection, personnel qualifications shall be in accordance with 14.8.

14.3 Inspection of Welding. The Designated Inspector shall verify that welding is being done:

- (1) In accordance with 5.4, and all applicable drawings and specifications.
- (2) Using consumables in accordance with 5.5.
- (3) Meeting workmanship requirements given in Clause 6.
- (4) In compliance with written welding procedure specifications that are either prequalified in accordance with Clauses 7 and 8, or have been qualified in accordance with Clause 10.
- (5) Using welders, welding operators, or tack welders who have been qualified in accordance with Clause 11, 12, or 13.

14.4 Weld Size and Location. The Designated Inspector shall make sure that the size, location, and length of all welds meet the specified requirements. Unspecified welds shall not be added without the approval of the Fabricator's Engineer.

14.5 Visual Inspection of Completed Welds. All completed welds shall be visually inspected by the Designated Inspector for compliance in 17.2.

14.6 Documentation. Designated Inspectors shall document acceptance of all welds as required by industry standards and contractual agreements (individual welds or assemblies).

14.7 Verification Inspection. Verification inspection and testing are the prerogatives of the purchaser who may perform this function or, when provided in the contract, waive independent verification, or stipulate that both inspection and verification shall be performed by the company. The Verification Inspector is the duly designated person who acts for and in behalf of the purchaser on all inspection and quality matters within the scope of the contract documents.

14.7.1 The Verification Inspector shall be guided by but is not limited to the following:

14.7.1.1 The Verification Inspector has the authority to ascertain that all fabrication welding is performed in accordance with requirements of this specification or contract documents exceeding those requirements.

14.7.1.2 The Verification Inspector, where possible, shall be furnished with complete detailed drawings showing the size, type, and location of all welds to be made. This Inspector shall also be furnished with the portion of the contract documents that describes material and quality requirements for the products to be fabricated, assembled, or repaired.

14.7.1.3 The Verification Inspector shall be notified in advance of the start of operations subject to inspection and verification.

14.7.2 Inspection of Materials. The Verification Inspector may ascertain that only materials conforming to the requirements of this specification are used.

14.7.3 Inspection of Welding Procedure Qualification and Equipment

14.7.3.1 The Verification Inspector may ascertain that all welding procedures are prequalified and covered by a welding procedure specification or are qualified in accordance with Clause 10.

14.7.3.2 The Verification Inspector may inspect the welding equipment to be used for the work to make certain that it conforms to the requirements of 6.1.2.

14.7.4 Inspection of Welder, Welding Operator, and Tack Welder

14.7.4.1 The Verification Inspector may ascertain that the welding will be performed only by welders, welding operators, and tack welders who are qualified in accordance with the requirements of Clause 11, 12, or 13, as applicable.

14.7.4.2 When the quality of a welder's, welding operator's, or tack welder's work appears to be below the requirements of this specification, the Verification Inspector may require the welder, welding operator, or tack welder to demonstrate an ability to produce sound welds by means of a simple test, such as the fillet weld break test, or by requiring complete requalification in accordance with the subclauses pertaining to retest for Welders, Welding Operators, and/or Tack Welders, as applicable.

14.7.4.3 The Verification Inspector may require requalification of any welder or welding operator who has not used the process for which the welder or welding operator has been qualified for a period exceeding six months.

14.7.4.4 The Verification Inspector may require repairs to welds found not conforming to specifications or approved drawings.

14.7.5 Inspection of Work and Records

14.7.5.1 The Verification Inspector may ascertain that the size, length, and location of all welds conform to the requirements of this specification and to the detail drawings and that no unspecified welds have been added without approval of the Engineer.

14.7.5.2 The Verification Inspector may ascertain that only welding procedure specifications are employed that meet the provisions of 9.1 or are qualified in accordance with Clause 10.

14.7.5.3 The Verification Inspector may ascertain that if electrodes are used, they are used only in the positions and with the type of welding current and polarity for which they are classified.

14.7.5.4 The Verification Inspector may, at suitable intervals, observe the technique and performance of each welder, welding operator, and tack welder to make certain that the applicable technique requirements are met.

14.7.5.5 At suitable intervals, the Verification Inspector may examine the work to make certain that it meets the requirements of this specification. Size and contour of welds shall be measured with suitable gages. Visual inspection for cracks in welds and base metal and other discontinuities should be aided by a strong light, magnifiers, or such other devices as may be found helpful.

14.8 Personnel Qualifications. For other than visual inspection, personnel performing nondestructive testing shall be qualified in accordance with a written practice modeled after the American Society for Nondestructive Testing Recommended Practice SNT-TC-1A or other mutually agreed upon practices.

14.8.1 Exemption of QC1 Requirements. Personnel performing NDT under the provisions of 14.8 need not be qualified and certified under the provisions of AWS QC1.

15. NDE General Requirements

15.1 Nondestructive Testing. The limitations and complementary use of each method are explained in the latest edition of AWS B1.10M/B1.10, *Guide for the Nondestructive Examination of Welds*. As an alternative to the NDE procedures, techniques, and personnel qualification requirements of this section, AAR MSRP C-III, Appendix T, may be utilized.

15.1.1 Welds tested nondestructively that do not meet the requirements of this specification shall be repaired by the methods permitted by 6.5.

16. NDE Methods

16.1 Radiographic Testing of Groove Welds. When radiographic testing is used, the procedure and technique shall be in accordance with the following, and the acceptance criteria in accordance with 17.3:

16.1.1 General Requirements

16.1.1.1 Butt Joints. The procedures and standards set forth in 16.1.1.2 govern radiographic testing of welds when such inspection is required by the contract documents. The requirements listed herein are specifically for testing groove welds in butt joints in plate, shapes, and bars by X-ray or gamma ray sources. The methodology shall conform to ASTM E94, *Guide for Radiographic Testing*, ASTM E747, *Standard Method for Design, Manufacture and Material Grouping Classification of Wire Image Quality Indicators (IQI) Used for Radiography*, and ASTM E1032, *Standard Test Method for Radiographic Examination of Weldments*, except as provided herein.

16.1.1.2 Variations. Variations in testing procedures, equipment, and acceptance standards may be used upon agreement between the manufacturer and the purchaser. Such variations include but are not limited to the following:

- (1) Radiographic testing of fillet, T, and corner welds
- (2) Changes in source-to-film distance
- (3) Unusual application of film
- (4) Unusual penetrameter applications (including film side penetrameters and wire penetrameters)
- (5) Radiographic testing of thicknesses greater than 6 in [152 mm]
- (6) Film-type densities
- (7) Variations in exposure, development, and viewing techniques
- (8) Digital Radiography
- (9) Radiographic testing of weld repairs on castings.

16.1.2 Examination, Report, and Disposition of Radiographs

16.1.2.1 The manufacturer shall provide a suitable variable intensity illuminator (viewer) with spot review or masked spot review capability. The viewer shall incorporate a means for adjusting the size of the spot under examination. The viewer shall have sufficient capacity to properly illuminate radiographs with an H & D density of 4.0.

16.1.2.2 Before a weld subject to radiographic testing by the manufacturer for the Owner is accepted, all of its radiographs, including any that show unacceptable quality prior to repair and a report interpreting them, shall be submitted to the Verification Inspector.

16.1.2.3 A full set of radiographs for welds subject to radiographic testing by the manufacturer for the Owner, including any that show unacceptable quality prior to repair, shall be delivered to the Owner upon completion of the work. The manufacturer's obligation to retain radiographs shall cease (1) upon delivery of this full set to the Owner, or (2) one full year after the completion of the manufacturer's work, provided the Owner is given prior written notice.

16.1.3 Acceptability of Welds. Welds shown by radiographic testing to have discontinuities prohibited by Figures 16.1, 16.2, 16.3, 16.4, and 16.5 shall be repaired in accordance with 6.5.

16.2 Ultrasonic Testing of Groove Welds. When ultrasonic testing is used, the procedure and technique shall be in accordance with AWS D1.1/D1.1M, Ultrasonic Testing (UT) of Groove Welds. As an alternative, a written procedure that meets the requirements of AWS D1.1/D1.1M, UT Examination of Welds by Alternative Techniques, or the latest addendum of ASME *Boiler and Pressure Vessel Code*, Section V, may be used. UT inspection flaw size evaluation shall be in accordance with 16.2.5. Acceptance criteria shall be in accordance with 17.4. When ultrasonic testing of aluminum is required by contract, the testing procedure and acceptance criteria shall be specified.

16.2.1 General Requirements

16.2.1.1 The procedures and standards set forth in 16.2.1.1 are to govern the ultrasonic testing of groove welds and heat-affected zone (HAZ) between the thicknesses of 5/16 in and 8 in [7.9 mm and 200 mm] inclusive, when such testing is used.

16.2.1.2 Variations in testing procedure, equipment, and acceptance standards not included in this subclause may be used upon agreement with the Engineer. Such variations include other thicknesses, weld geometries, transducer sizes, frequencies, couplant, painted surfaces, testing techniques, etc. Such approved variations shall be recorded in the contract records.

16.2.2 Ultrasonic Testing (UT) Operator Requirements

16.2.2.1 In satisfying the requirements of 14.8, the qualification of the ultrasonic testing operator shall include a specific and practical examination which shall be based on the requirements of this specification. This examination shall require the ultrasonic operator to demonstrate an ability to apply the rules of this specification in the accurate detection and disposition of flaws.

16.2.2.2 Prior to examination, the ultrasonic testing operator shall be furnished, or have access to, relevant information regarding weld joint geometry, material thickness, and welding processes used in making the weldment. Any subsequent record of repairs made to the weldment shall also be made available to the ultrasonic testing operator.

16.2.3 Base Metal. These procedures are not intended to be employed for the procurement testing of base metals. However, welding-related discontinuities (cracking, lamellar tearing, delaminations, etc.) in the adjacent base metal which would not be acceptable under the provisions of this specification shall be reported to the Engineer for disposition.

16.2.4 Extent of Testing

16.2.4.1 Weld joints requiring ultrasonic testing by specification shall be tested for their full length unless partial or spot testing is specified.

16.2.4.2 When partial testing is specified, the location and lengths of welds or categories of weld to be tested shall be clearly designated in the contract documents.

16.2.4.3 When spot testing is required, the number of spots in each designated category of weld or the number of spot tests required to be made in a stated length of weld shall be specified. Each spot test shall cover at least 4 in [102 mm] of the weld length. When spot testing reveals indications of rejectable discontinuities, the extent of those discontinuities shall be determined, and two additional spots in the same weld joint shall be tested. These spots should be adjacent to or near the originally determined discontinuity. If indications of flaws requiring repair are revealed in either of the two spots, the entire length of the welded joint shall be tested ultrasonically.

16.2.5 UT Inspection Flaw Size Evaluation

16.2.5.1 The length of flaws shall be determined in accordance with this procedure. Each discontinuity shall be accepted or rejected on a basis of its indication rating and its length in accordance with Table 17.2.

16.2.5.2 Each rejectable discontinuity shall be indicated on the weld by a mark directly over the discontinuity for its entire length. The depth from the surface and type of discontinuity shall be noted on nearby base metal.

16.2.5.3 Welds found unacceptable by ultrasonic testing shall be repaired by methods permitted by 6.5 of this specification. Repaired areas shall be retested ultrasonically with results tabulated on the original form (if available) or an additional report form.

16.2.5.4 Evaluation of retested repaired weld areas shall be tabulated on a new line on the report form. If the original report form is used, an "R1, R2...Rn" shall prefix the indication number. If additional report forms are used, the R number shall prefix the report number.

16.2.6 Preparation and Disposition of Reports

16.2.6.1 A report form that clearly identifies the work and the area of inspection shall be completed by the ultrasonic inspector at the time of inspection. The report form for welds that are acceptable need only contain sufficient information to identify the weld, the inspector's signature, and the acceptability of the weld. An example of such a form is shown in Annex D, Form D-7.

16.2.6.2 Before a weld subject to ultrasonic testing by the manufacturer for the purchaser is accepted, all report forms pertaining to the weld, including any that show unacceptable quality prior to repair, shall be made available to the inspector.

16.2.6.3 A full set of completed report forms of welds subject to ultrasonic testing by the manufacturer for the Owner, including any that show unacceptable quality prior to repair, shall be delivered to the Owner upon completion of the work. The manufacturer's obligation to retain ultrasonic reports shall cease (1) upon delivery of this full set to the Owner, or (2) one full year after completion of the manufacturer's work, provided that the Owner is given prior written notice.

16.3 Liquid Penetrant Testing of Welds. When liquid penetrant inspection is used, the inspection shall be in accordance with a written procedure that meets the requirements of ASTM E165, *Practice for Liquid Penetrant Inspection Method*, and shall be evaluated on the basis of the relevant portions of the acceptance criteria of 17.2. For aluminum welds, liquid penetrant testing shall not be used for intermediate passes of multipass welds.

16.4 Magnetic Particle Testing of Welds. When magnetic particle inspection is used, the inspection shall be in accordance with a written procedure that meets the requirements of ASTM E709, *Practice for Magnetic Particle Examination*, and shall be evaluated on the basis of the relevant portions of the acceptance criteria of 17.2.

Legend for Figures 16.1, 16.2, and 16.3

Dimensions of Discontinuities

B = Maximum allowed dimension of a radiographed discontinuity.

L = Largest dimension of a radiographed discontinuity.

L' = Largest dimension of adjacent discontinuities.

C = Minimum clearance measured along the longitudinal axis of the weld between edges of porosity or fusion-type discontinuities (larger of adjacent discontinuities governs), or to an edge or an end of an intersecting weld.

C₁ = Minimum allowed distance between the nearest discontinuity to the free edge of a plate or tubular, or the intersection of a longitudinal weld with a girth weld, measured parallel to the longitudinal weld axis.

W = Smallest dimension of either of adjacent discontinuities.

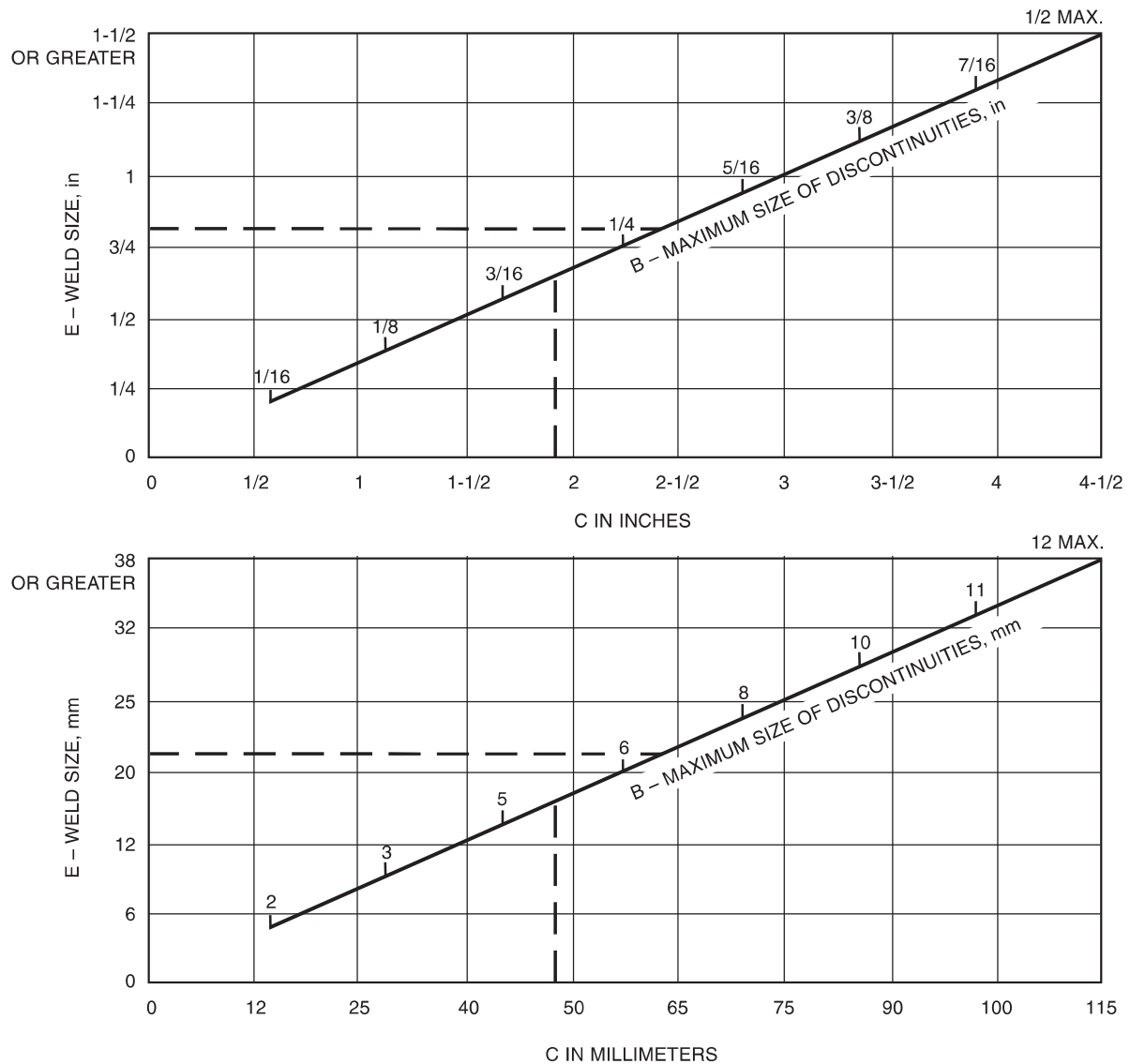
Material Dimensions

E = Weld size.

T = Plate or pipe thickness for CJP groove welds.

Definitions of Discontinuities

- An elongated discontinuity shall have the largest dimension (L) exceed 3 times the smallest dimension.
- A rounded discontinuity shall have the largest dimension (L) less than or equal to 3 times the smallest dimension.
- A cluster shall be defined as a group of non-aligned, acceptably-sized, individual adjacent discontinuities with spacing less than the minimum allowed (C) for the largest individual adjacent discontinuity (L'), but with the sum of the greatest dimensions (L) of all discontinuities in the cluster equal to or less than the maximum allowable individual discontinuity size (B). Such clusters shall be considered as individual discontinuities of size L for the purpose of assessing minimum spacing.

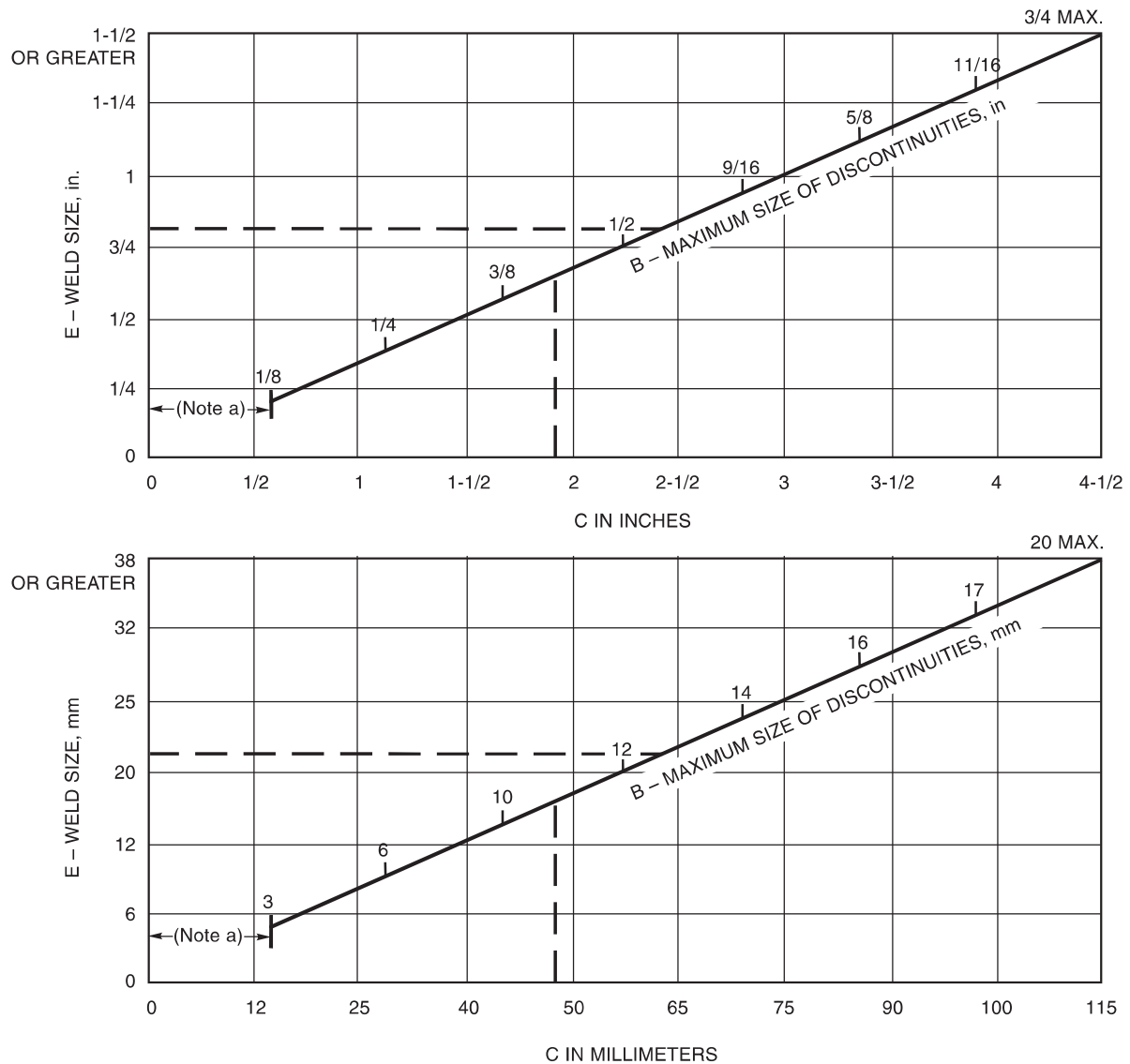


Notes:

1. To determine the maximum size of discontinuity allowed in any joint or weld size, project E horizontally to B.
2. To determine the minimum clearance allowed between edges of discontinuities of any size greater than or equal to 3/32 in [2.5 mm], project B vertically to C.
3. See Legend on page 142 for definitions.

