

AWS D1.2/D1.2M:2014
An American National Standard

Structural Welding Code— Aluminum



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AWS D1.2/D1.2M:2014
An American National Standard

Approved by the
American National Standards Institute
June 11, 2013

Structural Welding Code— Aluminum

Sixth Edition

Supersedes AWS D1.2/D1.2M:2008

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

Under the Direction of the
AWS Technical Activities Committee

Approved by the
AWS Board of Directors

Abstract

This code covers the welding requirements for any type structure made from aluminum structural alloys, except for aluminum pressure vessels and pressure piping. Clauses 1 through 8 constitute a body of rules for the regulation of welding in aluminum construction. A commentary on the code is also included with the document.



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ISBN: 978-0-87171-840-2
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Dedication

In Memoriam

Paul J. Sullivan
1926–2013

This issue of AWS D1.2, *Structural Welding Code—Aluminum*, is dedicated to the memory of Paul J. Sullivan. Among his many contributions to the American Welding Society, Paul was one of the charter members of the D1G Aluminum Subcommittee. He was a faithful member for many years and served as the Subcommittee Chairman for six years. Without Paul’s wisdom and guidance, the D1.2 Code would not be the document we have today. Paul’s intelligence, parliamentary knowledge, mentorship, and warm good humor will be missed by all of us.

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Foreword

This foreword is not part of AWS D1.2/D1.2M:2014, *Structural Welding Code—Aluminum*, but is included for informational purposes only.

In the early 1970s, interest was expressed in developing a consolidated code for the structural welding of aluminum similar to the AWS D1.1, *Structural Welding Code—Steel*. Because of the interest of both the Aluminum Association and the American Welding Society, it was decided to begin in the mid-70s the task of developing a structural welding code for aluminum. Initially, the effort was undertaken by a task force of the Aluminum Association. In 1979, this task force became a subcommittee of the AWS Structural Welding Committee and the *Structural Welding Code—Aluminum* resulted from the continued activity of that subcommittee.

The first edition of the *Structural Welding Code—Aluminum* (hereafter referred to as the *code*) represented the continuing AWS policy to provide standards for structural welding. This code is provided for the fabrication, erection, and manufacturing industries as a set of rules and regulations for the welding of structural aluminum. Some of the more important aspects of this edition of the code are outlined in the following paragraphs.

Recommended joint details have been prepared for numerous complete joint penetration groove welded joints. Herein lies one of the major differences between the *Structural Welding Code—Steel* and this code. While the steel code allows for prequalified welding procedures, this code does not. This is mainly because of the many and varied possible welding conditions that can be obtained with semiautomatic welding variables most often used with aluminum and the wide range of both heat-treatable and nonheat-treatable alloys that may be welded under this code. Therefore, all of the joint details and the welding procedures used with this code shall be individually qualified and included in the Welding Procedure Specification (WPS).

Procedures and standards are outlined for several methods of nondestructive testing. Methods included are visual, radiographic, and dye-penetrant. Ultrasonic testing is permitted, but the procedure and acceptance criteria shall be specified in the contract documents.

This code does not concern itself with such design considerations as the arrangements of parts, loading, and the computation of stresses for proportioning the load-carrying members of a structure and their connection. Such considerations, it is assumed, are covered elsewhere in a general code or specification, such as the *Specification for Aluminum Structures* (the Aluminum Association).

Many of the users of this code will also be users of the *Structural Welding Code—Steel*. As a result, it was felt that as much similarity as possible between the codes for steel and aluminum should be achieved. Thus, the same general format was used in the development of the 1983 and 1990 editions of the aluminum code as in the steel code. The D1.2-97 code was reorganized so that the 1990 Clauses 4 and 5 (Technique and Qualification) were merged into one new Clause 4. Furthermore, Appendix H of D1.2-90 was moved to after the Preface. Clauses 1 through 7 constitute a body of rules for the regulation of welding on aluminum structures. The 2003 edition represented a major reorganization of the D1.2-97 format. For example, Clauses 7, 8, and 9 of D1.2-97 were eliminated, and their provisions distributed throughout the code. The 2008 edition added design criteria and new alloys, revised inspection criteria, and included recommended PJP groove-welded joint details.

In this 6th edition, the following major revisions were made:

- (1) Responsibilities of the Engineer, Contractor, and Inspector were added.
- (2) Class I and Class II structure types were eliminated.
- (3) 5652 was deleted from D1.2 because the Aluminum Association deactivated the alloy.
- (4) A change from conventional to pulsed power supply is no longer an essential variable for WPS qualification.
- (5) GTAW current type (AC or DC) is now an essential variable for performance qualification.

- (6) A change in shielding gas is no longer an essential variable requiring welder requalification.
- (7) Requirements for the preparation of base metal were revised.
- (8) Base metal meeting ASTM B928 in alloys 5083, 5086, and 5456 was added.
- (9) A requirement to RT or UT the entire length of CJP groove welds welded from one side without backing and inaccessible for visual inspection of the back side was added.
- (10) The torque test for qualifying stud weld WPSs was eliminated.
- (11) Studs other than 5xxx series were deleted.
- (12) Minimum tensile strengths for studs were revised.
- (13) Friction stir welding was added.
- (14) The minimum size of reinforcing fillet welds in corner and tee joints was revised.
- (15) Deletion of Annex E—Effective Throat.
- (16) Annex J—Safe Practices. Safety clauses were updated including references to additional material; the safety annex was deleted.

A vertical line in the margin or underlined text in clauses, tables, or figures indicates an editorial or technical change from the 2008 edition.

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

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

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

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

Errata. It is the Structural Welding Committee's policy that all errata should be made available to users of the code. Therefore, any significant errata will be published in the Society News Section of the *AWS Welding Journal* and posted on the AWS web site at: <http://www.aws.org/technical/d1/>.

Suggestions. Your comments for improving AWS D1.2/D1.2M:2014, *Structural Welding Code—Aluminum*, are welcome. Submit comments to the Managing Director, Technical Services Division, American Welding Society, 8669 NW 36 St, # 130, Miami, FL 33166; telephone (305) 443-9353; fax (305) 443-5951; e-mail info@aws.org; or via the AWS web site <<http://www.aws.org>>.

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Structural Welding Code—Aluminum

1. General Requirements

1.1 Scope

This code contains requirements for fabricating and erecting welded aluminum structures. When this code is stipulated in contract documents, conformance with all requirements of this code is required except those that the Engineer (see 1.2.1) or contract documents modifies or exempts.

1.2 Definitions

The welding terms used in this code shall be as defined in AWS A3.0, *Standard Welding Terms and Definitions, Including Terms for Adhesive Bonding, Brazing, Soldering, Thermal Cutting, and Thermal Spraying*, supplemented by the following:

1.2.1 Engineer. “Engineer” is the entity who acts in behalf of the Owner on matters within the scope of this code.

1.2.2 Contractor. “Contractor” is the entity responsible for fabrication in conformance with this code.

1.2.3 Inspectors

1.2.3.1 Contractor’s Inspector. “Contractor’s Inspector” is the entity who acts for, and in behalf of, the Contractor on all inspection within the scope of the code and the contract documents.

1.2.3.2 Verification Inspector. “Verification Inspector” is the entity who acts in behalf of the Owner or Engineer on inspection specified by the Engineer.

1.2.3.3 Inspector (unmodified). When the unmodified term “Inspector” is used, it applies equally to the Contractor’s Inspector and the Verification Inspector.

1.2.4 OEM (Original Equipment Manufacturer). “OEM” is the single Contractor that assumes some or all of the responsibilities assigned by this code to the Engineer.

1.2.5 Owner. “Owner” is the entity that exercises legal ownership of the structure produced under this code.

1.2.6 Code Terms “Shall,” “Should,” and “May.” “Shall,” “should,” and “may” have the following meanings:

1.2.6.1 Shall. Code provisions that use “shall” are mandatory.

1.2.6.2 Should. Code provisions that use “should” are recommended but not mandatory.

1.2.6.3 May. The word “may” allows the use of requirements that are alternates to this code’s requirements. The Contractor may use alternate requirements provided in this code when the code does not require the Engineer’s approval.

1.3 Responsibilities

1.3.1 Engineer’s Responsibilities. The Engineer is responsible for the contract documents that govern structures produced under this code. The Engineer may add to, delete from, or otherwise modify the requirements of this code to meet the requirements of a specific structure. Requirements that modify this code shall be incorporated into the contract documents.

The Engineer shall specify the following in contract documents:

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

(2) Additional NDT that is not specifically addressed in this code.

(3) Verification inspection.

(4) Weld acceptance criteria other than that specified in Clause 5.

(5) Whether the structure is statically or cyclically loaded.

(6) Additional requirements that are not specifically addressed in the code.

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

1.3.2 Contractor's Responsibilities. The Contractor is responsible for the qualification, fabrication, and inspection required by this code and the contract documents.

1.3.3 Inspector's Responsibilities

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

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

1.4 Approval

All references to approval mean approval by the Authority Having Jurisdiction or the Engineer.