Source: AWS D1.1/D1.1M:2006, *Structural Welding Code—Steel*, Figure 6.4, American Welding Society.

Figure 16.1—Weld Quality Requirements for Discontinuities Occurring in Cyclically Loaded Nontubular Tension Welds (Limitations of Porosity and Fusion Discontinuities)



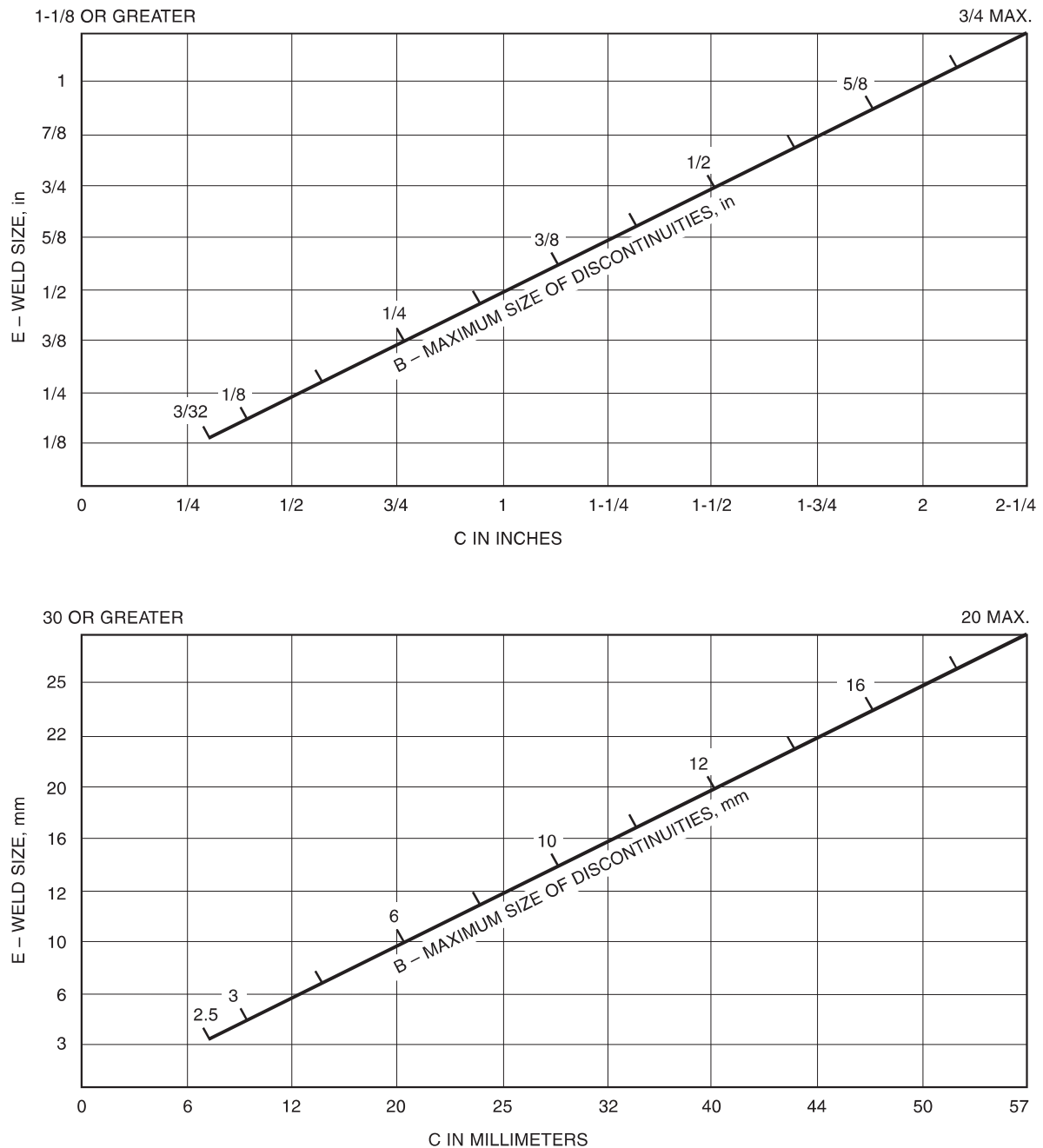
^a The maximum size of a discontinuity located within this distance from an edge of plate shall be 1/8 in [3 mm], but a 1/8 in [3 mm] discontinuity shall be 1/4 in [6 mm] or more away from the edge. The sum of discontinuities less than 1/8 in [3 mm] in size and located within this distance from the edge shall not exceed 3/16 in [5 mm]. Discontinuities 1/16 in [2 mm] to less than 1/8 in [3 mm] shall not be restricted in other locations unless they are separated by less than 2 L (L being the length of the larger discontinuity); in which case, the discontinuities shall be measured as one length equal to the total length of the discontinuities and space and evaluated as shown in Figure 16.2.

Notes:

1. To determine the maximum size of discontinuity allowed in any joint or weld size, project E horizontally to B.
2. To determine the minimum clearance allowed between edges of discontinuities of any size, project B vertically to C.
3. See Legend on Page 142 for definitions.

Source: AWS D1.1/D1.1M:2006, *Structural Welding Code—Steel*, Figure 6.5, American Welding Society.

Figure 16.2—Weld Quality Requirements for Discontinuities Occurring in Cyclically Loaded Nontubular Compression Welds (Limitations of Porosity or Fusion-Type Discontinuities)

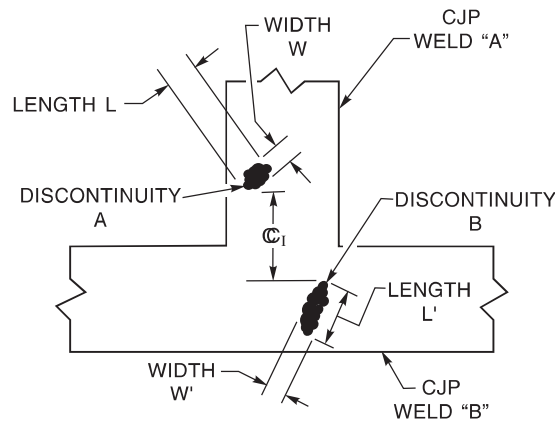


Notes:

1. To determine the maximum size of discontinuity allowed in any joint or weld size, project E horizontally to B.
2. To determine the minimum clearance allowed between edges of discontinuities of any size greater than or equal to 3/32 in [2 mm], project B vertically to C.
3. See Legend on Page 142 for definitions.

Source: AWS D1.1/D1.1M:2006, *Structural Welding Code—Steel*, Figure 6.6, American Welding Society.

Figure 16.3—Weld Quality Requirements for Elongated Discontinuities as Determined by RT of Tubular Joints



KEY FOR FIGURE 6.6, CASES I, II, III, AND IV
WELD A = LONGITUDINAL TUBULAR CJP GROOVE WELD
WELD B = TUBULAR GIRTH CJP GROOVE WELD
DISCONTINUITY A = ROUNDED OR ELONGATED DISCONTINUITY LOCATED IN WELD A
DISCONTINUITY B = ROUNDED OR ELONGATED DISCONTINUITY LOCATED IN WELD B
L AND W = LARGEST AND SMALLEST DIMENSIONS, RESPECTIVELY, OF DISCONTINUITY A
L' AND W' = LARGEST AND SMALLEST DIMENSIONS, RESPECTIVELY, OF DISCONTINUITY B
E = WELD SIZE
C₁ = SHORTEST DISTANCE PARALLEL TO THE WELD A AXIS, BETWEEN THE NEAREST DISCONTINUITY EDGES

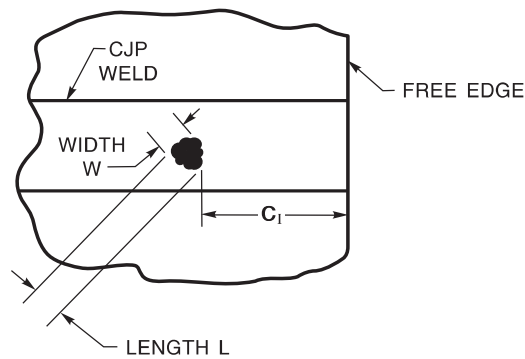
CASE I DISCONTINUITY LIMITATIONS ^a		
DISCONTINUITY DIMENSION	LIMITATIONS	CONDITIONS
L	$< E/3, \leq 1/4 \text{ in [6 mm]}$	$E \leq 2 \text{ in [51 mm]}$
	$\leq 3/8 \text{ in [10 mm]}$	$E > 2 \text{ in [51 mm]}$
C _I	$\geq 3L$	(A) ONE DISCONTINUITY ROUNDED, THE OTHER ROUNDED OR ELONGATED ^a (B) $L \geq 3/32 \text{ in [2.5 mm]}$

^a The elongated discontinuity may be located in either the longitudinal or girth weld. For the purposes of this illustration, discontinuity B was located in the girth weld.

Case I—Discontinuity at Weld Intersection

Source: AWS D1.1/D1.1M:2006, *Structural Welding Code—Steel*, Figure 6.6, American Welding Society.

Figure 16.3 (Continued)—Weld Quality Requirements for Elongated Discontinuities as Determined by RT of Tubular Joints



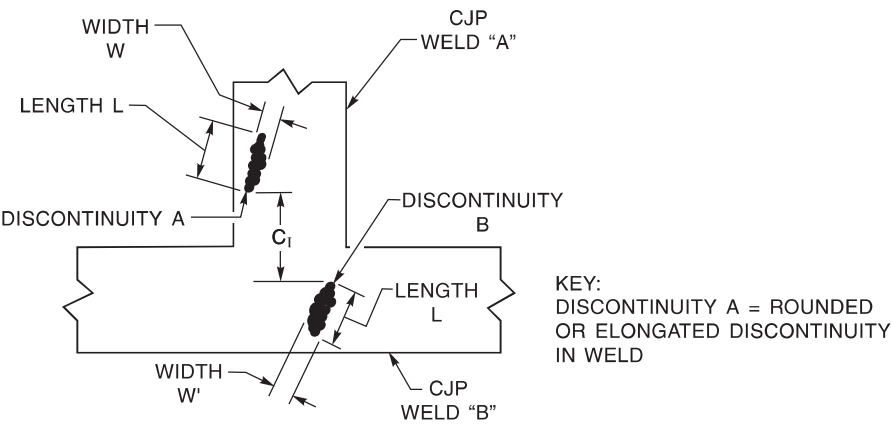
CASE II DISCONTINUITY LIMITATIONS

DISCONTINUITY DIMENSION	LIMITATIONS	CONDITIONS
L	$<E/3, \leq 1/4$ in [6 mm]	$E \leq 2$ in [51 mm]
	$\leq 3/8$ in [10 mm]	$E > 2$ in [51 mm]
C_1	$\geq 3L$	$L \geq 3/32$ in [2.5 mm]

Case II—Discontinuity at Free Edge of CJP Groove Weld

Source: AWS D1.1/D1.1M:2006, *Structural Welding Code—Steel*, Figure 6.6, American Welding Society.

Figure 16.3 (Continued)—Weld Quality Requirements for Elongated Discontinuities as Determined by RT of Tubular Joints



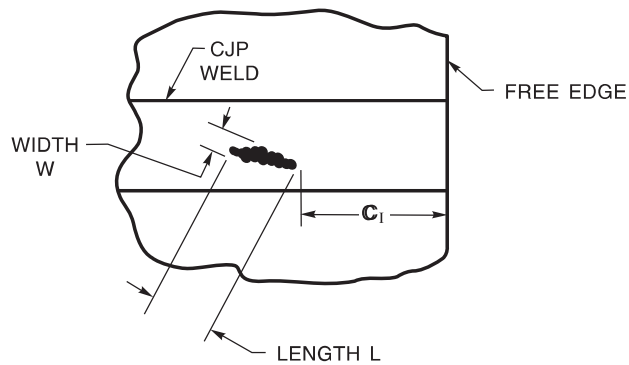
CASE III DISCONTINUITY LIMITATIONS

DISCONTINUITY DIMENSION	LIMITATIONS	CONDITIONS
L	$\leq 2E/3$	$L > 3W$
C ₁	$\geq 3L$ OR $2E$, WHICHEVER IS GREATER	$L \geq 3/32$ in [2.5 mm]

Case III—Discontinuity at Weld Intersection

Source: AWS D1.1/D1.1M:2006, *Structural Welding Code—Steel*, Figure 6.6, American Welding Society.

Figure 16.3 (Continued)—Weld Quality Requirements for Elongated Discontinuities as Determined by RT of Tubular Joints



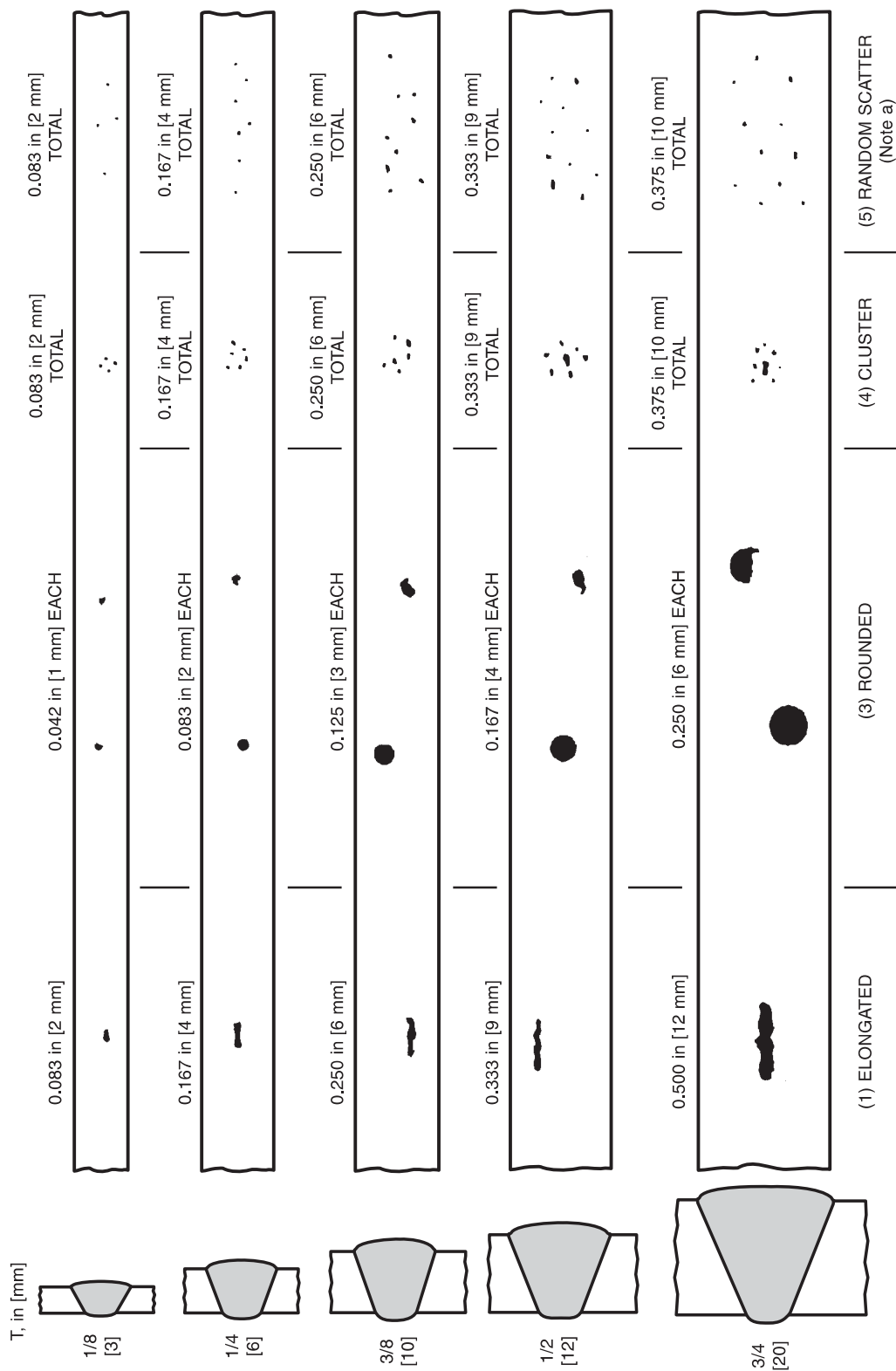
CASE IV DISCONTINUITY LIMITATIONS

DISCONTINUITY DIMENSION	LIMITATIONS	CONDITIONS
L	$\leq 2E/3$	$L/W > 3$
C_1	$\geq 3L$ OR $2E$, WHICHEVER IS GREATER	$L \geq 3/32$ in [2.5 mm]

Case IV—Discontinuity at Free Edge of CJP Groove Weld

Source: AWS D1.1/D1.1M:2006, *Structural Welding Code—Steel*, Figure 6.6, American Welding Society.

Figure 16.3 (Continued)—Weld Quality Requirements for Elongated Discontinuities as Determined by RT of Tubular Joints



^aIndependent of (1) and (3). May also be in combination with (1) or (3) even though not shown.

Source: AWS D1.1/D1.1M:2006, *Structural Welding Code—Steel*, Figure 6.2, American Welding Society.

Figure 16.4—Maximum Acceptable RT Images

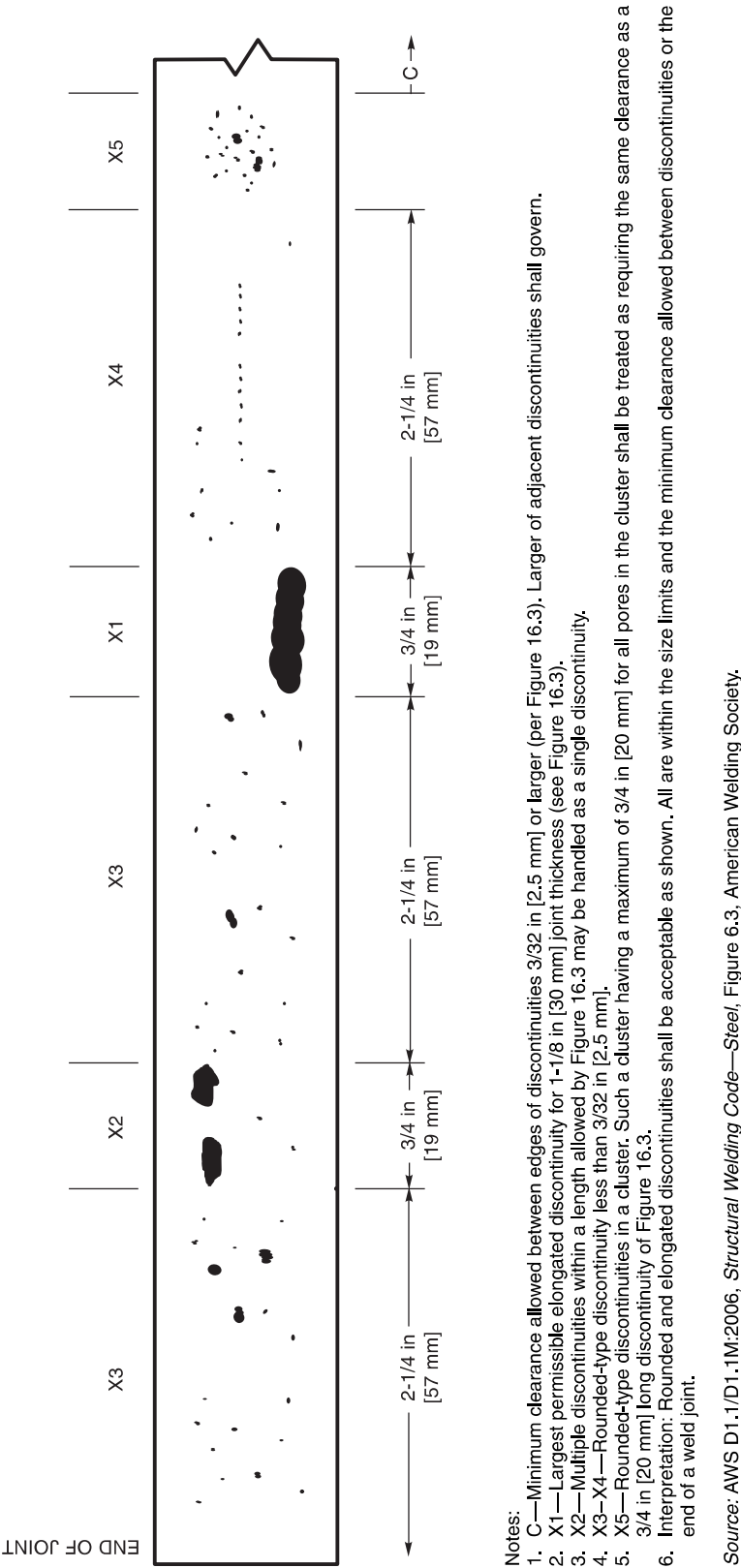


Figure 16.5—For RT of Tubular Joints 1-1/8 in [30 mm] and Greater, Typical of Random Acceptable Discontinuities

17. Acceptance Criteria

17.1 Temporary Welds. Welds that are to be removed are not subject to visual inspection acceptance criteria. When welds are removed, the surface shall be made flush with the original surface.

17.2 Visual Inspection Acceptance Criteria

17.2.1 Cracks shall not be permitted (see 8.7.1 for Side Frame Column Guide wear plate welding).

17.2.2 Incomplete fusion shall not be permitted.

17.2.3 Craters (see Table 17.1)

17.2.4 Weld profiles shall be in accordance with 6.4.

17.2.5 Undercut and porosity shall conform to the limits of the applicable class shown in Table 17.2.

17.2.6 Weld size of fillet welds shall not be below the specified size by more than 1/32 in [1 mm] except that fillet welds over 3/16 in [5 mm] may be 1/16 in [2 mm] undersize for up to 10% of the length of the weld.

17.2.7 Spatter shall not be permitted in areas where it would interfere with the function, inspection, or corrosion protection of the member.

17.3 Radiographic Inspection Acceptance Criteria

17.3.1 Welds that are subject to radiographic inspection in addition to visual inspection shall have no cracks or incomplete fusion. CJP welds shall have no incomplete joint penetration.

17.3.2 Welds shall be unacceptable if inspection shows individual discontinuities (tungsten inclusions shall be considered porosity) having a greatest dimension greater than those allowed by Figure 16.1, 16.2, or 16.3, as applicable, or showing greater dimensions than those shown in Figure 16.4 or 16.5, as applicable.

17.4 Ultrasonic Inspection Acceptance Criteria. Welds that are subject to ultrasonic inspection shall be acceptable if they meet the acceptance criteria of Table 17.3.

17.5 Liquid Penetrant Acceptance Criteria. Welds that are subject to liquid penetrant inspection shall be evaluated on the basis of the relevant portions of the acceptance criteria in 17.2.

17.6 Magnetic Particle Acceptance Criteria. Welds that are subject to magnetic particle inspection shall be evaluated on the basis of the relevant portions of the acceptance criteria in 17.2.

Table 17.1
Weld Crater Limitations

Material	Weld Type and Size	Allowable Crater Depth
Steel	Fillet < 3/16 in [5 mm]	1/32 in [1 mm] max. ^a
	Fillet 3/16 in [5 mm] and larger	1/16 in [2 mm] max. ^a
	Groove < 1/2 in [13 mm]	1/32 in [1 mm] max. ^a
	Groove 1/2 in [13 mm] and larger	1/16 in [2 mm] max. ^a
Aluminum	Fillet or Groove—All sizes	None—All craters shall be filled

^a Crater depths in excess of these limits shall be filled

Table 17.2
Undercut and Porosity Limitations

Quality Level		
	Class 1 ^a	Class 2 ^b
Undercut:	Less than 1/64 in [0.5 mm]	1/32 in [1 mm] max. ^c
Porosity:	No more than one pore in each 4 in [102 mm] of weld. No pore exceeding 3/32 in [2 mm] diameter.	No single pore exceeding 3/32 in [2 mm] diameter. Sum of the diameters of pores shall not exceed 3/8 in [10 mm] in any linear inch [25 millimeters] of weld and shall not exceed 3/4 in [20 mm] in any 12 linear inches [300 linear millimeters].

^a All Class 1 welds shall be specified on the drawing.

^b All other welds shall be considered to be in Class 2 unless otherwise specified in the drawing.

^c In any event, undercut shall not exceed 12-1/2% (1/8) of the material thickness.

^d If welds have not been categorized with regard to primary stress by the Engineer, then undercut and porosity limits shall be per the Class 1 Quality Level.

Table 17.3
Ultrasonic Testing Acceptance—Rejection Criteria

Weld Thickness, in [mm] and Search Unit Angle											
Flaw Severity	5/16 to 3/4 [8 to 19]	>3/4 to 1-1/2 [>19 to 38]	>1-1/2 to 2-1/2 [>38 to 64]			>2-1/2 to 4 [>64 to 100]			>4 to 8 [>100 to 200]		
Class	70°	70°	70°	60°	45°	70°	60°	45°	70°	60°	45°
A	+5 and lower	+2 and lower	−2 and lower	+1 and lower	+3 and lower	−5 and lower	−2 and lower	0 and lower	−7 and lower	−4 and lower	−1 and lower
B	+6	+3	−1 0	+2 +3	+4 +5	−4 −3	−1 0	+1 +2	−6 −5	−3 −2	0 +1
C	+7	+4	+1 +2	+4 +5	+6 +7	−2 to +2	+1 +2	+3 +4	−4 to +2	−1 to +2	+2 +3
D	+8 and up	+5 and up	3 and up	+6 and up	+8 and up	+3 and up	+3 and up	+5 and up	+3 and up	+3 and up	+4 and up

Notes:

- Class B and C flaws shall be separated by at least 2L, L being the length of the longer flaw, except that when two or more such flaws are not separated by at least 2L, but the combined length of flaws and their separation distance is equal to or less than the maximum allowable length under the provision of Class B or C, the flaw shall be considered a single acceptable flaw.
- Class B and C flaws shall not begin at a distance less than 2L from weld ends carrying primary tensile stress, L being the flaw length.

Class A (large flaws)

Any indication in this category shall be rejected (regardless of length).

Class B (medium flaws)

Any indication in this category having a length greater than 3/4 in [19 mm] shall be rejected.

Class C (small flaws)

Any indication in this category having a length greater than 2 in [51 mm] shall be rejected.

Class D (minor flaws)

Any indication in this category shall be accepted regardless of length or location in the weld.

Scanning Levels

Sound Path, in ^a [mm ^a]	Above Zero Reference, dB
to 2-1/2 [64]	14
>2-1/2 to 5 [>64–127]	19
>5 to 10 [>127–254]	29
>10 to 15 [>254–381]	39

^a This column refers to sound path distance, NOT material thickness.

18. Requirements for Welding Sheet Metal

This clause is applicable for welds made on base metal thinner than 1/8 in [3 mm]. The provisions of Clauses 5 through 17 apply to these materials, except as noted below.

18.1 Design of Welded Joints

18.1.1 General. Welded connections may be made using groove welds, arc spot or arc seam welds, lap, T or corner fillet welds, and single-flare-bevel or single-flare-V-groove welds as shown in Figures 18.1 through 18.8.

18.1.2 Square Grooves. Square grooves shall be used in butt joints with the welding preferably done in the flat position. Root opening (gap) conditions shall be as shown in Figure 18.1.

18.1.3 Arc Spot Welds. Arc spot welds through one or two thicknesses of base metal onto a supporting member as shown in Figure 18.2 shall be made in the position qualified. For sheets thinner than 0.028 in [0.5 mm], a washer, as shown in Figure 18.3 shall be used to prevent burn back. The weld metal shall have a diameter of at least 3/8 in [10 mm] on the supporting structural member.

The minimum distance(s) from the center of an arc spot weld to any edge of the sheet material shall be as follows:

$$e_{min} = \frac{P}{0.5F_u t} \text{ for } \frac{F_u}{F_y} \geq 1.15 \quad (\text{Eq. 2})$$

or

$$e_{min} = \frac{P}{0.45F_u t} \text{ for } \frac{F_u}{F_y} < 1.15 \text{ but not less than } 1.5d \quad (\text{Eq. 3})$$

(See Figure 18.4)

where

- P = force transferred by the arc spot or arc slot weld
- F_u = specified minimum ultimate tensile strength of base metal (ksi)
- F_y = specified yield strength of base metal
- t = thickness of base metal exclusive of thickness of coating for single sheet or combined thickness of base metal for double sheet
- e_{min} = minimum distance from center of the arc spot or arc slot weld to the edge of the top sheet

NOTE: Formulas for U.S. standards only. Convert e_{min} to SI Units after final calculation.

18.1.4 Single-Flare-Bevel-Groove Welds. The minimum length shall be 3/4 in [19 mm] (see Figure 18.7) unless otherwise specified on the drawing or dictated by part size.

18.1.5 Plug and Slot Welds. The effective area shall be the minimal area of the hole or slot in the plane of the faying surface.

18.1.6 Fillers. Filler shall be used only with approval by the Fabricator's Engineer and Owner's Engineer. When used, fillers shall conform to the requirements of 5.4.3.

18.2 Joint and Procedure Qualification for Welding Sheet Metal. Joints and welding procedure specifications for base metals less than 1/8 in [3 mm] thick, that are qualified under the provisions of AWS B2.1/B2.1M, are considered qualified under this specification. All other cases shall be qualified in accordance with 18.2.1.

18.2.1 WPS Requirements. WPSs shall be qualified for any change in process and essential variables as listed in Table 18.1.

18.2.1.1 Number of Tests, Methods of Testing, and the Results Required for the Qualification of Arc Welding Procedure Specifications

(1) Groove and Fillet Welds

(a) Two rectangular pieces of material to be tested, at a minimum of 4 in [102 mm] wide and long, shall be welded. The weld shall be a minimum of 4 in [102 mm] long (see Figure 18.11). Weldments and tests shall be in accordance with Table 18.2.

(b) The weld shall meet the visual inspection requirements of 17.2 except that the undercut shall not exceed 0.15 times the thickness of the thinner member.

(c) After the test joints have been made, they shall be bent back upon themselves, the axis of the bend being parallel to the axis of the weld (see Figure 18.9). In case of a joint welded from one side only, the root of the weld shall be on the face of the bend.

(d) A weld shall be considered satisfactory if no cracks are evident after bending except in the first and last 0.5 in [13 mm] of the weld.

(e) Cracks in the base metal shall not be cause for weld rejection.

(2) **Arc Spot Welds.** The company shall establish a welding procedure specification for each single and double thickness of sheet to be arc spot welded to a supporting member. Two welded assemblies shall be tested. First multiple rectangular pieces, 2-1/2 in [64 mm] or wider, shall be clamped as shown in Figure 18.2. Then the welder shall make an arc spot weld of the diameter required for procedure qualification, producing a nugget not less than 3/8 in [10 mm] in diameter. The crater of the spot weld shall be filled and 1/32 in [1 mm] minimum reinforcement provided.

(a) Appearance of the weld shall be in accordance with the requirements of 17.2.

(b) After the weld has cooled, the projecting part of the sheet shall be struck repeatedly with a hammer, as shown in Figure 18.10 until the failure occurs. The diameter of the weld nugget remaining shall be measured for the required minimum diameter as shown in Figure 18.2. If such minimum diameter has not been obtained or if the weld is otherwise not satisfactory, the welding current shall be adjusted and the test repeated until all requirements are met.

(c) The qualification of an arc spot weld between a single sheet, or multiple sheets and a supporting member shall qualify for the position tested.

(d) A change in one of the following essential variables, exceeding the requirements of 18.2.1.4, shall require requalification:

(1) For all welding processes a change in base metal, weld size, filler metal "F" number, or position of welding.

(2) For gas metal arc or flux cored arc welding, a change in welding current, shielding gas, or wire feed rate.

(3) **Stud Welding.** When qualifying studs to be forced through sheet steels onto structural members, the sheet steel shall be placed tightly against the structural member. The quality requirements of 6.13 shall apply.

Table 18.1
Essential and Non-Essential Variables^a for Inclusion in WPS
FCAW, GMAW, GTAW, and SMAW (See 18.2.1)

Essential Variable Changes Requiring Requalification:	Process			
	FCAW	GMAW	GTAW	SMAW
Joint Design				
(1) A change in joint design type from one of the below to another type:	X	X	X	X
(a) Square or V groove				
(b) Fillet				
(c) Flare Bevel or Flare V				
(2) A change in groove joint design that results in:	X	X	X	X
(a) An increase in root opening of more than 25%				
(b) The omission, but not addition, of backing material or back welding				
(c) The addition or omission of consumable inserts				
(d) The omission or inclusion of a spacer strip				
(e) The omission but not inclusion of backgouging				
(3) For plug and slot welds:	X	X	X	X
(a) A decrease in the specified slot width or hole diameter to less than material thickness +0.25 in [+6.35 mm] of the material with the hole or slot				
(b) A change in the depth (Material Thickness) of the slot or hole of more than 50%				
(c) A decrease in thickness of the specified backing base metal of more than 50%				
Base Metal				
(4) A change from one "M" number to another "M" number or to an unlisted base metal, unless the unlisted base metal can be shown to have mechanical properties in the same range and a similar chemical composition within the same range as verified by the Fabricator's Engineer	X	X	X	X
(5) A change in the type of coating material, or the addition, but not the deletion of coating material on the base metal. (<i>NOTE: Anti-spatter compound is not considered a coating material.</i>)	X	X	X	X
(6) A change in base metal thickness of more than 50%	X	X	X	X
Filler Metals				
(7) A change in electrode classification (e.g., change from E7018-1 to E7018, ER70S-3 to ER70S-6, E71T-1 to E71T-5, ER4043 to ER5554)	X	X	X	X
(8) A change in tungsten electrode type per AWS A5.12M/A5.12	—	—	X	—
(9) A change in the diameter of the electrode	X	X	X	X
(10) A change of more than 1/16 in [1.6 mm] in the diameter of filler wire	—	—	X	—
(11) The addition or deletion of filler metal	—	—	X	—

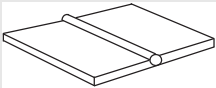
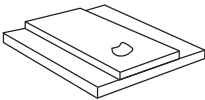
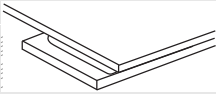
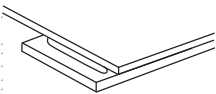
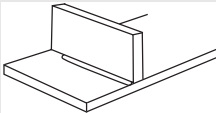
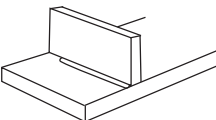
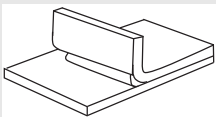
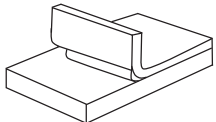
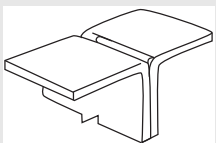
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Table 18.1 (Continued)
Essential and Non-Essential Variables^a for Inclusion in WPS
FCAW, GMAW, GTAW, and SMAW (See 18.2.1)

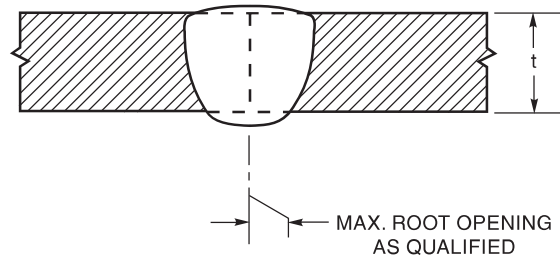
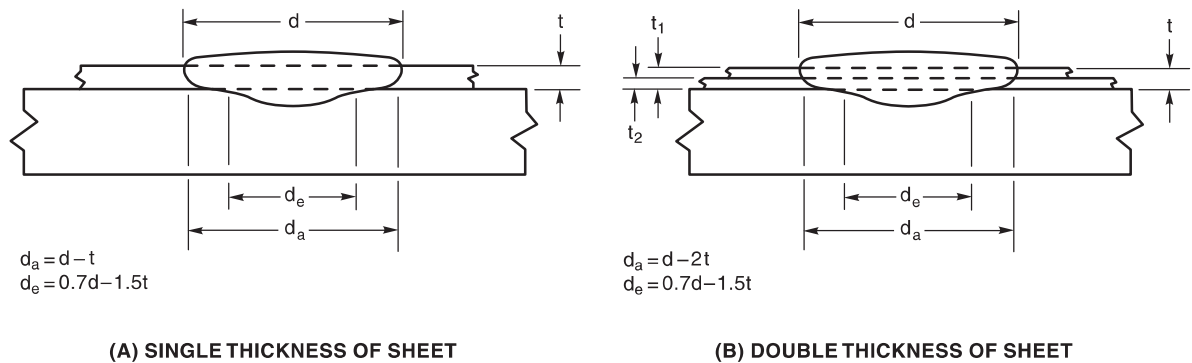
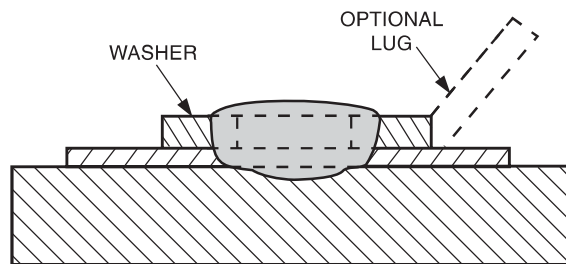
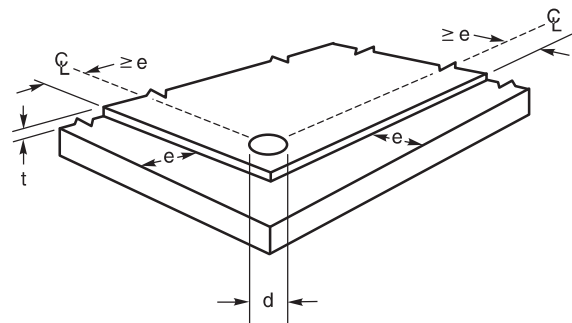
Essential Variable Changes Requiring Requalification:	Process			
	FCAW	GMAW	GTAW	SMAW
Process Parameters				
(12) A change in current or polarity	X	X	X	X
(13) A change in amperage or voltage of more than 25%	X	X	X	X
(14) A change of more than 25% of the qualified mean travel speed—Aluminum only	X	X	X	X
(15) A change in mode of metal transfer	—	X	—	—
Shielding Gas				
(16) A change from a single gas to any other gas or to a mixture of gases or a change in the specified percentage composition of gas mixture	X	X	X	—
(17) The omission but not inclusion of backing gas	X	X	X	—
Preheat and Interpass Temperature				
(18) A decrease of more than 50°F [28°C] but not below 32°F [0°C]	X	X	X	X
(19) For a preheat temperature of 32°F [0°C], or lower, the test temperature is the minimum preheat temperature.	X	X	X	X
(20) An increase of more than 50°F [28°C]	X	X	X	X
Technique				
(21) A change in the position of welding, as defined in Figures 10.1 and 10.2, except as permitted by Table 11.4	X	X	X	X
(22) In vertical welding, changes in progression for any pass from upward to downward or vice versa.	X	X	X	X

^a X = essential variable.