1.5 Welding Symbols

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

1.6 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 web site

Material or Equipment Manufacturers:

(1) Material Safety Data Sheets supplied by materials manufacturers

(2) Operating Manuals supplied by equipment manufacturers

Applicable Regulatory Agencies

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

1.7 Units of Measurement

This standard makes use of both U.S. Customary Units (US) 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.

1.8 Normative References

The standards listed below contain provisions, which, through reference in this text, constitute mandatory provisions of this code. 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 A3.0, *Standard Welding Terms and Definitions, Including Terms for Adhesive Bonding, Brazing, Soldering, Thermal Cutting, and Thermal Spraying*

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

¹AWS standards are published by the American Welding Society, 8669 NW 36 St, # 130, Miami, FL 33166.

AWS A5.12/A5.12M, Specification for Tungsten and Oxide-Dispersed Tungsten Electrodes for Arc Welding and Cutting

AWS A5.32/A5.32M, Welding Consumables— Gases and Gas Mixtures for Fusion Welding and Allied Processes

AWS B2.1, Specification for Welding Procedure and Performance Qualification

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

AWS QC1, Standard for AWS Certification of Welding Inspectors

Aluminum Association (AA) standard:²

AA Aluminum Design Manual Specification for Aluminum Structures

American Society of Mechanical Engineers (ASME) standards:³

ASME Boiler and Pressure Vessel Code, Section V, Nondestructive Examination

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

ASTM International (ASTM) standards:⁴

ASTM B26, Specification for Aluminum-Alloy Sand Castings

ASTM B108, Specification for Aluminum-Alloy Permanent Mold Castings

ASTM B209, Specification for Aluminum and Aluminum-Alloy Sheet and Plate

ASTM B210, Specification for Aluminum and Aluminum-Alloy Drawn Seamless Tubes

ASTM B211, Specification for Aluminum and Aluminum-Alloy Bar, Rod, and Wire

ASTM B221, Specification for Aluminum and Aluminum-Alloy Extruded Bars, Rods, Wire, Profiles, and Tubes

ASTM B241, Specification for Aluminum and Aluminum-Alloy Seamless Pipe and Seamless Extruded Tube

ASTM B247, Specification for Aluminum and Aluminum-Alloy Die Forgings, Hand Forgings, and Rolled Ring Forgings

ASTM B308, Specification for Aluminum-Alloy 6061-T6 Standard Structural Profiles

ASTM B313, Specification for Aluminum and Aluminum-Alloy Round Welded Tubes

ASTM B361, Specification for Factory-Made Wrought Aluminum and Aluminum-Alloy Welding Fittings

ASTM B429, Specification for Aluminum-Alloy Extruded Structural Pipe and Tube

ASTM B483, Specification for Aluminum and Aluminum-Alloy Drawn Tube and Pipe for General Purpose Applications

ASTM B557, Test Methods for Tension Testing Wrought and Cast Aluminum- and Magnesium-Alloy Products

ASTM B618, Specification for Aluminum-Alloy Investment Castings

ASTM B686, Specification for Aluminum Alloy Castings, High-Strength

ASTM B928, Specification for High Magnesium Aluminum-Alloy Sheet and Plate for Marine Service and Similar Environments

ASTM E94, Guide for Radiographic Examination

ASTM E165/E165M, Practice for Liquid Penetrant Examination for General Industry

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

ASTM E1032, Test Method for Radiographic Examination of Weldments

American Society for Nondestructive Testing (ASNT) standards:⁵

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

Canadian Standard Association (CSA) standard:⁶

CSA W178.2, Certification of Welding Inspectors

²AA standards are published by the Aluminum Association, 1525 Wilson Blvd., Suite 600, Arlington, VA 22209.

³ASME standards are published by the American Society of Mechanical Engineers, Three Park Avenue, New York, NY 10016.

⁴ASTM standards are published by ASTM International, 100 Barr Harbor Drive, West Conshohocken, PA 19428.

⁵ASNT standards are published by the American Society for Nondestructive Testing, 1711 Arlingate Lane, Columbus, OH 43228.

⁶CSA standards are published by the Canadian Standards Association, 5060 Spectrum Way, Mississauga, ON L4W 5N6.

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2. Design

2.1 Scope

This clause includes requirements for the design of welded connections. This code addresses two types of structures: (1) statically loaded structures, and (2) cyclically loaded structures, i.e., those structures subjected to cyclic loads of sufficient magnitude and frequency to cause the potential for fatigue failure.

2.2 Structural Design

Welds shall be sized for strength requirements using the effective areas defined in Clause 2 of this code in conformance with the *Aluminum Design Manual Specification for Aluminum Structures* unless otherwise required by the contract documents.

2.3 Drawings

2.3.1 Drawing Information. Complete information regarding location, type, size, and extent of all welds shall be shown on the drawings. The drawings shall distinguish between shop and field welds.

2.3.2 Joint Welding Sequence. Drawings of those joints or groups of joints in which it is especially important that the welding sequence and technique be carefully controlled to minimize shrinkage stresses and distortion shall be so noted.

2.3.3 Weld Size and Length. Design drawings shall specify the effective weld length and weld size. Shop drawings shall specify the groove depths, "S," applicable for the weld size, "(E)" specified on the design drawings, taking into account the WPS to be used.

2.3.4 Groove Welds. Drawings shall clearly indicate by welding symbols or sketches the details of groove welded joints and the preparation of material required to make them. Material, width, thickness, and contour of backing shall be shown.

2.3.4.1 Symbols. It is recommended that design drawings show CJP or PJP groove weld requirements without specifying the groove dimensions. The welding symbol without dimensions designates a CJP weld as follows:



The welding symbol with dimensions above or below the reference line designates a PJP weld, as follows:



where

E_2 = weld size, other side

E_1 = weld size, arrow side

2.3.4.2 Special Details. When special groove details are required, they shall be detailed on the drawings.

2.3.5 Special Inspection Requirements. Special inspection requirements shall be noted on the drawings or in the specification.

2.4 Groove Welds

2.4.1 Effective Weld Length. The effective weld length of a groove weld is the length of the weld perpendicular to the direction of tensile or compressive stress, and shall not exceed the width of the part joined. For groove welds transmitting shear, the effective length is the length specified.

2.4.2 Weld Size

2.4.2.1 CJP Groove Welds. The weld size of a CJP groove weld shall be the thickness of the thinner part joined.

2.4.2.2 PJP Groove Welds. The size of a PJP groove weld made with GMAW or GTAW regardless of the position of welding is the depth of preparation for V- and bevel-joints with an included angle greater than 45° and all U- and J-joints.

2.4.3 Effective Area. The effective area is the effective weld length multiplied by the weld size.

2.4.4 CJP. The following types of welds are CJP groove welds:

- (1) Groove welds welded from both sides with the root of the first weld backgouged to sound metal before welding the second side.
- (2) Groove welds welded from one side using permanent or temporary backing.
- (3) Groove welds without backing with root passes made from one side using GTAW (AC or DCEN).
- (4) Groove welds welded from one side using PAW-VP in the keyhole mode.

Recommended details of CJP groove welds in butt, corner, and T-joints are given in Annex B1.

2.4.5 PJP. Groove welds without backing welded from one side and groove welds welded from both sides but without backgouging are PJP groove welds, except as noted in 2.4.4.

Recommended details of PJP groove welds for butt, corner, and T-joints are given in Annex B2.

2.5 Fillet Welds

2.5.1 Effective Throat. The effective throat is the shortest distance from the joint root to the face of the diagrammatic weld.

2.5.2 Length

2.5.2.1 Effective Length (Straight). The effective length of a straight fillet weld is the overall length of the full-size fillet, including boxing. No reduction in effective length shall be required for the start or stop crater of the weld.

2.5.2.2 Effective Length (Curved). The effective length of a curved fillet is measured along the centerline of the effective throat. If the weld area of a fillet weld in a hole or slot calculated from this length is greater than the area calculated from 2.6.1, then this latter area shall be used as the effective area of the fillet.

2.5.2.3 Minimum Length. The minimum effective length of continuous and intermittent fillet welds shall be

at least four times its nominal size, or the effective weld size shall be 25% of the effective length.

2.5.3 Effective Area. The effective area is the effective weld length multiplied by the effective throat. Stress on a fillet weld shall be considered to be shear on this effective area for any direction of applied load.

2.5.4 Lap Joints

2.5.4.1 Double Fillet Welds. Unless lateral deflection of the parts is prevented, they shall be connected by at least two transverse lines of fillet, plug, or slot welds, or by two or more longitudinal fillet or slot welds.

2.5.4.2 Minimum Overlap. The minimum overlap of parts in stress-carrying lap joints shall be five times the thickness of the thinner part, but not less than 1 in [25 mm].

2.5.4.3 Fillet Welds in Holes or Slots. Minimum spacing and dimensions of holes or slots when fillet welding is used shall conform to 2.6. Fillet welds in holes or slots in lap joints may be used to transfer shear or to prevent buckling or separation of lapped parts. These fillet welds may overlap, subject to the requirements of 2.5.4.2. Fillet welds in holes or slots shall not be considered plug or slot welds.

2.5.4.4 Maximum Size for Lap Joints. The maximum fillet weld size for a lap joint detailed along edges of material shall be:

- (1) The thickness of the base metal, for metal less than 1/4 in [6 mm] thick.
- (2) 1/16 in [2 mm] less than the thickness of the base metal, for metal 1/4 in [6 mm] or more in thickness, unless the weld is designated on the drawing to be built out to obtain full throat thickness. The distance between the edge of the base metal and the toe of the weld may be less than 1/16 in [2 mm] provided the weld size is verifiable.

2.5.5 Fillets in Skewed T-Joints. Fillet welds may be used in skewed T-joints with a dihedral angle between 60° and 135°, inclusive (see Figure 2.1, Details A and B).

2.6 Plug and Slot Welds

2.6.1 Effective Area. The effective area is the nominal area of the hole or slot in the plane of the faying surface.

2.6.2 Fill Depth. The fill depth of plug or slot welds in metal 5/8 in [16 mm] thick or less shall be the thickness of the metal. In metal over 5/8 in [16 mm] in thickness, it shall be at least one-half the thickness of the metal, but not less than 5/8 in [16 mm] except for M27 alloys where the fill depth shall be the thickness of the metal.

2.6.3 Minimum Plug Hole Diameter. The minimum diameter of the hole for a plug weld shall be as described in Table 2.1.

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

2.6.5 Maximum Slot Length. The length of the slot for a slot weld shall not exceed ten times the thickness of the base metal.

2.6.6 Minimum Slot Width. The minimum width of the slot shall be as shown in Table 2.1.

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

2.6.8 Slot Ends. The ends of a slot shall be semicircular or shall have the corners rounded to a radius not less than the thickness of the part containing the slot, except those ends which extend to the edge of the part.

2.7 Filler Plates

2.7.1 Where Allowed. Filler plates may be used in:

(1) Welding parts of different thicknesses

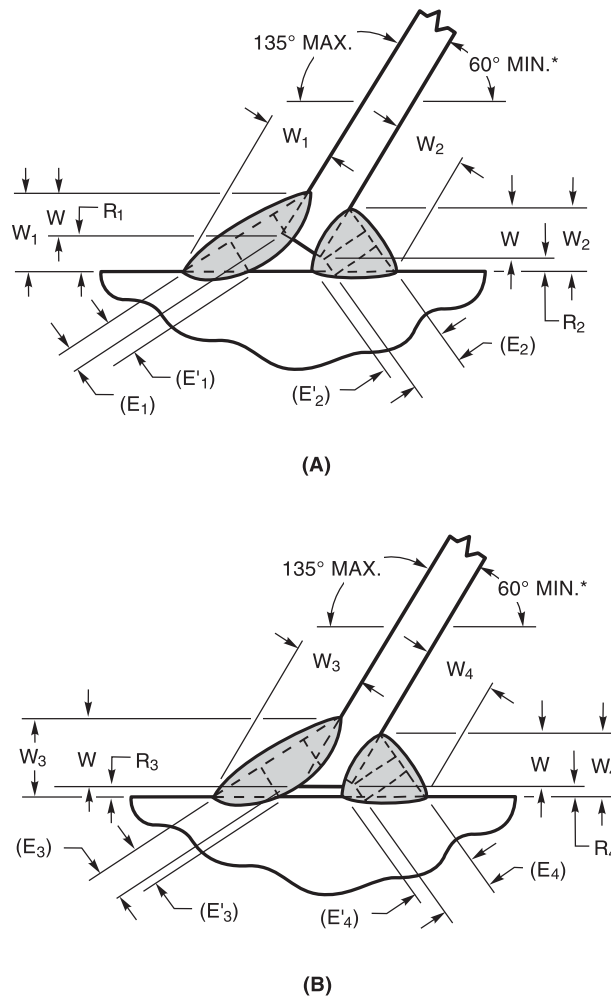
(2) Connections that, due to existing geometric alignment, accommodate offsets to allow simple framing

2.7.2 Filler Plates Less Than 1/4 in [6 mm] Thick (see Figure 2.2). Filler plates less than 1/4 in [6 mm] thick shall not be used to transfer stress and shall be kept flush with the welded edges of the stress-carrying part. The weld (2) size along such edges shall be increased over the size required for strength by an amount equal to the thickness of the filler plate.

2.7.3 Filler Plates 1/4 in [6 mm] Thick or Thicker (see Figure 2.3). Filler plates 1/4 in [6 mm] or more in thickness shall extend beyond the edges of the part carrying load across the joint. Such filler plates shall be welded (3) to the part on which they are fitted and this weld shall have sufficient strength to transmit the eccentric load. The welds (2) joining the part carrying load through the joint to the filler plate shall be sufficient to transmit the load on the parts being joined and long enough to avoid overstressing the filler plate.

Table 2.1
Minimum Diameter of Hole for Plug Welds or Width of Slot for Slot Welds
(see 2.6.3 and 2.6.6)

Material Thickness T	Minimum Hole Diameter or Slot Width
Less than 1/8 in [3 mm]	3T
1/8 in [3 mm] or greater	2.5T

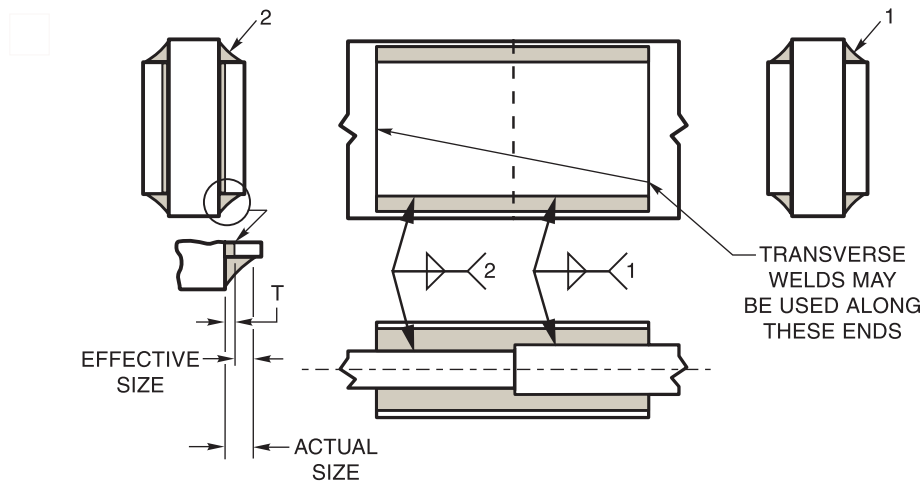


W'_n = fillet weld size if root opening $\leq 1/16$ in [2 mm]
 W_n = fillet weld size if root opening $> 1/16$ in [2 mm]
 E'_n = effective throat if root opening $\leq 1/16$ in [2 mm]
 E_n = effective throat if root opening $> 1/16$ in [2 mm]
 R_n = root opening

where $n = 1, 2, 3$, or 4

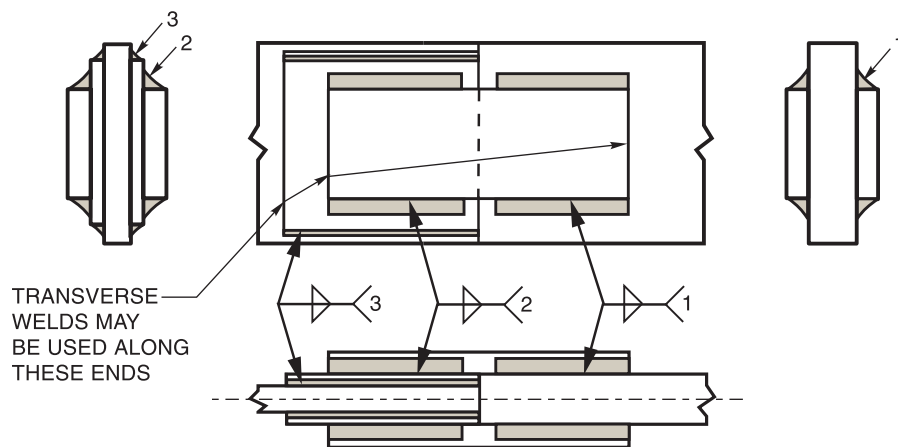
*Angles smaller than 60° are allowed; however, in such cases, the weld shall be considered to be a PJP groove weld.

Figure 2.1—Details of Skewed T-Joints (see 2.5.5)



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

Figure 2.2—Filler Plates Less Than 1/4 in [6 mm] in Thickness (see 2.7.2)



Notes:

1. The effective area of weld 2 shall equal that of weld 1. The length of weld 3 shall be sufficient to avoid overstressing the filler plate along the toe of the weld.
2. The effective area of weld 3 shall be 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 plates.

Figure 2.3—Filler Plates 1/4 in [6 mm] or More in Thickness (see 2.7.3)

3. Qualification

Part A *General Requirements*

3.1 General

The qualification requirement of this code is to assure that the fabrication procedures actually used in production meet a recognized standard with an objective of producing consistent product quality. To accomplish this objective, each Contractor, shall, prior to the start of production, perform the following:

(1) Qualify and record the essential variables for a PQR (Procedure Qualification Record) to be used to define a WPS (Welding Procedure Specification) in conformance with Part C of this clause using material, equipment, cleaning and preparation methods, welding conditions, etc., that will be contained in the WPS.