Table 18.2
Procedure Qualification Tests

Test Assemblies as Shown are:	Type of Welded Joint Tested	Number of Tests Required for Each Welding Position, Thickness, and Type of Cost Weld ^a	Type of Test	Qualifies for:
	Square or V groove butt joint, sheet to sheet, with any position	2	Bend	Square and V groove butt joint, sheet to sheet
	Arc spot weld, sheet to supporting member	2	Twist	Arc spot weld and arc seam weld, sheet to supporting member
	Fillet welded lap joint	2	Bend	Fillet welded lap joint, sheet to sheet, or sheet to supporting member, any position
	Fillet welded lap joint, sheet to supporting member	2	Bend	Fillet welded lap joint, sheet to supporting member
	Fillet welded T-joint, sheet to sheet	2	Bend	Fillet welded T- or lap or lap joint, sheet to sheet, or sheet to supporting member
	Fillet welded T-joint, sheet to supporting member	2	Bend	Fillet welded T- or lap joint, sheet to supporting member
	Flare bevel, sheet to sheet	2	Bend	Flare-bevel-groove weld, sheet to sheet, or sheet to supporting member or flare V-groove weld, sheet to sheet
	Flare bevel, sheet to supporting member	2	Bend	Flare-bevel-groove weld, sheet to supporting member
	Flare-V, sheet to sheet	2	Bend	Flare-V-groove weld, sheet to sheet or flare-bevel-groove weld, sheet to sheet, or sheet to supporting member

^a Within the limits of assembled variables.

**Figure 18.1—Square-Groove Weld in Butt Joint****Figure 18.2—Arc Spot Welds****Figure 18.3—Arc Spot Weld Using Washer****Figure 18.4—Edge Distances for Arc Spot Welds**

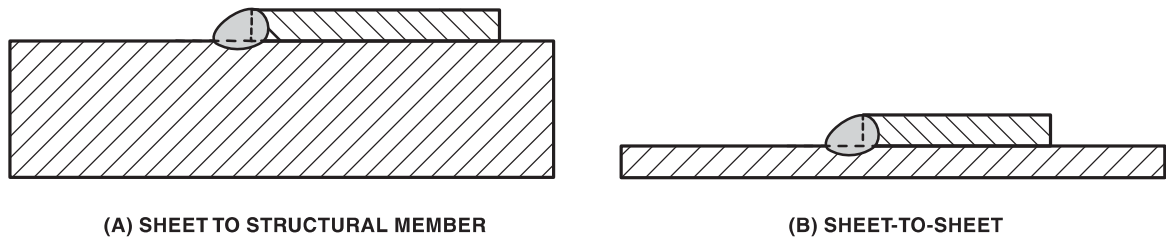


Figure 18.5—Lap-Fillet Welds

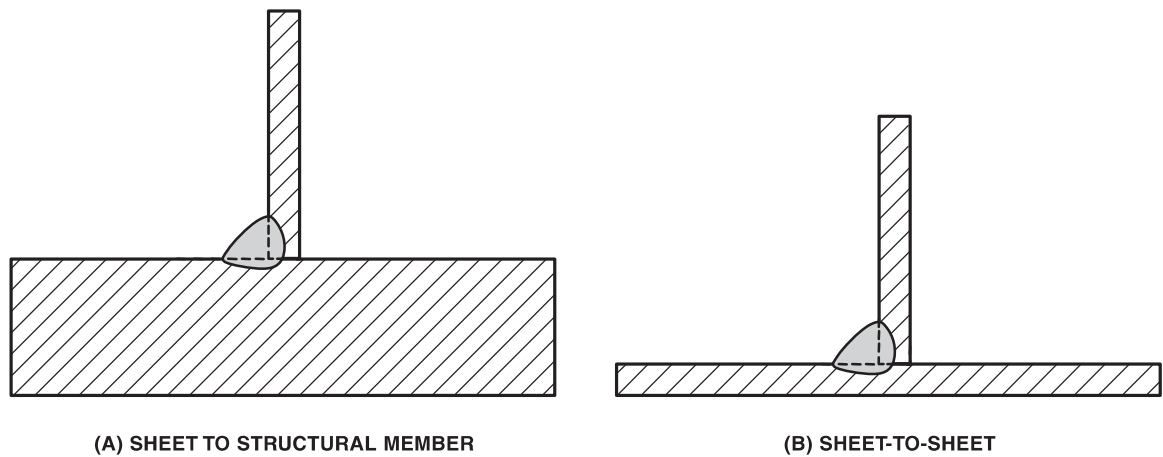


Figure 18.6—Fillet Welds in T-Joints

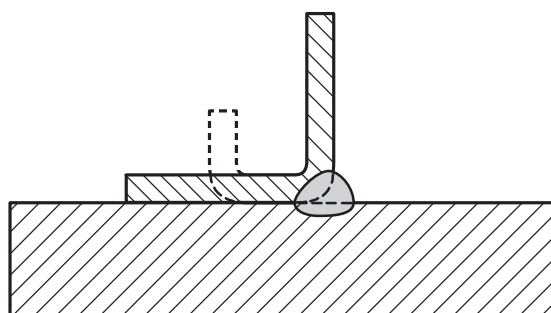


Figure 18.7—Single-Flare-Bevel-Groove Weld—Horizontal

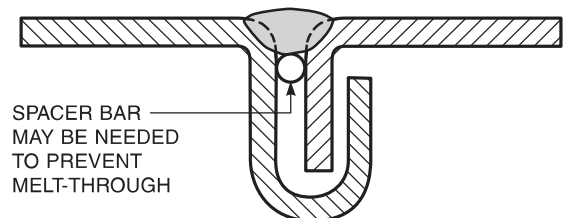


Figure 18.8—Single-Flare-V-Groove Weld—Flat

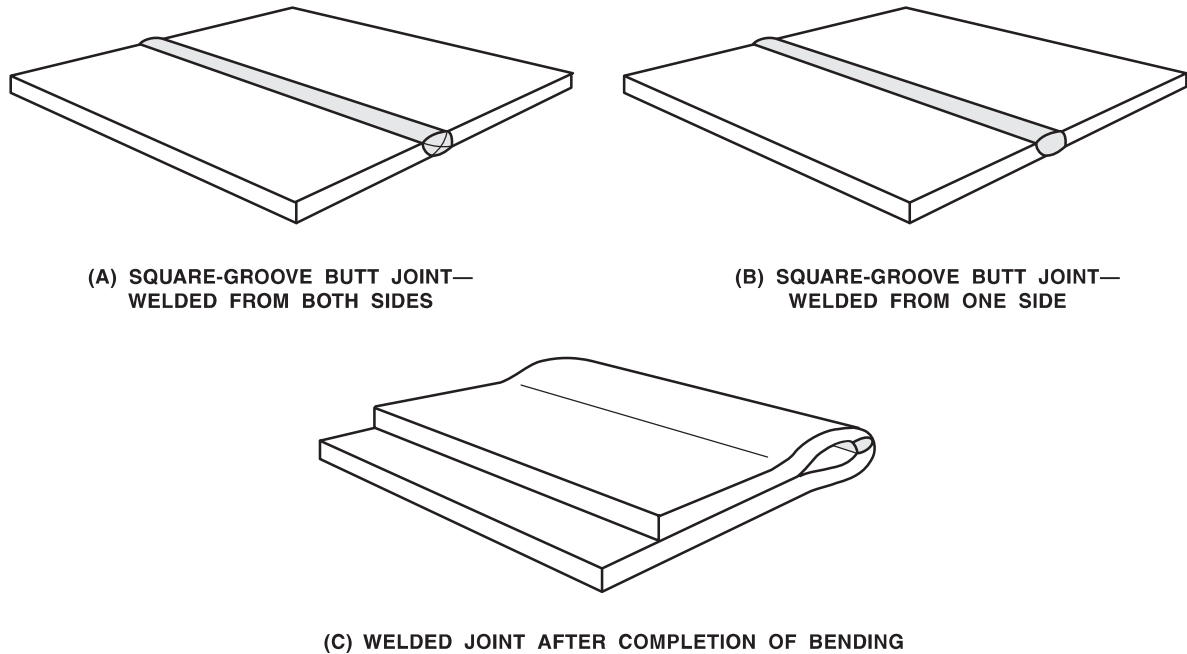


Figure 18.9—Square-Groove Butt Joints

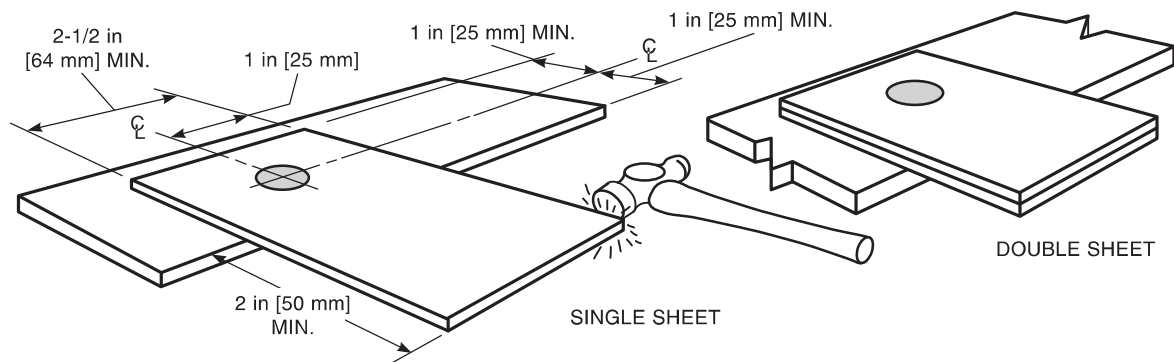


Figure 18.10—Test for Arc Spot Weld

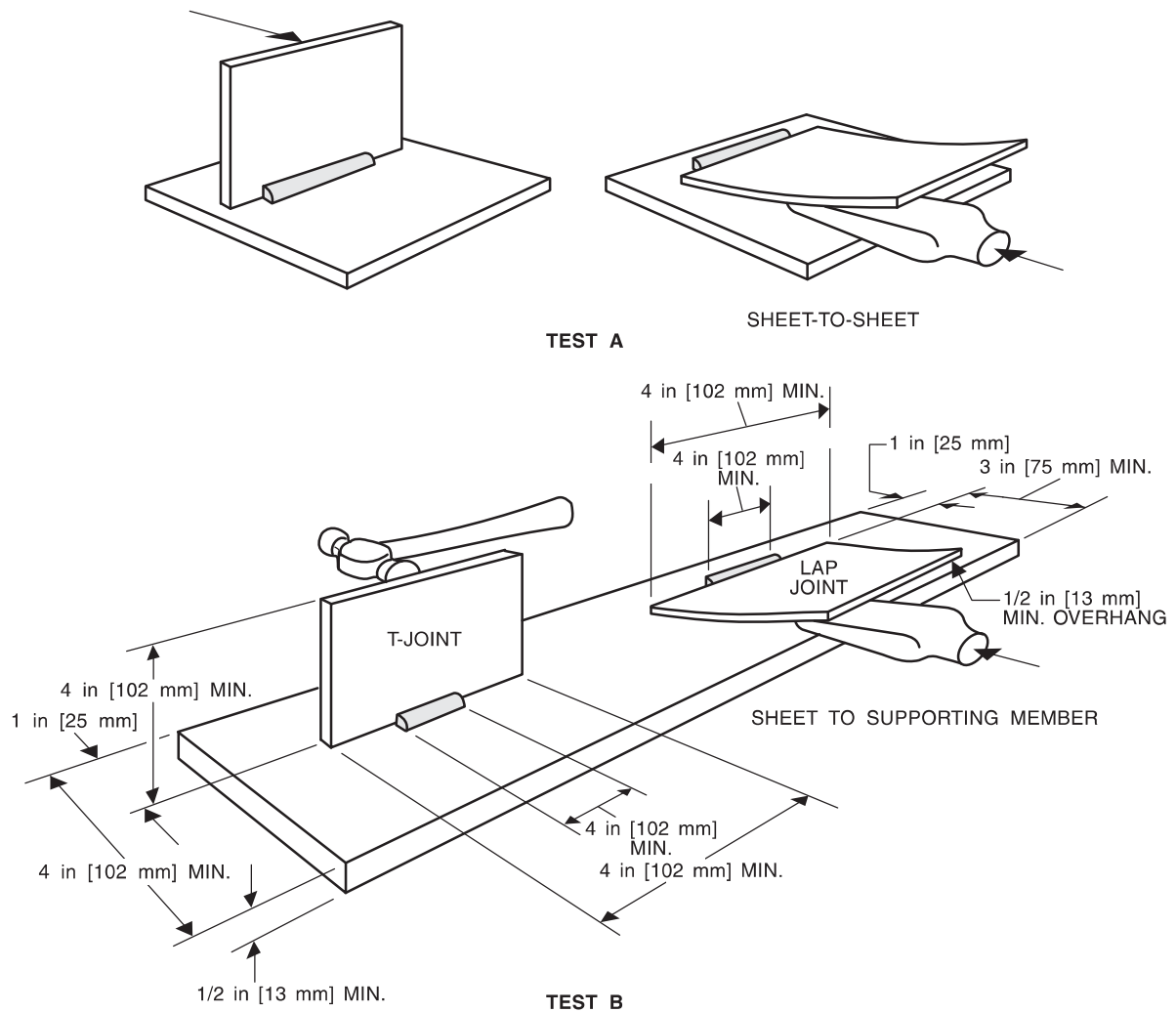
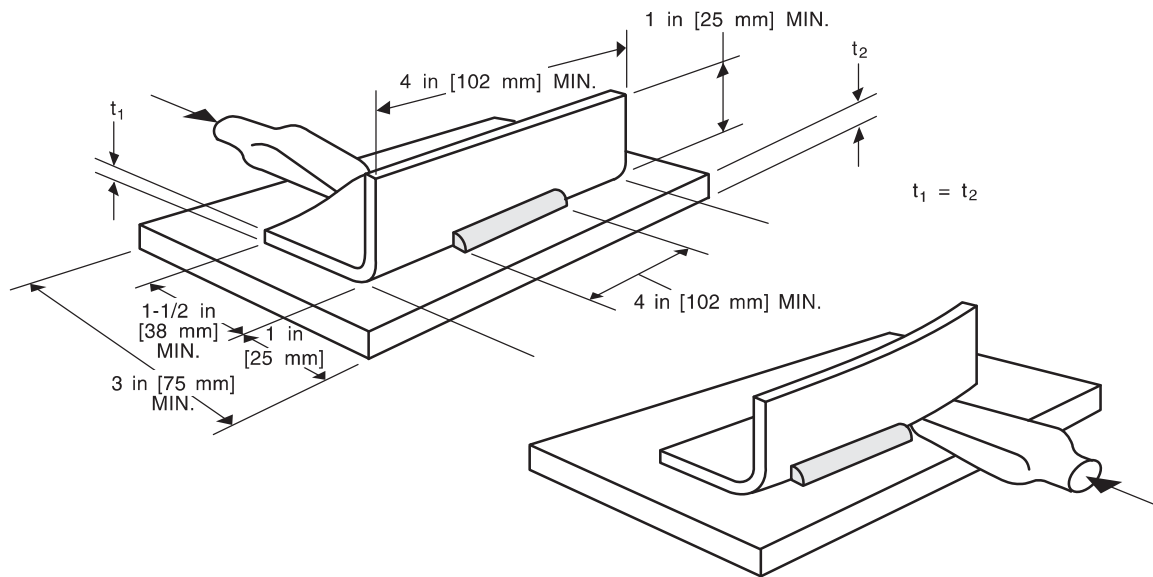
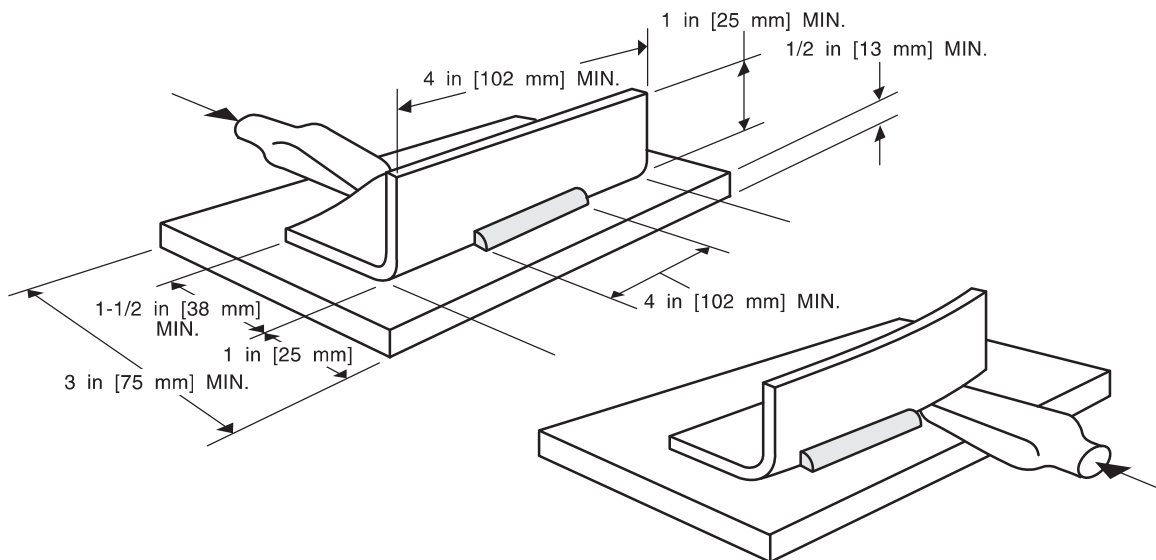


Figure 18.11—Fillet Weld Test Assembly



**Figure 18.12—Standard Test Assembly for Flare-Bevel-Groove Welds;
Test C—Sheet-to-Sheet**



**Figure 18.13—Standard Test Assembly for Flare-Bevel-Groove Weld;
Test D—Sheet-to-Supporting Plate**

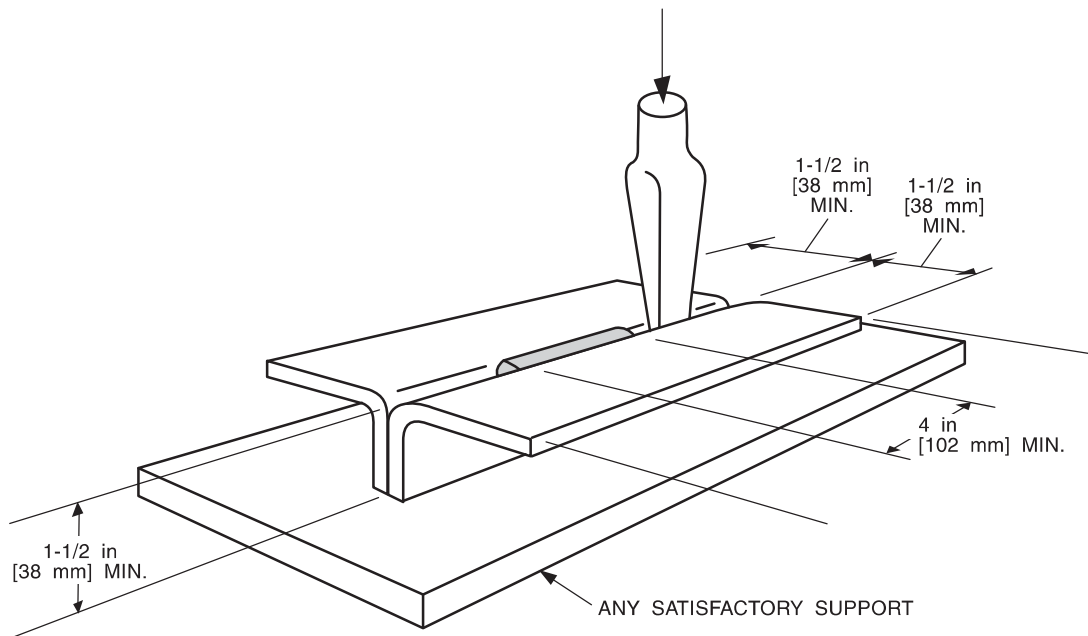


Figure 18.14—Standard Test Assembly for Flare-V-Groove Welds

19. Welder, Welding Operator, and Tack Welder Qualification—Carbon, Low Alloy, and Stainless Steel Sheet Metals

For welding on base metals less than 1/8 in [3 mm], the following qualification requirements apply:

19.1 General. The qualification tests described herein are specially devised tests to determine the welder's ability to produce sound welds. The qualification tests, shown in Table 19.2, shall be performed in accordance with the requirements of the procedure specification and recorded on a form similar to that of Form D4 in Annex D. These tests are not intended to be used as a guide during actual construction.