(2) Prepare a written WPS in conformance with 3.12.2 (see Annex E).

(3) Qualify the welders, welding operators and tack welders in conformance with Part D of this clause.

(4) Conduct the tests required by this code to qualify the WPSs and the welders, welding operators, and tack welders who will apply these WPSs.

(5) Certify and maintain records of all tests and WPSs on forms as shown in Annex E or similar, and make available such records to those authorized to examine them.

(6) Supply the written WPSs to all welders, welding operators, tack welders, and quality control personnel engaged in the work.

The Engineer may accept properly documented evidence of previous qualification of the WPSs to be employed as well as properly documented welder performance qualifications.

3.2 Qualification of WPSs

Only WPSs with previous qualifications accepted by the Engineer or qualified in conformance with Part C of this clause shall be recognized as approved WPSs. AWS B2.1-X-XXX Series on Standard Welding Procedure Specifications, may, in this manner, be accepted for use in conjunction with this code. When welding joints are made between two base metals that have different M numbers, a procedure qualification test shall be required for the applicable combination of M numbers, whether or not qualification tests have been made for each of the two base metals welded to themselves.

3.2.1 Base Metal Group Designations. Base metals are grouped to reduce the number of WPSs as follows:

Group Designation	Aluminum Association Alloy Classification
M21	1060, 1100, 3003, Alclad 3003, 5005, 5050
M22	3004, Alclad 3004, 5052, 5154, 5254, 5454, 5652
M23	6005, 6005A, 6061, Alclad 6061, 6063, 6082, 6351
M24	2219
M25	5083, 5086, 5456
M26	A201.0, 354.0, C355.0, 356.0, A356.0, 357.0, A357.0, 359.0, 443.0, A444.0, 514.0, 535.0
M27	7005

3.2.2 Filler Metal Group Designations. Filler metals are grouped to reduce the number of WPSs as follows:

Group Designation	AWS Filler Metal Classification
<u>F21</u>	<u>ER1100, ER1188, R1100, R1188</u>
<u>F22</u>	<u>ER5183, ER5356, ER5554, ER5556, ER5654, R5183, R5356, R5554, R5556, R5654</u>
<u>F23</u>	<u>ER4010, ER4043, ER4047, ER4145, ER4643, R4010, R4043, R4047, R4145, R4643</u>
<u>F24</u>	<u>ER4009, R206.0, R357.0, R-A356.0, R-A357.0, R4009, R-C355.0, R4011</u>
<u>F25</u>	<u>ER2319, R2319</u>

3.2.3 Unlisted Material. When an alloy not listed in Table 4.1 is approved under the provisions of the contract documents the WPS shall be qualified by the Contractor in conformance with Clause 3.

3.3 Qualification of Welders, Welding Operators, and Tack Welders

3.3.1 Welders, welding operators, and tack welders to be employed on work under this code shall be qualified in conformance with Part D of this clause, or other qualification as approved by the Engineer. Welders and welding operators qualified by standard test to AWS B2.1, *Standard for Welding Procedure and Performance Qualification*, may, in this manner, be accepted for use in this code.

3.3.2 The welder's, welding operator's, or tack welder's qualification, as specified in Clause 3, Part D, shall be considered as remaining in effect indefinitely unless (1) the person is not engaged in a given process of welding for which that person is qualified for a period exceeding six months, or (2) there is reason to question the individual's ability.

3.4 Position of Test Welds

3.4.1 Each WPS shall be qualified by positioning and welding the test assembly in the manner stated below and as shown in Figures 3.1 through 3.6 for the position for which it is to be qualified. These positions are classified as: (1) flat, (2) horizontal, (3) vertical, or (4) overhead in conformance with Figures 3.1 and 3.2.

3.4.1.1 Groove Welds—Plate (see Figure 3.3). In making the tests to qualify groove welds, test plates shall be welded in the following positions:

(1) Position 1G (Flat)—The test plates shall be placed in an approximately horizontal plane and the weld metal deposited from the upper side [see Figure 3.3(A)].

(2) Position 2G (Horizontal)—The test plates shall be placed in an approximately vertical plane with the groove approximately horizontal [see Figure 3.3(B)].

(3) Position 3G (Vertical)—The test plates shall be placed in an approximately vertical plane with the groove approximately vertical [see Figure 3.3(C)].

(4) Position 4G (Overhead)—The test plates shall be placed in an approximately horizontal plane and the weld metal deposited from the underside [see Figure 3.3(D)].

3.4.1.2 Groove Welds—Pipe (see Figure 3.4). The term *pipe* as used herein shall include all tubular shapes. In making the tests to qualify groove welds, the test pipe shall be welded in the following positions:

(1) Position 1G (Pipe Horizontal-Rotated)—The test pipe shall be placed with its axis approximately 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 3.4(A)].

(2) Position 2G (Pipe Vertical-Fixed)—The test pipe shall be placed with its axis approximately vertical and the groove approximately horizontal. The pipe shall not be rotated during welding [see Figure 3.4(B)].

(3) Position 5G (Pipe Horizontal-Fixed)—The test pipe shall be placed with its axis approximately horizontal and the groove approximately vertical. The pipes shall not be rotated during welding [see Figure 3.4(C)].

(4) Position 6G (Pipe Inclined-Fixed)—The test pipe shall be inclined at approximately 45° with the horizontal. The pipe shall not be rotated during welding [see Figure 3.4(D)].

3.4.1.3 Fillet Welds—Plate (see Figure 3.5). In making the tests to qualify welds on plate, test plates shall be welded in the positions outlined below:

(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 3.5(A)].

(2) Position 2F (Horizontal)—The test plates shall be so placed that each fillet weld is deposited on the upper side of a horizontal surface and against a vertical surface [see Figure 3.5(B)].

(3) Position 3F (Vertical)—The test plates shall be placed in approximately vertical planes, and each fillet weld deposited on vertical surfaces [see Figure 3.5(C)].

(4) Position 4F (Overhead)—The test plates shall be so placed that each fillet weld is deposited on the under side of a horizontal surface and against a vertical surface [see Figure 3.5(D)].

3.4.1.4 Fillet Welds—Pipe (see Figure 3.6). In making the tests to qualify fillet welds on pipe, the test pipe shall be welded in the positions outlined below:

(1) Position 1F (Pipe Inclined-Rotated)—The test pipe shall be placed with its axis at approximately 45° and rotated during welding so that the filler metal is deposited in the flat position [see Figure 3.6(A)].

(2) Position 2F (Pipe Vertical-Fixed)—The test pipe shall be placed with its axis approximately vertical. The filler metal shall be placed on the outer surface of the pipe at its juncture with the abutting plate or pipe. The assembly shall not be rotated during welding [see Figure 3.6(B)].

(3) Position 2FR (Pipe Horizontal-Rotated)—The test pipe shall be placed with its axis approximately horizontal and rotated during welding so that filler metal is deposited in the horizontal position [see Figure 3.6(C)].

(4) Position 4F (Overhead-Fixed)—The test pipe shall be placed with its axis approximately vertical. The filler metal shall be placed against the outer surface of the pipe at its juncture with the abutting plate or pipe. The assembly shall not be rotated during welding [see Figure 3.6(D)].

(5) Position 5F (Pipe Horizontal-Fixed)—The test pipe shall be placed with its axis approximately horizontal and with the welding joint vertical. The assembly shall not be rotated during welding [see Figure 3.6(E)].

Part B

Types of Tests, Test Methods, and Acceptance Criteria

3.5 Types and Purposes of Tests

The tests described in Part B (3.5 through 3.11) are intended to determine the strength or degree of soundness of welds made in conformance with the WPS or the soundness of welds made by a welder, welding operator, or tack welder.

The provisions of AWS B4.0, *Standard Methods for Mechanical Testing of Welds*, may be used for the testing of welds made for WPS or performance qualification. However, in instances where the provisions of AWS B4.0

and AWS D1.2/D1.2M are in conflict, AWS D1.2/D1.2M shall take precedence.

3.5.1 Visual examination is required for WPS qualification and performance qualification.

3.5.2 Mechanical Tests

3.5.2.1 Tension tests for strength of groove welds shall be required for WPS qualification.

3.5.2.2 Bend tests for soundness and ductility of groove welds are required for WPS qualification and performance qualification, except as allowed in 3.5.3.

3.5.2.3 Nick-break fracture tests are required to determine soundness of groove welds containing castings for WPS qualification as described in 3.9.1.

3.5.2.4 To determine the soundness of fillet welds for performance qualification, a fillet weld fracture test shall be required. For WPS qualification, a fracture test or a fillet weld bend test may be used to determine soundness.

3.5.3 RT may be used in lieu of bend tests for performance qualification of groove joints in wrought materials. The RT procedure technique and acceptance criteria shall be in conformance with the requirements of Clause 5, Part B and Part D, respectively, of this code.

3.6 Visual Examination

3.6.1 Examination Procedure. Visual inspection of the weld surface shall be performed on the test weldment prior to cutting any mechanical test specimens, except that macroetching of cut sections is included in the examination of fillet welds and PJP groove welds. Liquid penetrants, magnifying lenses, scales or templates may be used as aids in determining whether the sample weldment passes the criteria described in 3.6.2 or 3.6.3.

3.6.1.1 For detecting discontinuities that are open to the surface, PT may be used. The methods set forth in ASTM E165, *Standard Recommended Practice for Liquid Penetrant Inspection Method*, shall be used, and the standards of acceptance shall be in conformance with 5.14.

3.6.1.2 The macroetched specimen for the fillet weld test assembly or the PJP groove weld test assembly shall be taken from the end of the sample weldment. The macroetch specimens for fillet welded pipe or tubing welded assemblies shall be taken by sectioning longitudinally through the center of the pipe or tubing. One cut face of the specimen shall be smoothed and etched with a suitable etchant to give a clear definition of the weld metal and HAZ. Etching solutions, procedures, and safety requirements are given in Annex G.

3.6.2 Acceptance Criteria—Visual Examination—Groove Welds, Plate, and Pipe (see Figure 4.2). The visual examination of the test weldment shall satisfy the following acceptance criteria:

- (1) Both the face and root surfaces shall be free of cracks.
- (2) All craters shall be filled to the full cross section of the weld.
- (3) The edges of the weld shall blend smoothly with the base metal.
- (4) Undercut shall not exceed 0.01 in [0.25 mm].
- (5) The root shall show (a) complete fusion for CJP groove welds, or (b) penetration equal to or greater than the weld size specified for PJP groove welds.
- (6) The maximum melt-through on groove welds in pipe or tubing shall not exceed 1/8 in [3 mm].
- (7) The root concavity shall not exceed 1/16 in [2 mm].
- (8) Total weld thickness shall be equal to or greater than the thickness of the base metal, but the weld reinforcement shall not exceed the value listed in Figure 4.2(D) or (E).

3.6.3 Acceptance Criteria—Visual Examination of Fillet Welds on Plate or Pipe (see Figure 4.2). The visual examination of the test weldment shall satisfy the following acceptance criteria:

- (1) The surface of the weld shall be free from cracks.
- (2) All craters shall be filled to the full cross section of the weld.
- (3) The edges of the weld shall blend smoothly with the base metal.
- (4) Undercut shall not exceed 0.01 in [0.25 mm].
- (5) The leg lengths shall meet the requirements of the WPS.
- (6) The weld shall exhibit complete fusion in the root and to the base metal by the macroetch test.
- (7) Root surface concavity (suck-back) shall not exceed 1/32 in [1 mm].

3.7 Tension Tests—Groove Welds

3.7.1 Specimens. Tension test specimens shall conform to one of the types illustrated in Figure 3.7, 3.8, or 3.9.

3.7.1.1 Reduced Section Test Specimens—Plate. Reduced section specimens from plate conforming to the

requirements given in Figure 3.7 shall be used for tension tests on all thicknesses of plate.

(1) A single specimen of full plate thickness shall be used for thicknesses up to and including 1 in [25 mm].

(2) For plate thicknesses greater than 1 in [25 mm], single or multiple specimens may be used.

(3) When multiple specimens are necessary because of the limitations of the testing equipment, the entire thickness shall be cut mechanically into the minimum number of approximately equal slices of a thickness that can be tested in the available equipment. Each specimen (slice) shall be tested, and collectively, shall represent a single required tension test.

3.7.1.2 Reduced Section Test Specimens—Pipe

(1) For pipe having an outside diameter greater than 3 in [75 mm], reduced section specimens conforming to the requirements given in Figure 3.7 shall be used for tension tests on all thicknesses.

(a) A single specimen of the full thickness shall be used for thicknesses up to and including 1 in [25 mm].

(b) For thicknesses greater than 1 in [25 mm], single or multiple specimens may be used.

(c) When multiple specimens are necessary because of the limitations of the testing equipment, the entire thickness shall be cut mechanically into the minimum number of approximately equal sizes of a thickness that can be tested in the available equipment. Each specimen (slice) shall be tested, and collectively shall represent a single required tension test.

(2) For pipe having an outside diameter of 3 in [75 mm] or less, test specimens conforming to the requirements given in Figure 3.8 shall be used for tension tests.

3.7.1.3 Full-Section Pipe. For pipe having an outside diameter of 3 in [75 mm] or less, full-section specimens conforming to the requirements given in Figure 3.9 may be used for tension tests.

3.7.1.4 PJP Groove Welds—Plate and Pipe. For PJP groove welds in plate and pipe, the excess material on the root side of the joint shall be removed by machining to the thickness of the weld size.

3.7.2 Tension Test Procedure. Each tension test specimen shall be ruptured under tensile load, and the maximum load shall be determined. The tensile strength shall be computed by dividing the maximum load by the least cross-sectional area of the specimen as determined from measurements made before the load was applied.

3.7.3 Acceptance Criteria—Tension Tests—Plate and Pipe

3.7.3.1 The tensile strength shall be no less than the applicable requirement in Table 3.2. When multiple specimens are used, as allowed in 3.7.1.1 and 3.7.1.2, each specimen (slice) shall meet the applicable requirement.

3.7.3.2 If base metals of different tensile strengths are used, the specified minimum tensile strength of the lower strength base metal, as shown in Table 3.2, applies.

3.8 Bend Tests—Groove Welds—Plate and Pipe

3.8.1 Specimens. Bend specimens are of five types, depending on whether the axis of the weld is transverse or parallel to the longitudinal axis of the specimen and which surface (side, face, or root) is on the convex (outer) side of the bent specimen. Longitudinal bend specimens may be used in lieu of transverse bend specimens for testing combinations of base and filler materials which differ markedly in bending properties. Bend test specimens shall conform to one of the types shown in Figure 3.10, 3.11, or 3.12. The cut surfaces shall be designated the sides of the specimen. The original surfaces of the specimen shall be called the face and root surfaces, the face surface having the greater width of weld.

3.8.1.1 Transverse Side Bend Specimen. The weld is transverse to the longitudinal axis of the specimen which is bent so that the side surface with the larger discontinuity, if any, becomes the convex surface of the bent specimen. Transverse side bend specimens shall conform to the dimensions shown in Figure 3.10. Specimens of base-metal thickness greater than 1-1/2 in [40 mm] may be bent full width or cut into strips of approximately equal width. The weld root shall be contained in one of the test strips. Each specimen (strip) shall be tested and, collectively, shall represent a single, required bend test.

3.8.1.2 Transverse Face Bend Specimen. Transverse face bend test specimens shall conform to the dimensions shown in Figure 3.12 and are bent so that the face surface becomes the convex surface of the bent specimen. Pipe less than or equal to 4 in [100 mm] in diameter shall have face bend specimens prepared as described in 3.8.1.4.

3.8.1.3 Transverse Root Bend Specimen. Transverse root bend test specimens shall conform to the dimensions shown in Figure 3.12 and are bent so that the root surface becomes the convex surface of the bent specimen. Pipe less than or equal to 4 in [100 mm] in diameter shall have root bend specimens prepared as described in 3.8.1.4. For PJP groove welds, the specimen shall be machined

so that the thickness of the specimen equals the weld size.

3.8.1.4 Subsize Transverse Face and Root Bend Specimen. For pipe 4 in [100 mm] or less in outside diameter, the width of the specimen may be 3/4 in [20 mm], measured around the outside surface. Alternatively, for pipe less than 2-3/8 in [60 mm] in outside diameter, the width of the specimen may be that obtained by cutting the pipe into quarter sections, less the allowance for cutting. The other dimensions shall be as in Figure 3.12.

3.8.1.5 Longitudinal Face Bend Specimen. The weld is parallel to the longitudinal axis of the specimen which is bent so that the face surface becomes the convex surface of the bent specimen. Longitudinal face bend test specimens shall conform to the dimensions in Figure 3.11.

3.8.1.6 Longitudinal Root Bend Specimen. The weld is parallel to the longitudinal axis of the specimen which is bent so that the root surface becomes the convex surface of the bent specimen. Longitudinal root bend test specimens shall conform to the dimensions in Figure 3.11. For PJP groove welds, the specimen shall be machined so that the thickness of the specimen equals the weld size.

3.8.1.7 Special Bending Conditions—M23, M24, M27 Base Metals, and F23 Filler Metals. Welds on M23 base metals may be bend tested under either of two conditions, as-welded or annealed. In the as-welded condition, the 1/8 in [3 mm] specimen shall be bent over a diameter of 2-1/16 in [52 mm]. Specimens of less than 1/8 in [3 mm] shall be bent over a diameter of 16-1/2t. Annealed specimens of M23 shall be bent over a 6-2/3t diameter. Annealing practice: Hold 2–3 h at 775°F [410°C] and cool at 50°F/h [28°C/h] to 500°F [260°C]. The rate of cooling below 500°F [260°C] is unimportant.

Welds made with M24 material shall be annealed and bent over an 8t diameter.

Welds made with M27 material shall be bend tested within two weeks of welding.

Welds made with F23 filler metal on any M21, M22, or M23 base metal shall be bent in the same manner as M23 material.

3.8.2 Test Procedures—Bend Tests—Plate and Pipe. Bend test specimens shall be bent in a test jig that is in substantial conformance with Figure 3.13, 3.14, or 3.15.