19.2 Limitation of Variables. The welder shall be required to qualify in each process to be used and for any change in the variables in each process as indicated in Table 19.1.

19.2.1 A qualified welding procedure specification shall be used for welder qualification. The number and type of test assemblies, the method of testing, and the test results shall be per Table 19.2).

19.2.2 The welder who completes a successful procedure qualification shall be considered qualified for the welding process within the parameters of Table 19.1 based on the Procedure Qualification Record.

19.2.3 For acceptance criteria refer to the applicable subclauses of 18.2.

19.3 Retests

19.3.1 In case a welder, welding operator, or tack welder fails to meet the requirements of one or more weld tests, a retest may be allowed. A retest shall be made consisting of one test specimen of each type which the welder, welding operator, or tack welder, failed. It is recommended that additional documented training be given prior to the retest.

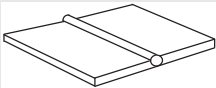
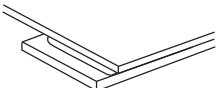
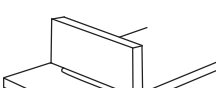
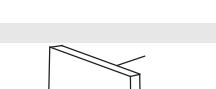
19.3.2 The performance test may be terminated at any stage of the testing procedure whenever it becomes apparent to the supervisor conducting the tests that the welder, welding operator, or tack welder, does not have the required skill to produce satisfactory results.

19.4 Period of Effectiveness. Qualification shall be considered as remaining in effect indefinitely unless (1) the welder, welding operator, or tack welder has not engaged in a given process of welding for which the welder is qualified for a period exceeding six months, or (2) there is some specific reason to question the welder, welding operator, or tack welder's ability.

Table 19.1
Limitation of Variables for Welder Qualification
FCAW, GMAW, GTAW, and SMAW (See 19.2)

Essential Variable Changes Requiring Requalification:	Process			
	FCAW	GMAW	GTAW	SMAW
Joint Design				
(1) A change in joint design type from one of the below to another type:	X	X	X	X
(a) Groove				
(b) Fillet, Plug, or Slot				
(c) Flare Bevel or Flare V				
(2) The omission, but not addition, of backing material	X	X	X	X
Base Metal				
(3) A change from ferrous to nonferrous or vice-versa	X	X	X	X
(4) A change in the “M” number of nonferrous materials (a change involving only aluminum alloys is exempt)	X	X	X	X
(5) A change in base metal thickness of more than 50% from that qualified	X	X	X	X
(6) A change in coated sheet steel-to-coated sheet steel or coated sheet steel-to-sheet steel with another coating	X	X	X	X
Filler Metals				
(7) A change in electrode “F” number to a higher “F” number as identified in Table 11.2	—	—	—	X
(8) A change in tungsten electrode type per AWS A5.12M/A5.12	—	—	X	—
(9) A change of more than 1/32 in [0.8 mm] in the diameter of the electrode	X	X	X	X
(10) A change of more than 1/32 in [0.8 mm] in the diameter of filler wire	—	—	X	—
(11) The addition or deletion of filler metal	—	—	X	—
Process Parameters				
(12) A change in mode of metal transfer	—	X	—	—
Shielding Gas				
(13) A change from a gas containing more than 85% Argon to a gas containing less than 85% Argon, or vice-versa	—	X	—	—
Technique				
(14) The omission, but not inclusion, of backgouging	X	X	X	X
(15) A change in position of welding except as permitted by Table 19.2	X	X	X	X
(16) In vertical welding, changes in progression for any pass from upward to downward or vice-versa	X	X	X	X

Table 19.2
Welder Qualification Tests
(See Clause 18 for Testing and Acceptance)

Test Assemblies as Shown are:	Type of:	Qualifies for:		Number of Tests	Type of Test
	Welded Joint	Welding Position	Welding Position		
	Groove joint, sheet to sheet	F H V OH	F F, H F, V F, OH	All groove joints	2 Bend
	Fillet welded lap joint, sheet to sheet	F H V OH	F F, H F, V F, OH	All fillet joints	2 Bend
	Fillet welded lap joint, sheet to supporting member	F H V OH	F F, H F, V F, OH	All fillet joints	2 Bend
	Fillet welded T-joint, sheet to sheet	F H V OH	F F, H F, V F, OH	All fillet joints	2 Bend
	Fillet welded T-joint, sheet to supporting member	F H V OH	F F, H F, V F, OH	All fillet joints	2 Bend
	Flare-bevel, sheet to sheet	F H V OH	F F, H F, V F, OH	All flare-bevel-groove and flare-V-groove joints	2 Bend
	Flare-bevel, sheet to supporting member	F H V OH	F F, H F, V F, OH	All flare-bevel-groove and flare-V-groove joints	2 Bend
	Flare-V sheet to sheet	F H V OH	F F, H F, V F, OH	All flare-bevel-groove and flare-V-groove joints	2 Bend

20. Technique and Workmanship for Welding Sheet Metal

20.1 Surfaces to be welded shall be smooth, uniform, and free from fins, tears, cracks, or other imperfections which would adversely affect the quality or strength of the weld.

20.2 Surfaces to be welded and surfaces adjacent to a weld shall also be free from loose or thick scale, slag, rust, moisture, grease, or other foreign material that would prevent proper welding or produce objectionable fumes.

20.3 Mill scale that withstands vigorous wire brushing, a thin rust inhibitive coating, a galvanized coating, or an antispatter compound may remain.

20.3.1 Welding shall not be done when surfaces are wet or exposed to rain, sleet, snow, or high wind. Additionally, for carbon and low-alloy steel base metals, the ambient and base metal temperatures shall be at least 32°F [0°C]. For the welding of aluminum base metals, the ambient and base metal temperatures shall be at least 50°F [10°C].

20.3.2 If temperatures are below those required by 6.1.3 and 6.1.4, preheating shall be required to achieve the minimum base metal temperature. The ambient temperature shall be not less than 50°F [10°C] without adequate preheating prior to welding.

20.4 Joint details shall be arranged to provide the most favorable position for welding (see Figures 10.1 and 10.2 for a definition of welding positions).

21. Inspection of Welding Procedure Qualification and Equipment for Welding Sheet Metal

21.1 The Verification Inspector may ascertain that all welding procedures are qualified and covered by a welding procedure specification in accordance with Clause 9, 18.2.1, or 18.2.2, as applicable.

21.2 The Verification Inspector may inspect the welding equipment to be used for the work to make certain that it conforms to the requirements of 6.1.2.

21.3 The Verification Inspector may ascertain that the welding will be performed only by welders, welding operators, and tack welders who are qualified in accordance with the requirements of Clause 11, 12, or 13, for material thicknesses 1/8 in [3 mm] and above. For material thicknesses less than 1/8 in [3 mm], the requirement of Clauses 19 and 20 shall apply.

22. Weld Details—Sheet Metal

Materials thinner than 1/8 in [3 mm] shall comply with the requirements listed for 1/8 in [3 mm] and thicker except as noted below:

22.1 Groove Welds (Butt Joints). Root openings of groove welds shall be in accordance with the requirements of Figure 18.1.

22.2 Fillet Welds. Root openings of fillet welds forming a T- or lap joint shall not exceed 0.5 times the thickness of the thinner member.

23. Sheet Metal Weld Quality—Visual Inspection Acceptance Criteria

The cumulative length of undercut shall be no longer than $L/8$, where L is the specified length of the weld, or in the case of arc spot welds, the circumference, provided fusion exists between the weld metal and base metal. Depth of undercut is not a subject of inspection and need not be measured. Melt-through that results in a hole is unacceptable.

Annex A (Normative)

Alternate Base Material Specifications (Steel)

This annex is part of AWS D15.1/D15.1M:2012, *Railroad Welding Specification for Cars and Locomotives*, and includes mandatory elements for use with this standard.

This annex provides M numbers and group numbers for steels used in the railroad industry that may or may not be included in AWS B2.1/B2.1M.

Table A.1
Numerical Indexing of Base Material Specifications (Steel)

Standard	Base Metal Specification	M No.	Group No.	Type, Grade, or Alloy	UNS Number	Type of Base Metal
ASTM	A27	1	1	Grade U		
ASTM	A27	1	1	Grade 60		
ASTM	A27	1	2	Grade 65		
ASTM	A27	1	2	Grade 70		
ASTM	A47	2C	4	Grade 32510		
ASTM	A47	2C	4	Grade 35018		
ASTM	A48	2A	4	Class 20		
ASTM	A48	2A	4	Class 25		
ASTM	A48	2A	4	Class 30		
ASTM	A48	2A	4	Class 35		
ASTM	A48	2A	4	Class 40		
ASTM	A48	2B	—	Class 45		
ASTM	A48	2B	—	Class 50		
ASTM	A48	2B	—	Class 55		
ASTM	A159	2A	4	Grade 1800		
ASTM	A159	2A	4	Grade 2500		
ASTM	A159	2A	4	Grade 3000		
ASTM	A159	2A	—	Grade 3500		
ASTM	A159	2A	—	Grade 4000		
ASTM	A197	2C	4	Grade 4000		
ASTM	A220	2D	4	Grade 40010		
ASTM	A220	2D	4	Grade 45006		
ASTM	A220	2D	4	Grade 45008		
ASTM	A220	2E	4	Grade 50005		
ASTM	A220	2E	4	Grade 60004		
ASTM	A436	2F	—	All		
ASTM	A439	2G	—	All		
ASTM	A602	2E	4	All		
ASTM	A659	1	1	—		
ASTM	A744	8	1	TP304L	S30403	Note a
ASTM	A744	8	1	TP316L	S30603	Note a
ASTM	A744	8	1	TP317L	S30703	Note a
ASTM	A744	8	1	TP321	S32103	Note a
ASTM	A744	8	1	TP347	S34703	Note a
AAR	M201	1	1	Grade A		
AAR	M201	1	2	Grade B		
AAR	M201	1	3	Grade B+		
AAR	M201	1	4	Grade C		
AAR	TC128	1	3	Grade B		

^aAs Welded Wrought Fittings.

Annex B (Informative)

Filler Metal Classifications

This annex is not part of AWS D15.1/D15.1M:2012, *Railroad Welding Specification for Cars and Locomotives*, but is included for informational purposes only.

The “F” Number grouping of welding electrodes and rods, shown in Table B.1, is based primarily on their usability characteristics, which fundamentally determine the ability to make satisfactory welds with a given filler metal and process. This grouping is made to minimize the number of procedure and performance qualifications where this can logically be done. The grouping does not imply that filler metals within a group may be indiscriminately substituted for a metal which was used in the qualification test without consideration of the compatibility of the base and filler metals from the standpoint of metallurgical properties, and postweld heat treatment, design, service requirements, and mechanical properties.

Table B.1
Grouping of Welding Electrodes and Rods for Qualification

F-No.	AWS Specification	AWS Classification
Steel and Steel Alloys		
1	A5.1/A5.1M	EXX20, EXX22, EXX24, EXX27, EXX28
1	A5.4/A5.4M	EXXX(X)-26
1	A5.5/A5.5M	EXX20-X, EXX27-X
2	A5.1/A5.1M	EXX12, EXX13, EXX14, EXX19
2	A5.5/A5.5M	E(X)XX13-X
3	A5.1/A5.1M	EXX10, EXX11
3	A5.5/A5.5M	E(X)XX10-X, E(X)XX11-X
4	A5.1/A5.1M	EXX15, EXX16, EXX18, EXX18M, EXX48
4	A5.4/A5.4M other than austenitic and duplex	EXXX(X)-15, EXXX(X)-16, EXXX(X)-17
4	A5.5/A5.5M	E(X)XX15-X, E(X)XX16-X, E(X)XX18-X, E(X)XX18M, E(X)XX18M1
5	A5.4/A5.4M austenitic and duplex	EXXX(X)-15, EXXX(X)-16, EXXX(X)-17
6	A5.2/A5.2M	All classifications
6	A5.9/A5.9M	All classifications
6	A5.17/A5.17M	All classifications
6	A5.18/A5.18M	All classifications
6	A5.20/A5.20M	All classifications
6	A5.22/A5.22M	All classifications
6	A5.23/A5.23M	All classifications
6	A5.25/A5.25M	All classifications
6	A5.26/A5.26M	All classifications
6	A5.28/A5.28M	All classifications
6	A5.29/A5.29M	All classifications
6	A5.30/A5.30M	INMs-X, IN5XX, IN3XX(X)
Aluminum and Aluminum Alloys		
21	A5.3/A5.3M	E1100
21	A5.3/A5.3M	E3003
21	A5.10/A5.10M	ER1100
21	A5.10/A5.10M	R1100
21	A5.10/A5.10M	ER1188
21	A5.10/A5.10M	R1188
22	A5.10/A5.10M	ER5183
22	A5.10/A5.10M	R5183
22	A5.10/A5.10M	ER5356
22	A5.10/A5.10M	R5356
22	A5.10/A5.10M	ER5554
22	A5.10/A5.10M	R5554

(Continued)

Table B.1 (Continued)
Grouping of Welding Electrodes and Rods for Qualification

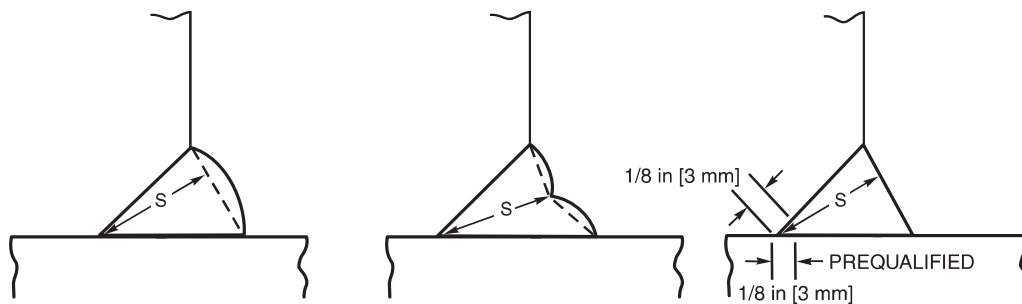
F-No.	AWS Specification	AWS Classification
Aluminum and Aluminum Alloys (Continued)		
22	A5.10/A5.10M	ER5556
22	A5.10/A5.10M	R5556
22	A5.10/A5.10M	ER5654
22	A5.10/A5.10M	R5654
23	A5.3/A5.3M	E4043
23	A5.10/A5.10M	ER4010
23	A5.10/A5.10M	R4010
23	A5.10/A5.10M	ER4043
23	A5.10/A5.10M	R4043
23	A5.10/A5.10M	ER4047
23	A5.10/A5.10M	R4047
23	A5.10/A5.10M	ER4145
23	A5.10/A5.10M	R4145
23	A5.10/A5.10M	ER4643
23	A5.10/A5.10M	R4643
24	A5.10/A5.10M	ER4009
24	A5.10/A5.10M	R4009
24	A5.10/A5.10M	R4011
24	A5.10/A5.10M	R-206.0
24	A5.10/A5.10M	R-C355.0
24	A5.10/A5.10M	R-A356.0
24	A5.10/A5.10M	R-357.0
24	A5.10/A5.10M	R-A357.0
25	A5.10/A5.10M	ER2319
25	A5.10/A5.10M	R2319

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Annex C (Informative)

Effective Weld Size—Special Cases

This annex is not part of AWS D15.1/D15.1M:2012, *Railroad Welding Specification for Cars and Locomotives*, but is included for informational purposes only.



C1. Combination Partial Penetration Groove Weld and Fillet Weld

The effective weld size (S) is the minimum distance from the weld root to the face of the diagrammatic weld, with a reduction of 1/8 in [3 mm] as required by 7.1.1, less any convexity.

C2. Effective Weld Sizes of Fillet Welds in Skewed T-Joints

Table C.1 is a tabulation showing equivalent leg size factors for the range of dihedral angles between 60° and 135°, assuming no root opening. Root openings 1/16 in [2 mm] or greater, but not exceeding 3/16 in [5 mm] shall be added directly to the leg size. The required leg size for fillet welds in skewed joints is calculated using the equivalent leg size factor for a given dihedral angle, as shown in the example.

EXAMPLE:

(U.S. Customary Units)

Given: Skewed T-joint angle, 75°; root opening, 1/16 in

Required: Strength equivalent to 90° fillet weld of size: 5/16 in

Procedure: (1) Factor for 75° from Table 7.2 = 0.86

(2) Equivalent leg size, w, of skewed joint, without root opening:

$$w = 0.86 \times 0.313 = 0.269 \text{ in}$$

(3) With root opening:

$$0.063 \text{ in}$$

(4) Required leg size, w, of skewed fillet weld: [(2) + (3)]

$$w = 0.332 \text{ in}$$

(5) Rounding up to a practical dimension:

$$w = 3/8 \text{ in}$$

EXAMPLE:

(SI Units)

Given: Skewed T-joint, angle 75°; root opening, 2 mm

Required: Strength equivalent to 90° fillet weld of size 8.0 mm

Procedure: (1) Factor for 75° from Table 7.2 = 0.86

(2) Equivalent leg size, w , of skewed joint, without root opening:

$$w = 0.86 \times 8.0 = 6.9 \text{ mm}$$

(3) With root opening of:

$$\underline{2 \text{ mm}}$$

(4) Required leg size, w , of skewed fillet weld: [(2) +(3)]

$$8.5 \text{ mm}$$

(5) Rounding up to a practical dimension:

$$w = 9.0 \text{ mm}$$

For fillet welds having equal measured legs (W), the distance from the root of the joint to the face of the diagrammatic weld (t_n) may be calculated as follows:

For root openings $>1/16$ in and $<3/16$ in [>2 mm and <5 mm], use

$$E = \frac{W - R}{2 \sin \frac{\Psi}{2}} \quad (\text{Eq. 1})$$

For root openings $<1/16$ in [2 mm], use: $R = 0$

Where the measured leg of such fillet weld (W) is the perpendicular distance from the surface of the joint to the opposite toe, and (R) is the root opening, if any, between parts (see Figure 5.4). Acceptable root openings are defined in 6.3.

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Table C.1
Equivalent Fillet Weld Leg Size Factors for Skewed T-Joints

Dihedral angle, Ψ	60°	65°	70°	75°	80°	85°	90°	95°	100°	105°	110°	115°	120°	125°	130°	135°
Equivalent leg size factor (see Clause B2)	0.71	0.76	0.81	0.86	0.91	0.96	1.00	1.03	1.08	1.12	1.16	1.19	1.23	1.25	1.28	1.31

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Annex D (Informative)

Sample Report Forms

This annex is not part of AWS D15.1/D15.1M:2012, *Railroad Welding Specification for Cars and Locomotives*, but is included for informational purposes only.

PREQUALIFIED WELDING PROCEDURE SPECIFICATION (WPS)

Material specification _____
 Welding process _____
 Manual or machine _____
 Position of welding _____
 Filler metal specification _____
 Filler metal classification _____
 Flux _____
 Weld metal grade* _____
 Shielding gas _____ Flow rate _____
 Single or multiple pass _____
 Single or multiple arc _____
 Welding current _____
 Polarity _____
 Welding progression _____
 Root treatment _____
 Preheat and interpass temperature _____
 Postweld Heat Treatment _____ None _____
 *Applicable only when filler metal has no AWS classification.