3.8.2.1 Wraparound Jig. When a jig of the wrap-around type (see Figure 3.13) is used, the face surface of the specimen is turned toward the outer roller for face bend tests, the root surface for root bend tests, and the side with the larger discontinuity, if any, for side bend

tests. The specimen shall be wrapped around the center roller by a 180° movement of the outer roller.

3.8.2.2 Plunger Jig. When a plunger-type jig (see Figure 3.14 or 3.15) is used, the face surface of the specimen shall be turned toward the gap of the jig for face bend tests, the root surface for root bend tests, and the side with the larger discontinuity, if any, for side bend tests. The specimen shall be centered on the jig and forced into the gap by applying a load to the plunger. With jigs of the type in Figure 3.14, the final position of the specimen is such that a 1/8 in [3 mm] diameter wire cannot be inserted between the specimen and die. With jigs of the type in Figure 3.15, the specimen shall be ejected from the bottom.

3.8.2.3 Wide Specimens. Where specimens wider than 1-1/2 in [40 mm] are to be bent, the test jig mandrel shall be at least 1/4 in [6 mm] wider than the specimen.

3.8.3 Acceptance Criteria—Bend Tests—Pipe and Plate

3.8.3.1 The weld and HAZ of a transverse weld bend specimen shall be completely within the bent portion of the specimen after bending.

3.8.3.2 The convex surface of the bend test specimen shall be visually examined for surface discontinuities. For acceptance, the surface shall not contain any discontinuities exceeding the following dimensions:

- (1) 1/8 in [3 mm] measured in any direction on the surface.
- (2) 3/8 in [10 mm]—for the sum of the greatest dimensions of all discontinuities exceeding 1/32 in [1 mm], but less than or equal to 1/8 in [3 mm]. This is based on a 1-1/2 in [40 mm] specimen width. For other specimen widths, a proportional sum of the greatest dimensions shall apply.
- (3) 1/4 in [6 mm]—Maximum for a corner crack, except when that corner crack resulted from a visible inclusion or other fusion-type discontinuity, then the 1/8 in [3 mm] maximum shall apply.
- (4) Specimens with corner cracks exceeding 1/4 in [6 mm], with no evidence of inclusions or other fusion-type discontinuities, may be disregarded and a replacement test specimen from the original weldment shall be tested.

3.9 Soundness Tests—Groove Welds in Castings

3.9.1 Specimens. Nick-break fracture test specimens shall be removed from CJP groove welds of 3/16 in [5 mm]

and thicker. They shall conform to Figure 3.16. For plate welds the specimens shall be removed from locations specified for face bend specimens in Figure 3.20(A) or the center side bend specimens in Figure 3.19. For pipe welds, the specimens shall be removed adjacent to the tension specimens and 180° apart (see Figures 3.21, 3.22, 3.23, and 3.24).

The notched specimen shall be broken by fixing one leg of the specimen in a vise and applying a force to fracture the specimen in the notched area. The exposed edges of the fracture shall be visually examined.

3.9.2 Groove Weld Soundness—Acceptance Criteria. The fractured surface shall show complete fusion of the joint and shall exhibit no inclusion or porosity larger than 1/8 in [3 mm] in the greatest dimension for 1/4 in [6 mm] thickness and greater. Also the sum of the greatest dimensions of all inclusions and porosity shall not exceed 1/2 in [12 mm] in each 2 in [50 mm] segment. For material thinner than 1/4 in [6 mm] the fractured surface of the tension specimen shall be visually examined. The surface shall exhibit no discontinuity greater than one half the base-metal thickness and the sum of the greatest dimensions shall be proportionally less than allowed for the 1/4 in [6 mm] material.

3.10 Soundness Tests—Fillet Welds

3.10.1 Specimens

3.10.1.1 Option 1—Fillet Weld Fracture Test—Pipe and Plate. The dimensions and preparation of fillet weld test weldments shall conform to Figure 3.17 or 3.18. The test weldment for plate (see Figure 3.17) shall be cut to provide two 4 in [100 mm] center sections. The ends shall be retained for macroetch specimens. The test weldment for pipe (see Figure 3.18) shall be cut into eight sections, transverse to the welds.

3.10.1.2 Option 2—Fillet Weld Root Bend Test—Plate. The dimensions and preparation of the fillet weld test specimens shall conform to the requirements in Figure 3.19. The backing material and reinforcement shall be removed flush with the base metal.

All M23 materials and all materials welded with F23 filler metals shall have the face side removed to provide a 1/8 in [3 mm] thick bend specimen as shown in Figure 3.12 except as described in 3.8.1.7.

3.10.2 Fillet Weld Soundness—Test Procedures

3.10.2.1 Option 1—Fracture Test—Pipe and Plate. The specimen load shall be increased steadily or applied by repeated blows until it breaks or folds flat on itself.

3.10.2.2 Option 2—Root Bend Test—Plate. The specimen shall be loaded in such a way that the root of the weld becomes the convex surface of the bent specimen. The testing procedure for fillet weld root bend specimens shall be the same as for groove welds in 3.8.2.

3.10.3 Fillet Weld Soundness—Acceptance Criteria

3.10.3.1 Option 1—Fracture Test—Pipe and Plate. If the specimen folds flat on itself, the specimen shall have satisfactorily passed the test. If the specimen fractures, the broken surface shall be examined visually. To pass, it 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 the greatest dimension. The sum of the greatest dimensions of all inclusions and porosity shall not exceed 3/4 in [20 mm] in each 4 in [100 mm] segment.

3.10.3.2 Option 2—Root Bend Test—Plate. The specimen shall conform to the root bend criteria for groove welds (see 3.8.3.2).

3.11 Radiographic Examination

(RT shall be optional for performance qualification of groove welds.)

3.11.1 Examination Procedure. The RT procedure and technique shall conform to Clause 5, Part B. 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 [100 mm] in diameter or larger shall be examined for a minimum of one-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 [100 mm] in diameter shall require 100% RT.

3.11.2 Radiographic Examination—Acceptance Criteria. When the RT option is used for performance qualification, the acceptability shall be based on 5.15.1 and 5.15.2, as applicable.

Part C *WPS Qualification*

3.12 General

WPS qualification shall be conducted by the Contractor. The WPS qualification tests required in Part C are

devised to determine the strength and degree of soundness of welds made by a specific WPS. Results of these tests are used to establish proper welding variables and define the limitations of essential variables applicable to production welding under this code.

3.12.1 Procedure Qualification Record (PQR). The specific values of conditions involved in qualifying a WPS shall be recorded in a form called the Procedure Qualification Record (PQR). On this form shall be recorded the essential variables for the specific welding process (see Annex E for sample PQR).

3.12.2 WPS. The WPS shall list in detail the group numbers of the base metals to be joined, the filler metal(s) to be used, the range of preheat and postweld heat treatments, thicknesses, and other variables associated with the welding process (see Annex E for sample WPS).

3.12.3 Combination of WPSs. More than one WPS may be used in a single production joint, provided each WPS is qualified either separately or in combination with the other WPS(s) within the thickness limits in Table 3.4 or 3.5, as applicable, for each of the WPSs.

3.13 Limits of Qualified Positions for WPSs

To reduce the number of WPS qualifications that may be required, qualification in certain positions also qualifies for other conditions as described in Table 3.3.

3.14 Limitation of Essential Variables—WPS Qualification

Changes greater than the limits set in Table 3.1 shall be considered essential changes in a WPS (see Annex E) and shall require qualification of the altered WPS.

3.15 Tests—WPS Qualification

3.15.1 Groove Welds. The following are required tests for groove welds:

- (1) Visual examination (see 3.6).
- (2) Macroetch test for soundness and weld size in PJP groove welds (see 3.6.1.2).
- (3) Tension test for strength (see 3.7).
- (4) Bend test for soundness and ductility, except castings (see 3.8).

(5) When welding castings to other castings or wrought materials, the bend test for soundness and ductility of groove welds and fillet welds shall be omitted. A nick-break fracture test shall be conducted (see 3.9).

3.15.2 Fillet Welds. The following are required tests for fillet welds:

(1) Visual examination for weld surface quality and dimensions (see 3.6).

(2) Macroetch test for penetration and weld size (see 3.6.1.2).

(3) Fracture test for soundness or root bend test for soundness, except castings (see 3.10).

3.15.3 Plug and Slot Welds. Qualification of any groove or fillet weld procedure qualifies any WPS for making plug or slot welds.

3.15.4 Test Specimens—Number, Type, and Preparation. The type and number of specimens that shall be tested to qualify a WPS shall be found in the following tables:

(1) Table 3.4 (CJP)

(2) Table 3.5 (PJP)

(3) Table 3.6 (Fillet)

3.15.5 Location of Test Specimens for WPS Qualification. One sample weldment of sufficient size to obtain the number of test specimens required by Table 3.4, 3.5, or 3.6, as applicable, shall be prepared in conformance with the WPS.

3.15.5.1 Test Specimens—Groove Welds—Plate. The location of test specimens shall conform to Figure 3.20(A), 3.20(B), or 3.20(C). CJP groove welds made on plates 3/4 in [20 mm] or greater in thickness shall be tested using the test specimens in Figure 3.20(B). PJP groove welds shall be tested with the unfused side machined off to the depth of the effective weld size. For base metals and combinations of base and filler metals which differ significantly in ductility, test specimen coupons in Figure 3.20(C) shall be used.