WELDING PROCEDURE

Pass No.	Electrode Size	Electrical Characteristics		Travel Speed	Joint Detail
		Amperes	Volts		

This procedure may vary due to fabrication sequence, fit-up, pass size, etc., within the limitation of variables given in AWS D15.1: (_____) *Railroad Welding Specification for Cars and Locomotives*.
 (year)

Procedure no. _____

Manufacturer or Contractor _____

Revision no. _____

Authorized by _____

Form D-1

Date _____

PROCEDURE QUALIFICATION RECORD (PQR)**PROCEDURE SPECIFICATION**

Material specification _____
 Welding process _____
 Manual or machine _____
 Position of welding _____
 Filler metal specification _____
 Filler metal classification _____
 Weld metal grade* _____
 Shielding gas _____ Flow rate _____
 Single or multiple pass _____
 Single or multiple arc _____
 Welding current _____
 Welding progression _____
 Preheat temperature _____
 Postheat treatment _____
 Welder's name _____

*Applicable when filler metal has no AWS classification.

VISUAL INSPECTION

Appearance _____
 Undercut _____
 Piping porosity _____
 Test date _____
 Witnessed by _____

GROOVE WELD TEST RESULTS

Tensile strength, psi

1. _____
 2. _____

Guided-bend tests (2 root-, 2 face-, or 4 side-bend)

Root

Face

1. _____ 1. _____
 2. _____ 2. _____

Radiographic-ultrasonic examination

RT report no. _____

UT report no. _____

FILLET WELD TEST RESULTS

Minimum size multiple pass Maximum size single pass
 Macroetch Macroetch

1. _____ 2. _____ 1. _____ 3. _____
 3. _____ 2. _____

All-weld-metal tension test

Tensile strength, psi _____

Yield point/strength, psi _____

Elongation in 2 in, % _____

Laboratory test no. _____

WELDING PROCEDURE

Pass No.	Electrode Size	Electrical Characteristics		Travel Speed	Joint Detail
		Amperes	Volts		

We, the undersigned, certify that the statements in this record are correct and that the test welds were prepared, welded, and tested in accordance with the requirements of AWS D15.1: (_____) *Railroad Welding Specification for Cars and Locomotives*.
 (year)

Procedure no. _____

Manufacturer or Contractor _____

Revision no. _____

Authorized by _____

Form D-2

Date _____

TEST QUALIFIED WELDING PROCEDURE SPECIFICATION (WPS)

Qualified by procedure qualification no. _____
 Material specification _____
 Welding process _____
 Manual or machine _____
 Position of welding _____
 Filler metal specification _____
 Filler metal classification _____
 Flux _____
 Weld metal grade* _____
 Shielding gas _____ Flow rate _____
 Single or multiple pass _____
 Single or multiple arc _____
 Welding current _____
 Polarity _____
 Welding progression _____
 Root treatment _____
 Preheat and interpass temperature _____
 Postweld Heat Treatment _____

*Applicable only when filler metal has no AWS classification.

WELDING PROCEDURE

Pass No.	Electrode Size	Electrical Characteristics		Travel Speed	Joint Detail
		Amperes	Volts		

This procedure may vary due to fabrication sequence, fit-up, pass size, etc., within the limitation of variables given in AWS D15.1: (_____) *Railroad Welding Specification for Cars and Locomotives*.
 (year)

Procedure no. _____

Manufacturer or Contractor _____

Revision no. _____

Authorized by _____

Form D-3

Date _____

WELDER AND WELDING OPERATOR QUALIFICATION RECORD

Welder or welding operator's name _____ Identification no. _____
 Welding process _____ Manual _____ Semiautomatic _____ Machine _____
 (Flat, horizontal, overhead, or vertical—if vertical, state whether upward or downward.)
 In accordance with procedure specification no. _____
 Material specification _____
 Diameter and wall thickness (if pipe)—otherwise, joint thickness _____
 Thickness range this qualifies _____

FILLER METAL

Specification no. _____ Classification _____ F-no. _____
 Describe filler metal (if not covered by AWS specification) _____

 Is backing strip used? _____
 Filler metal diameter and trade name _____ Flux for submerged arc or gas for gas metal arc or flux
 cored arc welding _____

VISUAL INSPECTION

Appearance _____ Undercut _____ Piping porosity _____

Guided Bent Test Results

Type	Result	Type	Result

Test conducted by _____ Laboratory test no. _____
 per _____ Test date _____

Fillet Test Results

Appearance _____ Fillet size _____
 Fracture test root penetration _____ Macroetch _____
 (Describe the location, nature, and size of any crack or tearing of the specimen.)
 Test conducted by _____ Laboratory test no. _____
 per _____ Test date _____

RADIOGRAPHIC TEST RESULTS

Film Identification	Results	Remarks	Film Identification	Results	Remarks

Test witnessed by _____ Laboratory test no. _____
 per _____ Test date _____

We, the undersigned, certify that the statements in this record are correct and that the test welds were prepared and tested in accordance with the requirements of AWS D15.1: (_____) *Railroad Welding Specification for Cars and Locomotives*.
 (year)

Manufacturer or Contractor _____

Authorized by _____

Date _____

Form D-4

Project _____
Quality requirements—Section no. _____
Reported to _____

Technique

Source _____
Film to source _____
Exposure time _____
Screens _____
Film type _____

[illegible]

Radiographer(s) _____ Manufacturer or Contractor _____
 Interpreter _____ Authorized by _____
 Test date _____ Date _____
 Form D-5

Project _____
Quality requirements—Section no. _____
Reported to _____

[illegible]

Inspector _____ Manufacturer or Contractor _____

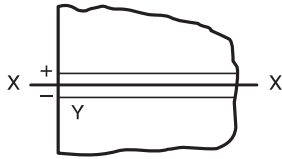
Test date _____ Authorized by _____

Method of inspection: _____ Date _____

Form D-6

REPORT OF ULTRASONIC TESTING OF WELDS

Project _____ Report no. _____



Weld identification _____

Material thickness _____

Weld joint AWS _____

Welding process _____

Quality requirements—Section no. _____

Remarks _____

Line Number	Indication Number	Transducer Angle	From Face	Leg*	Decibels				Discontinuity				Discontinuity Evaluation	Remarks
					Indication Level	Reference Level	Attenuation Factor	Indication Rating	Length	Angular Distance (Sound Path)	Depth from "A" Surface	Distance		
												a	b	
1														
2														
3														
4														
5														
6														
7														
8														
9														
10														
11														
12														
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26														

We, the undersigned, certify that the statements in this record are correct and that the test welds were prepared and tested in accordance with the requirements of AWS D15.1: (_____) *Railroad Welding Specification for Cars and Locomotives*.
(year)

Test date _____

Manufacturer _____

Inspected by _____

Authorized by _____

Form D-7

Date _____

Ultrasonic Unit Certification

Ultrasonic unit _____ Serial no. _____ Date _____
 Model _____
 Search unit _____ Type _____ By _____
 Size _____ MHz _____ ASNT Level _____
 Frequency _____

TABULATION CHART					
No.	a dB Reading	b % Scale	c Corrected Reading	d dB Error	e Collective dB Error
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					
11					
12					
13					
14					
15					
16					
17					
18					
19					
20					
21					
22					
23					
24					
25					
26					

Find the average % screen values from column b disregarding the first three and last three tabulations. Use this percentage as %₂ in calculating the Corrected Reading c.

The dB Error d is established by subtracting the Corrected Reading from the dB Reading a. Beginning with the tabulated dB Error d nearest to 0.0, collectively add the dB Error d values up and down placing the subtotals in column e (Collective dB Errors).

Moving vertically up and down from the Average % line, find the largest vertical span in which the top and bottom Collective dB Error figures remain at or below 2 dB. Count the number of vertical spaces of movement, subtract one, and multiply the remainder by six. This dB value is the acceptable range of the unit.

In order to establish the acceptable range graphically, Form D-10 should be used in conjunction with Form D-8a as follows:

(1) Apply the collective dB Error "e" values vertically on the horizontal offset coinciding with the dB reading values "a."

(2) Establish a curve line passing through this series of points.

(3) Apply a 2 dB high horizontal window over this curve positioned vertically so that the longest section is completely encompassed within the 2 dB Error height.

(4) This window length represents the acceptable dB range of the unit.

$$dB_2 = 20 \times \log (\%_2 \div \%_1) + dB_1$$

%₂ (Average) _____ %

Total qualified range _____ dB to _____ dB = _____ dB

Total error _____ dB

Total qualified range _____ dB to _____ dB = _____ dB

Total error _____ dB

FORM D-8a

Notes:

1. In order to attain Rating "d"

(A) With instruments with gain control, use the formula $a - b - c = d$.(B) With instruments with attenuation control, use the formula $b - a - c = d$.

(C) A plus or minus sign must accompany the "d" figure unless "d" is equal to zero.

2. Distance from X is used in describing the location of a weld discontinuity in a direction perpendicular to the weld reference line. Unless this figure is zero, a plus or minus sign must accompany it.

3. Distance from Y is used in describing the location of a weld discontinuity in a direction parallel to the weld reference line. This figure is attained by measuring the distance from the "Y" end of the weld to the beginning of said discontinuity.

4. Evaluation of Retested Repaired Weld Areas must be tabulated on a new line on the report form. If the original report form is used, R_n shall prefix the indication number. If additional forms are used, the R number shall prefix the report number.

*Use Leg I, II, or III.

FORM D-8a (Continued)

Form D-8a (Continued)

Ultrasonic Unit Certification

Ultrasonic unit Serial no. Date 10-23-99
 Model UT77 00006
 Search unit Type By I. C. BLIPS
 Size 1" diam. MHz BT ASNT Level II
 Frequency 2.25

TABULATION CHART					
No.	a dB Reading	b % Scale	c Corrected Reading	d dB Error	e Collective dB Error
1	6	69	7.1	-1.1	-2.3
2	12	75	12.4	-0.4	-1.2
3	18	75	18.3	-0.3	-0.8
4	24	77	24.1	-0.1	-0.5
5	30	77	30.1	-0.1	-0.4
6	36	77	36.1	-0.1	-0.3
7	42	77	42.1	-0.1	-0.2
8	48	78	48.0	-0.0	-0.1
9	54	77	54.1	-0.1	-0.1
10	60	78	60.0	0.0	0.0
11	66	79	65.9	+0.1	+0.1
12	72	80	71.8	+0.2	+0.3
13	78	81	77.7	+0.3	+0.6
14	84	86	83.1	+0.9	+1.5
15					
16					
17					
18					
19					
20					
21					
22					
23					
24					
25					
26					

Average 78%—

Find the average % screen values from column b disregarding the first three and last three tabulations. Use this percentage as %₂ in calculating the Corrected Reading c.

The dB Error d is established by subtracting the Corrected Reading from the dB Reading a. Beginning with the tabulated dB Error d nearest to 0.0, collectively add the dB Error d values up and down placing the subtotals in column e (Collective dB Errors).

Moving vertically up and down from the Average % line, find the largest vertical span in which the top and bottom Collective dB Error figures remain at or below 2 dB. Count the number of vertical spaces of movement, subtract one, and multiply the remainder by six. This dB value is the acceptable range of the unit.

In order to establish the acceptable range graphically, Form D-10 should be used in conjunction with Form D-8a as follows:

(1) Apply the collective dB Error "e" values vertically on the horizontal offset coinciding with the dB reading values "a."

(2) Establish a curve line passing through this series of points.

(3) Apply a 2 dB high horizontal window over this curve positioned vertically so that the longest section is completely encompassed within the 2 dB Error height.

(4) This window length represents the acceptable dB range of the unit.

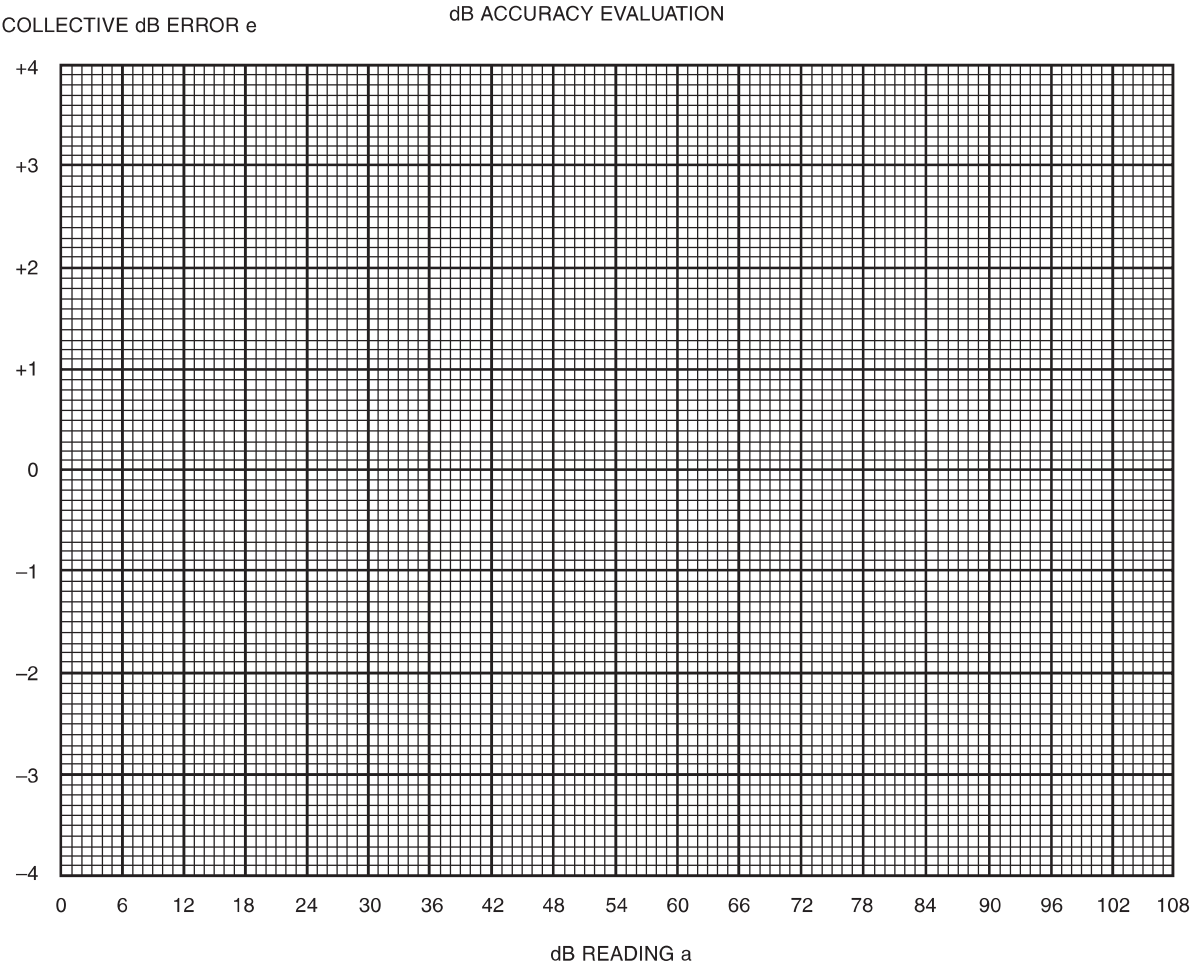
$$dB_2 = 20 \times \log (\%_2 \div \%_1) + dB_1$$

%₂ (Average) 78 %
 Total qualified range 12 dB to 78 dB = 66 dB
 Total qualified range 10 dB to 80 dB = 70 dB

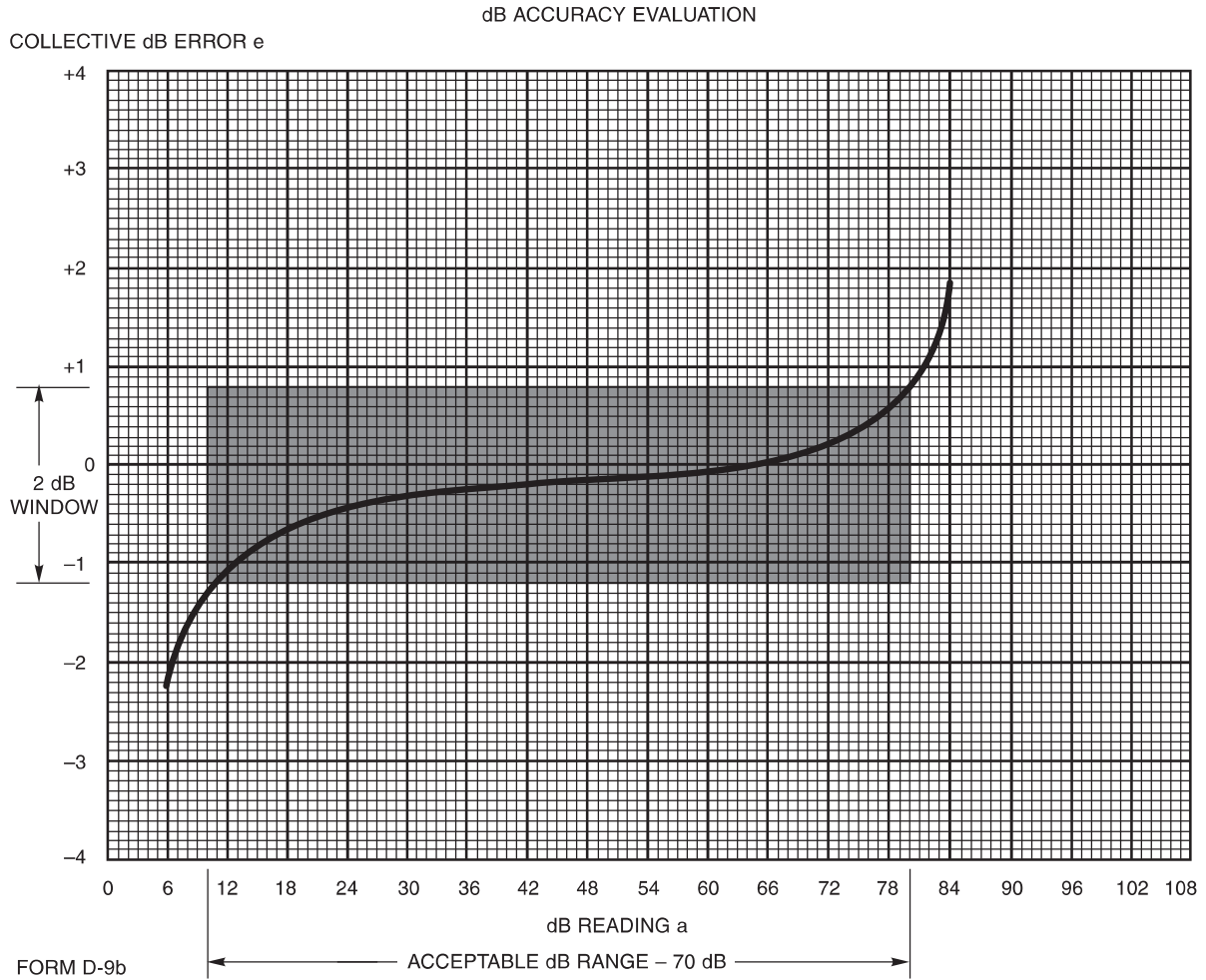
Total error 1.7 dB
 Total error 2.0 dB

FORM D-8b

Example of the Use of Form D-8a



FORM D-9a

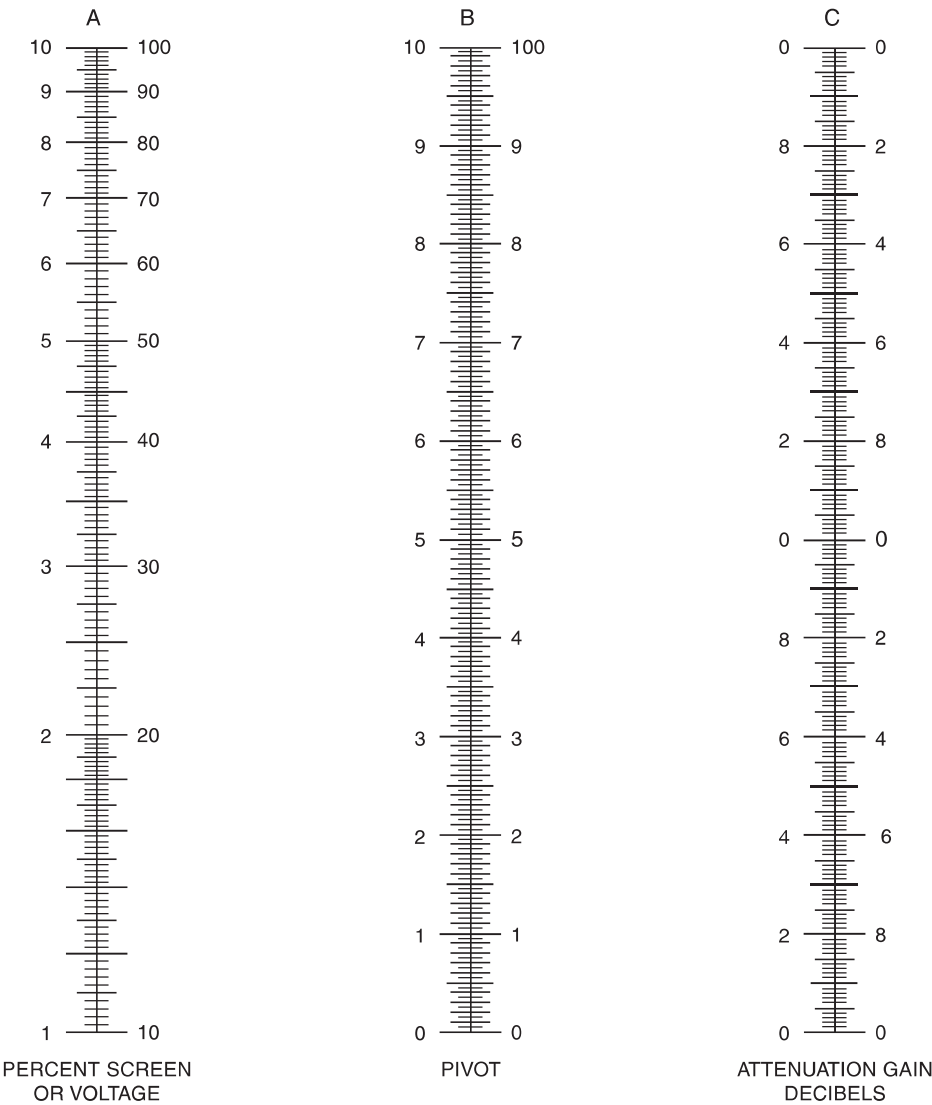


THE CURVE ON FORM D-9 EXAMPLE IS DERIVED FROM CALCULATIONS FROM FORM D-8 (FIGURE 10.1).
THE CROSS HATCHED AREA ON FIGURE 10.2 SHOWS THE AREA OVER WHICH THE EXAMPLE UNIT QUALIFIES TO THIS SPECIFICATION.