3.15.5.2 PJP Groove Welds—Plate or Pipe. A sample weld shall be made using the type of groove design and WPS to be used in construction, except the depth of groove need not exceed 1 in [25 mm].

If the PJP groove weld is to be used for corner or T-joints, the butt joints shall have a temporary restrictive plate in the plane of the square face to simulate the T-joint configuration. The sample weld shall be tested as follows:

(1) When a WPS has been qualified for a CJP groove weld and is applied to the welding conditions of a PJP

groove weld, three macroetch cross section test specimens are required.

(2) If a WPS is not covered by (1), then a sample joint shall be prepared and a macroetch test specimen made to determine the weld size. Then the excess material is machined off the bottom side of the joint to the thickness of the weld size.

Tension and bend specimens shall be prepared and tests performed as required for CJP groove welds.

3.15.6 Test Specimens—Groove Welds—Pipe. The location of test specimens shall conform to Figure 3.21, 3.22, 3.23, or 3.24.

3.15.7 Test Specimens—Fillet Welds. The location of test specimens shall conform to 3.10.1 and Figure 3.17, 3.18, or 3.19.

3.15.8 Acceptance Criteria—Groove Welds

3.15.8.1 Visual examination shall conform to 3.6.2.

3.15.8.2 Tension test results shall conform to 3.7.3.

3.15.8.3 Bend test results shall conform to 3.8.3 (castings excluded).

3.15.8.4 Macroetch examination shall conform to 3.6.1.2. PJP groove welds shall equal or exceed the specified weld size.

3.15.8.5 Nick-break fracture tests of CJP groove welds in cast material shall conform to 3.9.2.

3.15.9 Acceptance Criteria—Fillet Welds

3.15.9.1 Visual examination shall conform to 3.6.3.

3.15.9.2 Fracture test results shall conform to 3.10.3.1. Fillet weld root bend test results shall conform to 3.10.3.2. Cast material (M26) shall be tested by the macroetch of the test specimen only.

3.15.9.3 Macroetch examination in conformance with 3.6.1.2 shall exhibit complete penetration to the root of the joint but not necessarily beyond.

3.16 Retests

If any one specimen of all those tested fails to meet the test requirements for qualification, two retests of that particular type of test specimen may be performed with specimens cut from the same test weldment, or from an additional weldment made following the WPS being qualified. Both retest specimens shall meet the test requirements for the WPS to be qualified.

Part D

Performance Qualification

3.17 General

The qualification tests described in Part D are specially devised to determine the ability of a welder, welding operator, or tack welder to produce sound welds in conformance with the WPS. These qualification tests are not intended as a guide for selecting the WPS to be used for welding during construction. The test welds shall be made in conformance with the requirements for the WPS.

Welders, welding operators, and tack welders should demonstrate knowledge of safe practices and the particular hazards of the welding process and the procedures to be used in construction.

3.17.1 Definitions. For purposes of this code the following shall apply:

(1) A *welder* is a person who uses a manual or semi-automatic process.

(2) A *welding operator* is a person who operates automatic equipment and program-guided systems, but has a degree of control over setting the values of the welding conditions. The welding operator may also adjust the path of the equipment along a weld joint.

(3) A *tack welder* is a person who, under the direction of a fitter, or as a fitter, tack welds an assembly in order to hold the parts together until the final welds are made.

3.17.2 Identification of Welders, Welding Operators, and Tack Welders. Each qualified welder, welding operator, and tack welder shall be assigned an identifying number, letter or symbol by the Contractor which shall be used to identify the work of that person.

3.17.3 Records of Tests. The essential variables of the performance qualification test and the test results obtained by each welder, welding operator, or tack welder shall be recorded on a Record of Performance Qualification Tests. A suggested form for these records is given in Annex E, Form E(c).

3.17.4 Special Positions. A Contractor who does production welding in a special orientation may make the tests for performance qualification in this specific orientation. Such qualifications are valid only for the positions actually tested, except that an angular deviation of $\pm 15^\circ$ is allowed in the inclination of the weld axis and the rotation of the weld face, as described in Figure 3.1. or 3.2.

3.17.5 A welder, welding operator, or tack welder who satisfactorily completes a test weldment that meets the criteria for WPS qualification in Part C of this clause shall be considered qualified to weld joints within the type and position limitations for the qualification test weld described in Table 3.7 and subject to the limitation of variables for welders, welding operators, or tack welders in 3.20, 3.21, or 3.22, as applicable.

3.17.6 Welders qualified to make groove or fillet welds shall also be qualified to make any plug or slot weld.

3.18 Limits of Qualified Positions for Performance

To reduce the number of welding performance qualifications that may be required, qualification under certain conditions shall also qualify for other conditions as shown in Table 3.7.

3.19 Preparation of Test Weldments—Performance Qualification

Test plate thickness and type of bend test required shall be determined from Table 3.8(1). These qualify the welder, welding operator, or tack welder for the range of plate thickness required to be welded on the job.

3.19.1 Welder, Welding Operator, and Tack Welder Groove Weld Qualification Plates. The following figure numbers apply to the position and thickness requirements for welders.

(1) Figure 3.25—Qualification in all positions; plate thickness $\leq 1/8$ in [3 mm].

(2) Figure 3.26—Qualification in all positions; plate thickness $> 1/8$ in [3 mm].

(3) Figure 3.27—Qualification in the horizontal position; plate thickness $> 1/8$ in [3 mm].

3.19.2 Alternative Groove Weld Qualification Test for Plate. Test plates shall be prepared and welded using the joint details and welding parameters of a qualified WPS. Each half of the test plate assembly shall have minimum dimensions of 5 in by 10 in [125 mm by 250 mm] with the groove preparation along the 10 in [250 mm] dimension (see Figure 3.28).

3.19.3 Groove Weld Qualification Test for Pipe or Tube, Including T-, Y-, or K-Connections. Grooves for performance qualification tests for pipe or tube shall be prepared and welded using the joint details and welding

parameters of a qualified pipe or tube WPS. The joint detail shall be either:

(1) That shown in a WPS for a single-welded pipe groove weld; or

(2) Single V-groove, 60° included angle, 1/16 in [2 mm] maximum root face (f) and root opening (R) without backing (see Figure 3.29 or 3.30). A pipe diameter and wall thickness shall be selected from Table 3.8(2), 3.8(3), or 3.8(4), as required, that will qualify the welder, welding operator, or tack welder for the class of structure, range of diameters and wall thickness to be welded in production; or

(3) A single V-groove, 60° included angle and suitable root face (f) and root opening (R) with backing (see Figure 3.31).

3.19.4 Fillet Weld Qualification Test or Tack Welder Qualification Test

3.19.4.1 Plate. Weld a fillet weld soundness test weldment in conformance with Table 3.8(1) and Figure 3.32.

3.19.4.2 Pipe. Weld a fillet weld soundness test weldment in conformance with Table 3.8(4) and Figure 3.33.

3.20 Essential Variables

Changes beyond the limitation of essential variable for welders, welding operators, or tack welders described in Table 3.9 shall require requalification.

3.21 Tests—Performance Qualification

3.21.1 Required Tests—Groove Welds. The following tests shall be required for performance qualification:

- (1) Visual examination for appearance and dimensions.
- (2) Bend test for soundness and ductility (except castings), or RT (see 3.21.6.1 or 3.21.6.3).
- (3) When welding a casting to other castings or wrought materials, the bend test for soundness and ductility of groove welds shall be omitted, and a macroetch test for soundness shall be conducted (see 3.21.6.4).

3.21.2 Required Tests—Fillet Welds. The following tests shall be required for performance qualification:

- (1) Visual examination for appearance and dimensions and macroetch test.
- (2) Fracture test for soundness (see 3.21.6.2).
- (3) Macroetch test for soundness of welded castings (see 3.21.6.4).

3.21.3 Test Specimens—Number, Type, and Preparation. The type and number of test specimens that shall be tested to qualify a welder, welding operator, or tack welder are shown in Table 3.8 together with the range of material thicknesses that are qualified for use in construction in relation to the thickness of the test material used in making the qualification. RT of the groove-weld test assembly may be used at the Contractor's option in lieu of mechanical testing.

3.21.4 Location of Test Specimens for Performance Qualification. One sample weldment shall be made for the type of weld qualification being tested. Test size of the sample weldment and location of the test specimens to be removed shall be in conformance with the figures associated with the type of weldment being tested (see Figures 3.25 through 3.33). The removal of test specimens from pipe shall be as shown in Figure 3.34.

3.21.5 Preparation of Test Specimens. The test specimens shall be prepared in conformance with Clause 3, Part B.

3.21.6 Test Procedures

3.21.6.1 Bend tests shall be made as described in 3.8.2.

3.21.6.2 Fillet Weld Fracture Test. The entire length of the fillet weld shall be examined visually; then, the 6 in [150 mm] long specimen shall be tested as described in 3.10.2 (see Figure 3.32).