Note: The first line of example of the use of Form D-8 is shown in this example.

Example of the Use of Form D-9a

DECIBEL (ATTENUATION OR GAIN) VALUES NOMOGRAPH



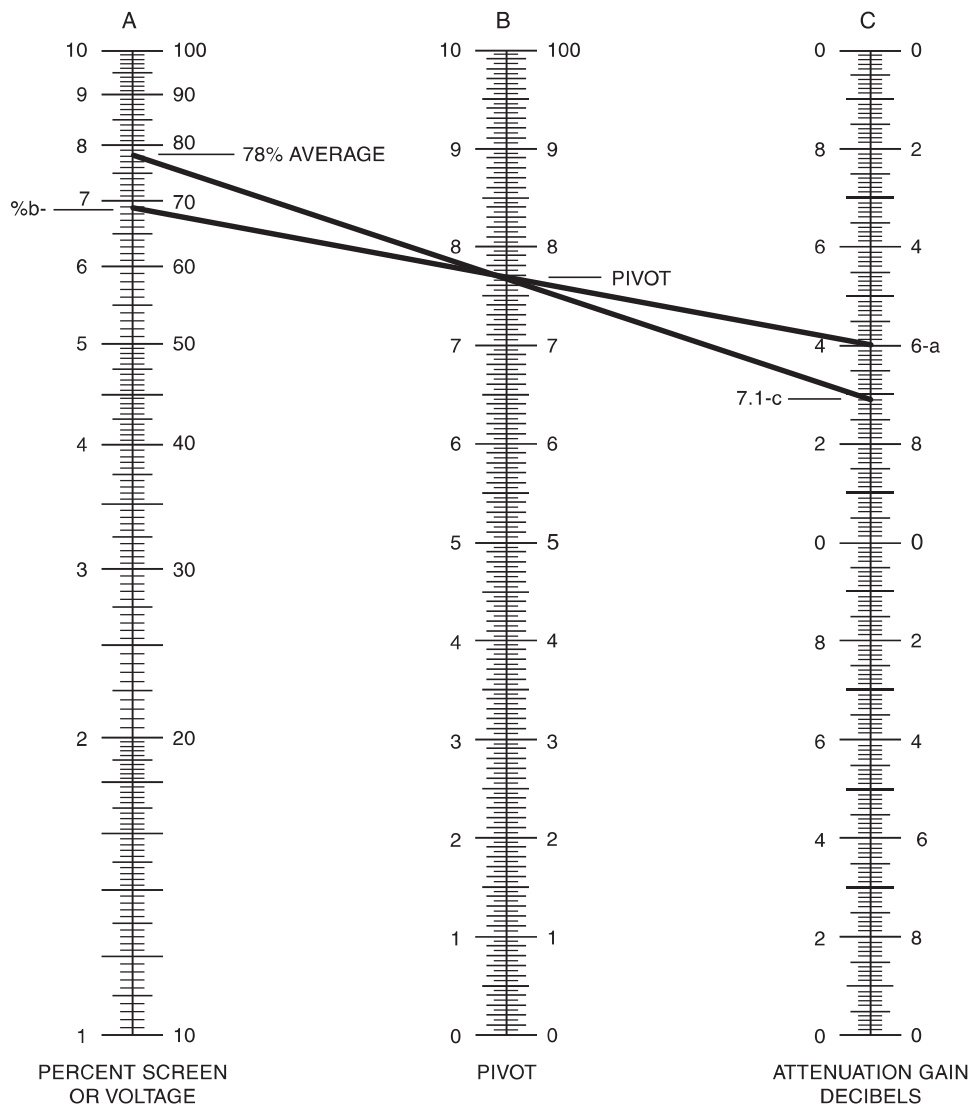
FORM D-10a

Notes:

1. The 6 dB reading and 67% scale are derived from the instrument reading and become dB "b₁" and %₁ "c," respectively.
2. %₂ is 80 – constant.
3. dB₂ (which is corrected dB "d") is equal to 20 times X log (80/67) + 6 or 7.54.

THE USE OF THE NOMOGRAPH IN RESOLVING LINE 3 IS AS SHOWN ON THE FOLLOWING EXAMPLE.

DECIBEL (ATTENUATION OR GAIN) VALUES NOMOGRAPH



THE CURVE ON FORM D-8 EXAMPLE IS DERIVED FROM CALCULATIONS FROM FORM D-8 EXAMPLE. THE CROSS HATCHED AREA ON FORM D-9 EXAMPLE SHOWS THE AREA OVER WHICH THE EXAMPLE UNIT QUALIFIES TO THIS SPECIFICATION.

FORM D-10b

Notes: Procedure for using the Nomograph:

1. Extend a straight line between the decibel reading from Column a applied to the C scale and the corresponding percentage from Column b applied to the A scale.
2. Use the point where the straight line from step 1 crosses the pivot line B as a pivot line for a second straight line.
3. Extend a second straight line from the average sign point on scale A, through the pivot point developed in step 2, and onto the dB scale C.
4. This point on the C scale is indicative of the corrected dB for use in Column C.

Example of the Use of Form D-10a

SAMPLE FORM FOR WELDING PROCEDURE QUALIFICATION TEST RECORD (PQR)
(For Carbon, Low Alloy, and Stainless Steel Sheet Metal)

Company name _____
 Procedure qualification test record no. _____ Date _____
 Welding procedure specification no. _____ Rev. _____ Date _____
 Welding process(es) _____ Type _____
 (Automatic, manual, etc.)
 Mode of transfer for GMAW _____
 (Short circuiting, spray, etc.)

JOINTS

Type of welded joint(s) _____

Backing ☐ Yes ☐ No

Backing material type _____

Groove welded from:

One side _____ Both sides _____

BASE METAL

Material specification type and grade:

Sheet steel _____ to _____

Thickness _____

Support steel _____ to _____

Thickness _____

Base metal preparation _____

POSITIONS

Position of groove _____

Position of fillet _____

Progression _____

GAS

Shielding gas _____ Flow rate _____

Percent mixture _____

FLUX

Filler metal (Table 5.1):

Specification _____

Classification _____

COATING(S)

Type _____

Thickness _____

VISUAL EXAMINATION RESULTS

Sketch of Joint Details

Specimen 1 _____

Specimen 2 _____

Diameter of arc spot nugget _____

Test conducted by _____

per _____

Lab test no. _____

Date of test _____

TECHNIQUE

Pass No.	Electrode Size	Electrical Characteristics		Travel Speed	Melting Rate	Wire Feed Speed
		Amperes	Volts			

Welder or welding operator name _____

Identification no. _____ Date of qualification _____

Welder's social security no. _____

The undersigned certifies that the statements in this record are correct and that the test welds were prepared, welded, and tested in accordance with the requirements of AWS D15.1: (_____) *Railroad Welding Specification for Cars and Locomotives.*
 (year)

Authorized by _____ Date _____

Form D-11

PROCEDURE QUALIFICATION RECORD (PQR) (For Aluminum and Aluminum Alloys)

Procedure qualification record no. _____ Date _____

WPS no. _____ Processes(es) 1. _____ 2. _____

1. _____ 2. _____

Design sketch

Welding sequence sketch

Base metals

Group no. _____ to _____

Alloy and temper _____ to _____

Thickness _____ to _____

Filler metals

F-number _____

AWS class _____

Diameter _____

Shielding gas(es) _____

Percent composition _____

Flow rate _____

Tungsten electrodes (STAW) _____

Size _____

Type _____

Backup type _____

Alloy _____

Backgouging _____

Pass No.	Process No.	Amps	Volts	Travel Speed

Type of welding power source _____

Single or multiple electrode _____

Stringer or weave bead _____

Welding current _____

Polarity _____ AC or DC

Position of groove _____

Cleaning procedure initial

Oxide removal method _____

Degreasing agent _____

Cleaning procedure interpass

Smut remover _____

Dye penetrant removal _____

Preheat

Preheat temperature _____

Interpass temperature _____

Postweld heat treatment

Original temper _____

Final temper _____

Temperature _____

Time _____

Quench _____

Form D-12A

PROCEDURE QUALIFICATION RECORD (PQR)
(For Aluminum and Aluminum Alloys)

GROOVE WELD TEST

Specimen No.	Width	Thickness	Area	Ultimate Tensile Load, lb	Ultimate Unit Stress, psi	Character of Failure and Location

GUIDED BEND TEST

Type of Bend	Bend Jig Figure No.	Result	Type of Bend	Bend Jig Figure No.	Result

Visual examination ☐ Pass ☐ Fail

Type and character of failure _____

FILLET WELD TEST

Fracture test ☐ Pass ☐ Fail

Root fusion ☐ Yes ☐ No

Macro test: Weld size and contour ☐ Sat. ☐ Unsat.

Penetration ☐ Sat. ☐ Unsat.

Welder's name _____

Clock no. _____ Stamp no. _____

Tests conducted by _____ Laboratory

Test number _____

Per _____

We certify that the statements in this record are correct and that the test welds were prepared, welded, and tested in accordance with the requirements of AWS D15.1: (_____) *Railroad Welding Specification for Cars and Locomotives.*
 (year)

Signed _____

Manufacturer

Date _____

By _____

Form D-12B

Title _____

**SAMPLE FORM FOR WELDING PROCEDURE SPECIFICATION (WPS)
(For Carbon, Low Alloy, and Stainless Steel Sheet Metal)**

Company name _____ By _____
 Welding procedure specification no. _____ Rev. _____ Date _____
 Supporting procedure qualification test record(s) no. _____
 Welding process(es) _____ Type _____
 (Automatic, manual, etc.)
 Mode of transfer for GMAW _____
 (Short circuiting, spray, etc.)

JOINTS

Type of welded joint(s) _____

Backing ☐ Yes ☐ No

Backing material type _____

Groove welded from:

One side _____ Both sides _____

BASE METAL

Material specification type and grade:

Sheet steel _____ to _____

Support steel _____

Thickness range:

Sheet steel _____

Support steel _____

Thickness _____

Base metal preparation _____

COATINGS

Type _____
 Thickness _____

Sketch of Joint Details

FILLER METAL

Specification _____

Classification _____

POSITIONS

Position of groove _____

Position of fillet _____

Progression _____

PREHEAT

Preheat temperature min. _____

Preheat temperature max. _____

GAS

Shielding gas _____ Flow rate _____

Percent mixture _____

Flow rate _____

FLUX**TECHNIQUE**

Pass No.	Electrode Size	Electrical Characteristics		Travel Speed	Melting Rate	Wire Feed Speed
		Amperes	Volts			

This procedure may vary due to fabrication sequence, fit-up, pass size, etc., within the limitation of variables given in AWS D15.1: (_____) *Railroad Welding Specification for Cars and Locomotives*.
 (year)

Authorized by _____ Date _____

Form D-13A

WELDING PROCEDURE SPECIFICATION (WPS) (For Aluminum and Aluminum Alloys)

Welding procedure

Specification no. _____ Date _____ Approved _____

Revisions _____ Date _____ Approved _____

Supporting PQR numbers _____

Joints**Groove Design Sketch**
Backing

Type _____

Permanent _____

Removed _____

Other _____

Base Metals

Group no. _____ Thickness _____ to _____

Alloy and Temper _____

Form D-13B (1)

Filler Metal

F-no. _____ AWS no. _____ AC or DC

Size of electrode _____

Type of electrode _____

Other _____

Shielding Gas

Shielding gas(es) _____

Percent composition _____

Flow rate _____

Other _____

Position

Position of groove _____

Welding progression _____

Other _____

Preheat

Preheat temperature _____

Interpass temperature _____

WELDING PROCEDURE SPECIFICATION (WPS) (For Aluminum and Aluminum Alloys)

Cleaning

Initial cleaning oxide _____

Initial cleaning oil and dirt _____

Interpass cleaning _____

Postweld heat treatment

Original temper _____

Final temper _____

Temperature _____

Time _____

Quench _____

Process(es)

Process _____ Type* _____

Process _____ Type* _____

Electrode (GTAW) _____

Technique

Stringer or weave bead _____

Orifice or gas cup size _____

Oscillation _____

Contact tube to work distance _____

Single pass or multipass _____

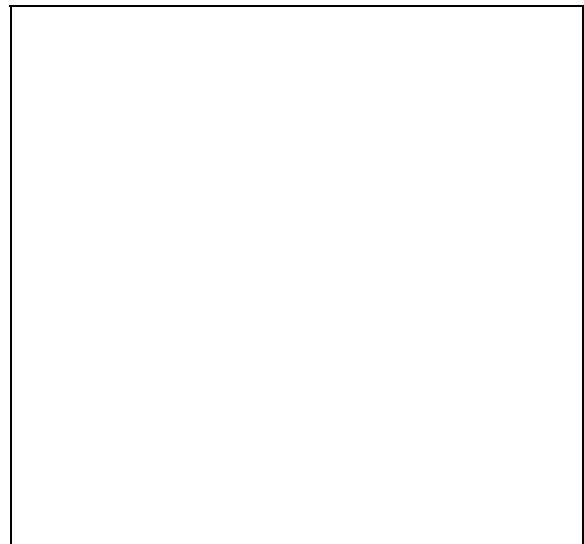
Tungsten extension _____ per side

Method of backgouging _____

Other _____

*Manual, automatic, polarity, pulse, etc.

Pass No.	Process No.	Amps	Volts	Travel Speed



Sketch of Welding Sequence

SAMPLE FORM FOR WELDER AND WELDING OPERATOR QUALIFICATION TEST RECORD
(For Carbon, Low Alloy, and Stainless Steel Sheet Metal)

Welder or welding operator's name _____

Identification no. _____ Qualification Date _____

Welder's social security no. _____

In accordance with WPS no. _____ Revision _____

Welding process(es) _____ Type _____

(Automatic, manual, etc.)

Mode of transfer for GMAW _____

(Short circuiting, spray, globular)

VARIABLE	ACTUAL VARIABLE USED IN QUAL.	QUALIFICATION RANGE
JOINT		
Joint type	_____	_____
Backing material type	_____	_____
Groove welded from:		
One side or both sides	_____	_____
BASE METAL		
Material specification:		
Sheet steel	_____ to _____	_____ to _____
Supporting steel	_____	_____
Sheet thickness:		
Groove	_____	_____
Fillet	_____	_____
Arc Spot	_____	_____
Arc Seam	_____	_____
COATING(S)		
Type	_____	_____
Thickness	_____	_____
POSITION		
Groove	_____	_____
Fillet	_____	_____
Arc Spot	_____	_____
Arc Seam	_____	_____
Progression	_____	_____
GAS		
ELECTRODE		
Size	_____	_____
Group Designation	_____	_____

VISUAL EXAMINATION RESULTS (6.7)

Specimen 1 _____ Specimen 2 _____

Appearance _____ Cracks _____ Undercut _____

Reinforcement _____ Diameter of arc spot nugget _____

Test conducted by _____ Per _____

Laboratory test no. _____ Date of test _____

The undersigned certifies that the statements in this record are correct and that the test welds were prepared and tested in accordance with the requirements of AWS D15.1: (_____) *Railroad Welding Specification for Cars and Locomotives.*

(year)

Company _____ Authorized by _____

Form D-14A

**MANUFACTURER'S RECORD QUALIFICATION TESTS
OF WELDER OR WELDING OPERATOR OR TACK WELDER
(For Aluminum and Aluminum Alloys)**

Name _____ Clock no. _____ Stamp no. _____ Retest _____
Welding process _____ Type _____
In accordance with welding procedure specification WPS no. _____ and PQR no. _____
Material group _____ to group _____ Alloy _____ to _____
Thickness of test material _____
Filler metal F-no. _____ AWS Class _____ Diameter _____
Other _____
Position _____ Backing material _____
(1G, 2G, 6G)
Electrical characteristics: Current _____ Polarity _____
Shielding gas _____ Flow _____

For Information Only

Power source _____
(Make, model, type)
Wire feeder _____
Welding torch _____

VISUAL INSPECTION

Appearance _____ Undercut _____ Piping porosity _____

GUIDED BENT TEST RESULTS

Type of Bend	Specimen Thick., in	Bend Jig Figure No.	Bend Diam., in	Result	Type of Bend	Specimen Thick., in	Bend Jig Figure No.	Bend Diam., in	Result

Radiographic results: Alternative qualification of groove welds by radiography in accordance with 5.7.3 _____

Test conducted by _____ Laboratory test no. _____
per _____

Fillet Test Results

Fracture test _____
(Describe the location, nature, and size of any crack or tearing of specimen)
Length and percent of defects _____ Inches _____ %
Appearance: Fillet size _____ Convexity or Concavity _____ in
Test conducted by _____ Laboratory test no. _____
per _____

We certify that the statements in this record are correct and that the test welds were prepared, welded, and tested in accordance with the requirements of AWS D15.1: (_____) *Railroad Welding Specification for Cars and Locomotives.*
(year)

Signed _____ By _____
(Organization)

Date _____ Title _____

Form D-14B

--	--

Reported to _____

Dye-penetrant type _____

[illegible][illegible]

Date _____

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Annex E (Informative)

Gage Thickness of Sheet Metal and Aluminum Filler Alloy Selection Guide

This annex is not part of AWS D15.1/D15.1M:2012, *Railroad Welding Specification for Cars and Locomotives*, but is included for informational purposes only.

The text and figures in Clauses 18 through 23 refer to the thickness of base metal in terms of inches [millimeters]. Fabricators may reference the thickness of sheet metal in terms of gage thickness. Tables E.1 and E.2 are standard conversions from sheet gage to thickness in inches for both steel and aluminum sheet.

Table E.3 is a summary of aluminum electrode/base metal information similar to that found in Volume 4, Seventh Edition of the *Welding Handbook* and in the annex of AWS A5.10/A5.10M, *Specification for Bare Aluminum and Aluminum Alloy Welding Electrodes and Rods*. It is reproduced here for the convenience of readers who do not have access to the other two sources.

Table E.1
Hot-Rolled and Cold-Rolled Sheet Metal

Manufacturer's Standard Gage Number	Thickness Equivalent in [mm]
3	0.2391 [6.07]
4	0.2242 [5.70]
5	0.2092 [5.31]
6	0.1943 [4.94]
7	0.1793 [4.55]
8	0.1644 [4.18]
9	0.1495 [3.80]
10	0.1345 [3.42]
11	0.1196 [3.04]
12	0.1046 [2.66]
13	0.0897 [2.28]
14	0.0747 [1.90]
15	0.0673 [1.71]
16	0.0598 [1.52]
17	0.0538 [1.37]
18	0.0478 [1.21]
19	0.0418 [1.06]
20	0.0359 [0.91]
21	0.0329 [0.84]
22	0.0299 [0.76]
23	0.0269 [0.68]
24	0.0239 [0.61]
25	0.0209 [0.53]
26	0.0179 [0.46]
27	0.0164 [0.41]
28	0.0149 [0.38]

Note: Table E.1 is for information only. This product is commonly specified to decimal thickness, not to gage number.

Table E.2
Galvanized Sheet Metal

Galvanized Sheet Gage Number	Thickness Equivalent in [mm]
8	0.1681 [4.27]
9	0.1532 [3.90]
10	0.1382 [3.51]
11	0.1233 [3.13]
12	0.1084 [2.75]
13	0.0934 [2.37]
14	0.0785 [1.99]
15	0.0710 [1.80]
16	0.0635 [1.61]
17	0.0575 [1.46]
18	0.0516 [1.31]
19	0.0456 [1.16]
20	0.0396 [1.01]
21	0.0366 [0.93]
22	0.0336 [0.85]
23	0.0306 [0.78]
24	0.0276 [0.70]
25	0.0247 [0.63]
26	0.0217 [0.55]
27	0.0202 [0.51]
28	0.0187 [0.47]
29	0.0172 [0.44]
30	0.0157 [0.40]
31	0.0142 [0.36]
32	0.0134 [0.34]

Note: Table E.2 is for information only. This product is commonly specified to decimal thickness, not to gage number.

Table E.3^{a, b}
Guide to the Choice of Filler Metal for General Purpose Welding of Aluminum

Base Metal	201.0 206.0 224.0	319.0, 333.0, 354.0, 355.0, C355.0	356.0, A356.0, 357.0, A357.0, 413.0, 443.0, A444.0	511.0, 512.0, 513.0, 514.0, 535.0	7004, 7005, 7039, 710.0, 712.0	6005, 6061, 6063, 6101, 6151, 6201, 6351, 6951	5456	5454
1060, 1070, 1080, 1350	ER4145	ER4145	ER4043 ^{e1, e2}	ER5356 ^{e3, e4}	ER5356 ^{e3, e4}	ER4043 ^{e2}	ER5356 ^{e4}	ER4043 ^{e2, e4}
1100, 3003, Alclad 3003	ER4145	ER4145	ER4043 ^{e1, e2}	ER5356 ^{e3, e4}	ER5356 ^{e3, e4}	ER4043 ^{e2}	ER5356 ^{e4}	ER4043 ^{e2, e4}
2014, 2036	ER4145 ^{e5}	ER4145 ^{e5}	ER4145	—	—	ER4145	—	—
2219	ER2319 ^{e1}	ER4145 ^{e5}	ER4145 ^{e2, e3}	ER4043 ^{e2}	ER4043	ER4043 ^{e1, e2}	—	ER4043 ^{e2}
3004, Alclad 3004	—	ER4043 ^{e2}	ER4043 ^{e2}	ER5356 ^{e6}	ER5356 ^{e6}	ER4043 ^{e2, e6}	ER5356 ^{e4}	ER5356 ^{e6}
5005, 5050	—	ER4043 ^{e2}	ER4043 ^{e2}	ER5356 ^{e6}	ER5356 ^{e6}	ER4043 ^{e2, e6}	ER5356 ^{e4}	ER5356 ^{e6}
5052, 5652i	—	ER4043 ^{e2}	ER4043 ^{e6}	ER5356 ^{e6}	ER5356 ^{e6}	ER4043 ^{e2}	ER5356 ^{e6}	ER5356 ^{e6}
5083	—	—	ER5356 ^{e3, e4}	ER5356 ^{e4}	ER5183 ^{e4}	—	ER5356 ^{e4}	ER5356 ^{e4}
5086	—	—	ER5356 ^{e3, e4}	ER5356 ^{e4}	ER5356 ^{e4}	—	ER5356 ^{e4}	ER5356 ^{e4}
5154, 5254i	—	—	ER4043 ^{e6}	ER5356 ^{e6}	ER5356 ^{e6}	—	ER5356 ^{e6}	ER5356 ^{e6}
5454	—	ER4043 ^{e2}	ER4043 ^{e6}	ER5356 ^{e6}	ER5356 ^{e6}	ER4043 ^{e2}	ER5356 ^{e6}	ER5356 ^{e6}
5456	—	—	ER5356 ^{e3, e4}	ER5356 ^{e4}	ER5556 ^{e4}	—	ER5356 ^{e4}	ER5556 ^{e4}
6005, 6061, 6063, 6101, 6151, 6201, 6351, 6951	ER4145	ER4145 ^{e2, e3}	ER4043 ^{e2, e6, e7}	ER5356 ^{e6}	ER5356 ^{e3, e6}	ER4043 ^{e1, e2, e7}	ER4043 ^{e2, e6, e7}	—
6009, 6010, 6070	ER4145	ER4145 ^{e2, e3}	ER4043 ^{e1, e2, e7}	ER4043	ER4043	ER4043 ^{e1, e2, e7}	—	—
7004, 7005, 7039, 710.0, 712.0	—	ER4043 ^{e2}	ER4043 ^{e2, e6}	ER5356 ^{e6}	ER5356 ^{e4}	—	—	—
511.0, 512.0, 513.0, 514.0, 535.0	—	—	ER4043 ^{e6}	ER5356 ^{e6}	—	—	—	—
356.0, A356.0, 357.0, A357.0, 413.0, 443.0, A444.0	ER4145	ER4145 ^{e2, e3}	ER4043 ^{e2, e8}	—	—	—	—	—
319.0, 333.0, 354.0, 355.0, C355.0	ER4145 ^{e5}	ER4145 ^{e2, e3, e8}	—	—	—	—	—	—
201.0, 206.0, 224.0	ER2319 ^{e1, e8}	—	—	—	—	—	—	—

(Continued)

Table E.3^{a, b} (Continued)
Guide to the Choice of Filler Metal for General Purpose Welding of Aluminum

Base Metal	5154 5254 ^{c9}	5086	5083	5052 5652 ^{c9}	5005 5050	3004 Alclad 3004	2219	2036 2014	1100 3003 Alclad 3003
1060, 1070, 1080, 1350	ER5356 ^{c3, c4}	ER5356 ^{c4}	ER5356 ^{c4}	ER4043 ^{c2, c4}	ER1100 ^{c2, c3}	ER4043 ^{c2, c4}	ER4145 ^{c2, c3}	ER4145	ER1100 ^{c2, c3}
1100, 3003, Alclad 3003	ER5356 ^{c3, c4}	ER5356 ^{c4}	ER5356 ^{c4}	ER4043 ^{c2, c4}	ER1100 ^{c2, c3}	ER4043 ^{c2, c4}	ER4145 ^{c2, c3}	ER4145	ER1100 ^{c2, c3}
2014, 2036	—	—	—	—	ER4145	ER4145	ER4145 ^{c5}	ER4145 ^{c5}	—
2219	ER4043	—	—	ER4043 ^{c2}	ER4043 ^{c1, c2}	ER4043 ^{c1, c2}	ER2319 ^{c1}	—	—
3004, Alclad 3004	ER5356 ^{c6}	ER5356 ^{c4}	ER5356 ^{c4}	ER5356 ^{c3, c6}	ER5356 ^{c6, c3}	ER5356 ^{c3, c6}	—	—	—
5005, 5050	ER5356 ^{c6}	ER5356 ^{c4}	ER5356 ^{c4}	ER5356 ^{c3, c4}	ER5356 ^{c3, c6}	—	—	—	—
5052, 5652 ^{c9}	ER5356 ^{c6}	ER5356 ^{c4}	ER5356 ^{c4}	ER5654 ^{c3, c6, c9}	—	—	—	—	—
5083	ER5356 ^{c4}	ER5356 ^{c4}	ER5183 ^{c4}	—	—	—	—	—	—
5086	ER5356 ^{c4}	ER5356 ^{c4}	—	—	—	—	—	—	—
5154, 5254 ^{c9}	ER5654 ^{c6, c9}	—	—	—	—	—	—	—	—

^a Service conditions such as immersion in fresh or salt water, exposure to specific chemicals, or a sustained high temperature (over 150°F [166°C]) may limit the choice of filler metals. Filler metals ER5183, ER5356, ER5556, and ER5654 are not recommended for sustained elevated temperature service.

^b Recommendations in this table apply to gas shielded arc welding processes. For oxyfuel gas welding, only ER1188, ER1100, ER4043, ER4047, and ER4145 filler metals are ordinarily used.

^c Where no filler metal is listed, the base metal combination is not recommended for welding.

1. ER4145 may be used for some applications.
2. ER4047 may be used for some applications.
3. ER4043 may be used for some applications.
4. ER5183, ER5356, or ER5556 may be used.
5. ER2319 may be used in some applications. It can supply high strength when the weldment is postweld solution heat related and aged.
6. ER5183, ER5356, ER5554, ER5556, and ER5654 may be used. In some cases, they provide:
 - (1) Improved color match after anodizing treatment
 - (2) Higher weld ductility
 - (3) Higher weld strength

ER5554 is suitable for sustained elevated temperature service.
 ER4643 will provide high strength in 1/2 in [13 mm] and thicker groove welds in 6XXX base alloys when postweld solution heat related and aged.

8. Filler metal with the same analysis as the base metal is sometimes used. The following wrought filler metals possess the same chemical composition as cast filler alloys: ER4009 and R4009 as R-C3550; ER4010 and R4010 as R-356.0; and R4011 as R-A356.0.

9. Base metal alloys 5254 and 5652 are used for hydrogen peroxide service. ER5654 filler metal is used for welding both alloys for service temperatures below 150°F [66°C].

10. ER1100 may be used for some applications.

Annex F (Informative)

Macroetch Procedures

This annex is not part of AWS D15.1/D15.1M:2012, *Railroad Welding Specification for Cars and Locomotives*, but is included for informational purposes only.

F1. General

This procedure provides recommendations for macroetching specimens in preparation for macro-examination. The surfaces to be etched should be smoothed by filing, machining, or by grinding on emery paper. With different alloys, the etching period will vary from a few seconds to several minutes and should be continued until there is a clear definition of the macrostructure. After etching, the specimens should be thoroughly rinsed and then dried with a blast of warm air. Coating the surface with a thin, clear lacquer will preserve the appearance.

F2. Safety Procedures

F2.1 Chemical Etchants. All chemicals used as etchants are potentially hazardous. All persons using any etchant shall be thoroughly familiar with all of the chemicals involved and the proper procedure for handling and mixing these chemicals.

F2.2 Handling and Mixing Acids. Precautions shall be used in mixing all chemicals, especially strong acids. In all cases, chemicals should be added slowly INTO the water or solvent while stirring. Never add water to acid.

F2.3 Hydrofluoric Acid, HF. Hydrofluoric acid solutions should be mixed and used in polyethylene vessels.

F2.4 Basic Recommendations for Handling of Etching Chemicals. Protective clothing and equipment (gloves, apron, protective glasses or face shield, etc.) should always be used when pouring, mixing, or etching.

- (1) Proper devices (glass or plastic) for weighing, mixing, containing, or storage of solutions should be used.
- (2) All etching should be done under a fume hood. All spills should be wiped up or flushed immediately.
- (3) Unidentified solutions SHOULD NOT be used. When in doubt, the solutions should be disposed of in accordance with the existing environmental laws covering the disposal of chemicals or chemical solutions.
- (4) Chemicals should be stored and handled according to manufacturer's recommendations, and users should read carefully and observe any printed precautions on chemical containers.
- (5) When in doubt about the proper use of a chemical, refer to the Material Safety Data Sheet for that chemical or contact your Safety Department or the supplier of the chemicals.

F2.5 Disposal of Etchants. Chemicals should be disposed of in accordance with federal, state, and local regulations.

F3. Etching Solutions and Procedures

CAUTION: Review F2 Safety Procedures for safe practices.

The following etching solutions, together with directions for their use, are suggested as applicable for the material being etched:

F3.1 Carbon and Low-Alloy Steels. Three etchants are suggested for use on carbon steel. These are listed below along with mixing and usage instructions.

(1) **Nitric Acid.** 1% to 10% nitric acid in water or alcohol (alcohol is preferred). The solution shall be used at room temperature and applied with a glass stirring rod.

(2) **Ammonium Persulfate.** One part of ammonium persulfate to nine parts of water by weight. The solution should be used at room temperature, and should be applied by vigorously rubbing the surface to be etched with a piece of cotton saturated with the solution.

(3) **Iodine and Potassium Iodide.** One part of powdered iodine, two parts of powdered potassium iodide, and ten parts of water, all by weight. The solution should be used at room temperature and applied by brushing.

F3.2 Stainless Steels. One etchant that is an effective macroetch for stainless steels is a ferric chloride, nitric acid, and water mixture. The solution contains:

Ferric chloride (FeCl_3)	200 g
Nitric acid (HNO_3)	300 ml
Water (H_2O)	100 ml

The solution should be used at room temperature and applied by swabbing.

F3.3 Aluminum and Aluminum Alloys. One etchant is suggested for use on metals of the aluminum family and their alloys. Its mix and use is provided below:

The following solution is to be used at room temperature. Etching is accomplished by either swabbing or immersing the specimen.

Hydrochloric acid (conc.)	15 ml
Hydrofluoric acid (conc.)	10 ml
Water	85 ml

F3.4 Copper and Copper Alloys. Concentrated nitric acid is recommended for etching the copper and copper-base alloys. The procedure for use is provided below:

Etching with the solution at room temperature is accomplished by either flooding or immersing the specimen for several seconds. After thorough rinsing with water, the process is repeated with a 50-50 solution of concentrated nitric acid and water. In the case of the silicon bronze alloys, it may be necessary to swab the surface with alcohol or water to remove a white (SiO_2) deposit.

F3.5 Nickel and Nickel-Base Alloys. Three etchants are suggested for use on nickel and nickel base alloys. These are listed below along with mixing and usage instructions.

F3.5.1 The following solution should be used on nickel, copper-nickel, nickel-chromium-iron, and nickel-copper material. The solution should be freshly mixed, and the specimen should be immersed for 30 seconds to 120 seconds. The solution is mixed as follows:

One part H_2O_2 (30%) hydrogen peroxide
Two parts HCl hydrochloric acid
Three parts H_2O water

F3.5.2 The following solution called Lepito's etch is suitable for use on nickel, nickel-chromium-iron, or on nickel-copper materials. It is applied by swabbing or immersion of the specimen. It is mixed as follows:

Solution #1—15 g of ammonium sulphate ($(\text{NH}_4)_2\text{SO}_4$) is dissolved in 100 ml of water
Solution #2—250 g of ferric chloride is dissolved in 100 ml of warm hydrochloric acid (concentrated)

Solution #1 and #2 are then mixed and, after mixing, 30 ml of nitric acid (concentrated) is added. The resulting solution is Lepito's etch.

F3.5.3 The following etchant is used on nickel-chromium-molybdenum, nickel-chromium-molybdenum-iron, and nickel-molybdenum alloys. The solution should be freshly mixed, and the reaction time may be decreased by heating the specimen. The specimen should be immersed for 30 seconds to 120 seconds. The solution contains the following:

- 1 part H₂O₂ (30%) hydrogen peroxide
- 4 parts HCl hydrochloric acid

F3.6 Titanium and Titanium Alloys. Two general purpose etchants are suggested for use on titanium and titanium alloys. These are the Kroll's and Keller's etches listed below. Both are applied at room temperature by swabbing or immersion of the specimen. The treatments are followed by a rinse in cold water.

(1) Kroll's Etch

Hydrofluoric acid (48%)	1 ml to 3 ml
Nitric acid (conc.)	2 ml to 6 ml
Water to make	100 ml

(2) Keller's Etch

Hydrofluoric acid (48%)	1/2 ml
Nitric acid (conc.)	2-1/2 ml
acid (conc.)	1-1/2 ml
Water to make	100 ml

F3.7 Zirconium and Zirconium Alloys. One etchant is suggested for use on the zirconium and zirconium alloy metals. The solution is shown below and is applied by either swabbing or immersion of the specimen.

Hydrofluoric acid (conc.)	3 ml
Nitric acid (conc.)	22 ml
Water	22 ml

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Annex G (Informative)

Guidelines for the Preparation of Technical Inquiries

This annex is not part of AWS D15.1/D15.1M:2012, *Railroad Welding Specification for Cars and Locomotives*, but is included for informational purposes only.

G1. Introduction

The American Welding Society (AWS) Board of Directors has adopted a policy whereby all official interpretations of AWS standards are handled in a formal manner. Under this policy, all interpretations are made by the committee that is responsible for the standard. Official communication concerning an interpretation is directed through the AWS staff member who works with that committee. The policy requires that all requests for an interpretation be submitted in writing. Such requests will be handled as expeditiously as possible, but due to the complexity of the work and the procedures that must be followed, some interpretations may require considerable time.

G2. Procedure

All inquiries shall be directed to:

Managing Director
Technical Services Division
American Welding Society
8669 Doral Blvd.
Doral, FL 33166

All inquiries shall contain the name, address, and affiliation of the inquirer, and they shall provide enough information for the committee to understand the point of concern in the inquiry. When the point is not clearly defined, the inquiry will be returned for clarification. For efficient handling, all inquiries should be typewritten and in the format specified below.

G2.1 Scope. Each inquiry shall address one single provision of the standard unless the point of the inquiry involves two or more interrelated provisions. The provision(s) shall be identified in the scope of the inquiry along with the edition of the standard that contains the provision(s) the inquirer is addressing.

G2.2 Purpose of the Inquiry. The purpose of the inquiry shall be stated in this portion of the inquiry. The purpose can be to obtain an interpretation of a standard's requirement or to request the revision of a particular provision in the standard.

G2.3 Content of the Inquiry. The inquiry should be concise, yet complete, to enable the committee to understand the point of the inquiry. Sketches should be used whenever appropriate, and all paragraphs, figures, and tables (or annex) that bear on the inquiry shall be cited. If the point of the inquiry is to obtain a revision of the standard, the inquiry shall provide technical justification for that revision.

G2.4 Proposed Reply. The inquirer should, as a proposed reply, state an interpretation of the provision that is the point of the inquiry or provide the wording for a proposed revision, if this is what the inquirer seeks.

G3. Interpretation of Provisions of the Standard

Interpretations of provisions of the standard are made by the relevant AWS technical committee. The secretary of the committee refers all inquiries to the chair of the particular subcommittee that has jurisdiction over the portion of the standard addressed by the inquiry. The subcommittee reviews the inquiry and the proposed reply to determine what the response to the inquiry should be. Following the subcommittee's development of the response, the inquiry and the response are presented to the entire committee for review and approval. Upon approval by the committee, the interpretation is an official interpretation of the Society, and the secretary transmits the response to the inquirer and to the *Welding Journal* for publication.

G4. Publication of Interpretations

All official interpretations will appear in the *Welding Journal* and will be posted on the AWS web site.

G5. Telephone Inquiries

Telephone inquiries to AWS Headquarters concerning AWS standards should be limited to questions of a general nature or to matters directly related to the use of the standard. The *AWS Board Policy Manual* requires that all AWS staff members respond to a telephone request for an official interpretation of any AWS standard with the information that such an interpretation can be obtained only through a written request. Headquarters staff cannot provide consulting services. However, the staff can refer a caller to any of those consultants whose names are on file at AWS Headquarters.

G6. AWS Technical Committees

The activities of AWS technical committees regarding interpretations are limited strictly to the interpretation of provisions of standards prepared by the committees or to consideration of revisions to existing provisions on the basis of new data or technology. Neither AWS staff nor the committees are in a position to offer interpretive or consulting services on (1) specific engineering problems, (2) requirements of standards applied to fabrications outside the scope of the document, or (3) points not specifically covered by the standard. In such cases, the inquirer should seek assistance from a competent engineer experienced in the particular field of interest.

List of AWS Documents on Railroad Welding

Designation	Title
D15.1/D15.1M	<i>Railroad Welding Specification for Cars and Locomotives</i>
D15.2/D15.2M	<i>Recommended Practices for the Welding of Rails and Related Components for Use by Rail Vehicles</i>

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