3.21.6.3 RT procedure shall be as described in Clause 5, Part B.

3.21.6.4 Macroetch test procedure is described in 3.6.1.2.

3.21.7 Acceptance Criteria—Groove Welds. The following criteria shall be used to evaluate groove welds:

3.21.7.1 Visual examination criteria shall conform to 3.6.2.

3.21.7.2 Guided bend test results shall conform to 3.8.3.

3.21.7.3 RT evaluation shall conform to 3.11.2.

3.21.7.4 Macroetch test results shall conform to 3.9.2.

3.21.8 Acceptance Criteria—Fillet Welds

3.21.8.1 Visual examination criteria shall conform to 3.6.3. Penetration through metal 1/8 in [3 mm] and thinner may be accepted.

3.21.8.2 Fracture test results shall conform to 3.10.3.1.

3.22 Retests

3.22.1 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.

3.22.2 In case a welder, welding operator, or tack welder fails to meet the requirements of one or more weld tests, a retest may be performed under the following conditions:

3.22.2.1 An immediate retest may be made consisting of two test specimens of each type on which the welder, welding operator, or tack welder failed. All retest specimens shall meet all the specified requirements.

3.22.2.2 A complete performance qualification retest may be made at a later date for any failed qualification tests, provided there is evidence that the welder, welding operator, or tack welder has had further training or practice.

3.23 Period of Effectiveness

The welder's, welding operator's, or tack welder's qualification, as specified in this code (Clause 3, Part D), shall be considered as remaining in effect indefinitely unless (1) the welder, welding operator, or tack welder is not engaged in a given process of welding for which the welder, welding operator, or tack welder is qualified for a period exceeding six months, or (2) there is some specific reason to question the welder's, welding operator's, or tack welder's ability.

Table 3.1
Limitations of Essential Variables of a WPS^a (see 3.14)

Essential Variable (Changes outside these limits require requalification)	GMAW	GTAW	PAW-VP
Welding Process			
(1) A change in the welding process, e.g., from GMAW to GTAW	X	X	X
(2) A change in the mode of metal transfer	X		
Base-Metal Alloy			
(3) A change from one M-number group to another M-number group or to an alloy that does not have an M-number ^b	X	X	X
Base-Metal Thickness			
(4) A change in thickness beyond the limitations of the qualified range as shown in Table 3.4, 3.5, or 3.6, as applicable	X	X	X
Filler-Metal Alloy			
(5) A change from one F-number group to another F-number group or to an alloy that does not have an F-number ^c	X	X	X
Filler Metal			
(6) The addition or deletion of filler metal		X	X
(7) A change in the method by which filler metal is added		X	X
(8) An increase or decrease in the nominal filler metal diameter by:	> 1/64 in [0.4 mm]	> 1/16 in [2 mm]	> 1/64 in [0.4 mm]
Electrical Parameters			
(9) An increase or decrease in the specified amperage by:	>20%	>20%	>20%
(10) An increase or decrease in the specified voltage by:	>15%	>15%	>15%
(11) A change from ac to dc or vice versa	X	X	
(12) A change from DCEP to DCEN and vice versa		X	
Shielding			
(13) A change in shielding gas from a single gas to any other single gas or to a mixture of gases	X	X	X
(14) A change of 10% or more in the specified nominal percentage composition of a gas mixture	X	X	X
(15) An increase in the total flow rate	>50%	>50%	>50%
(16) A decrease in the total flow rate	>20%	>20%	>20%
Number of Weld Passes			
(17) For a specified groove area, a change >25% in the number of passes specified ^d	X	X	X
Welding Position			
(18) A change in position in which welding is done exceeding the limitations of Table 3.3	X	X	X
Direction of Welding			
(19) A change from forehand to backhand and vice versa except as stated in Table 4.4	X	X	X

(Continued)

Table 3.1 (Continued)
Limitations of Essential Variables of a WPS^a (see 3.14)

Essential Variable (Changes outside these limits require requalification)	GMAW	GTAW	PAW-VP
Direction of Welding (Cont'd)			
(20) Vertical welding: For any pass from upward to downward or vice versa	X	X	X
Groove Type			
(21) A change in the type of groove; except the qualification of a CJP groove weld qualifies any groove detail as shown in Annex B1 except for square groove joints	X	X	X
(22) A change in the type of groove to a square groove	X	X	X
Groove Dimension			
(23) A decrease in the nominal groove angle by:	>5°	>5°	>5°
(24) A change in the root opening (when backing is not used) by:	>1/16 in [2 mm]	>1/16 in [2 mm]	>1/16 in [2 mm]
(25) An increase in the root face (when not back gouged) by:	>1/16 in [2 mm]	>1/16 in [2 mm]	>1/16 in [2 mm]
Technique			
(26) A change from stringer-bead technique to a weave-bead technique (for heat-treatable materials only) ^e	X	X	X
(27) An increase or decrease in the specified travel speed by:	>20%	>25%	>25%
Cleaning			
(28) A change in the type of cleaning used (mechanical, chemical, etc.)			
(a) in initial joint preparation	X	X	X
(b) in interpass cleaning of weld beads	X	X	X
Backing			
(29) A change from permanent backing to temporary or no backing	X	X	X
Backgouging			
(30) Omission, but not inclusion of	X	X	X
Preheat			
(31) Increase from specified (heat-treatable alloy only) ^e by:	>100°F [55°C]	>100°F [55°C]	>100°F [55°C]
Interpass Temperature			
(32) Increase from specified maximum (heat-treatable alloys only) ^e by:	>100°F [55°C]	>100°F [55°C]	>100°F [55°C]

^a An "X" indicates applicability for the process; a shaded area indicates nonapplicability.

^b M-numbers are shown in 3.2.1.

^c F-numbers are shown in 3.2.2.

^d If the area of the groove is changed, the number of passes may be changed in proportion to the area.

^e M23, M24, M26, and M27 are heat-treatable alloys.

Table 3.2
Tensile Strength of Welded Aluminum Alloys (see 3.7.3.1)

Material No.	Alloy and Temper(s)	Product Form	Product Thickness in inches [mm]	Minimum Tensile Strength in ksi [MPa]
21	1060-0, H12, H14, H16, H18, H22, H24, H26, H28, H112, H113, F	Sheet & Plate	Up thru 3.000 [75]	8 [55]
		Extrusions	All	8.5 [60]
21	1100-0, H12, H14, H16, H18, H22, H24, H26, H28, H112, H113, F	All	Up thru 3.000 [75]	11 [75]
24	2219-T62, T81, T851, T8510, T8511, T87, 2219-T6, T852	All	Up thru 2.999 [75]	35 [240]
		Plate	3.000–6.000 [75–150]	35 [240]
		Forgings	3.000–4.000 [75–100]	35 [240]
21	3003-0, H12, H14, H16, H18, H22, H24, H26, H28, H112, H113, F	All	Up thru 3.000 [75]	14 [95]
21	Alclad 3003-0, H12, H14, H16, H18, H112, H113, F, H22, H24, H26	Tube	All	13 [90]
		Sheet & Plate	Up thru 0.499 [13]	13 [90]
		Plate	0.500–3.000 [13–75]	14 [95]
22	3004-0, H22, H24, H26, H28, H32, H34, H36, H38, H112, F	All	Up thru 3.000 [75]	22 [150]
22	Alclad 3004-0, H22, H24, H26, H32, H34, H36, H38, H112, F	Sheet & Plate	Up thru 0.499 [13]	21 [145]
		Plate	0.500–3.000 [13–75]	22 [150]
21	5005-0, H12, H14, H16, H18, H22, H24, H26, H32, H34, H36, H38, H112, F	All	Up thru 3.000 [75]	15 [105]
21	5050-0, H22, H24, H26, H32, H34, H36, H38, H112, F	All	Up thru 3.000 [75]	18 [125]
22	5052-0, H22, H24, H26, H28, H32, H34, H36, H38, H112, F	All	Up thru 3.000 [75]	25 [170]
25	5083-0, H111, H112, 5083-0, H111, H112, F	Forgings	Up thru 4.000 [100]	38 [260]
		Extrusions	Up thru 5.000 [125]	39 [270]
	5083-0, H112, H116, H321, F	Sheet & Plate	0.051–1.500 [1–38]	40 [275]
		Plate	1.501–3.000 [38–75]	39 [270]
	5083-0, F	Plate	3.001–5.000 [75–125]	38 [260]
			5.001–7.000 [125–175]	37 [255]
			7.001–8.000 [175–200]	36 [250]
25	5086-0, H32, H34, H36, H38, H111, H112, H116, F	All	Up thru 2.000 [50]	35 [240]
	5086-0, H111, H112, F	Extrusions Plate	2.001–5.000 [50–125] 2.001–3.000 [50–75]	35 [240] 34 [235]
22	5154-0, H22, H24, H26, H28, H32, H34, H36, H38, H112, F	All	Up thru 3.000 [75]	30 [205]
22	5254-0, H32, H34, H36, H38, H112, F	All	0.051–3.000 [1–75]	30 [205]
22	5454-0, H32, H34, H111, H112, F	All	Up thru 3.000 [75]	31 [215]

(Continued)

Table 3.2 (Continued)
Tensile Strength of Welded Aluminum Alloys (see 3.7.3.1)

Material No.	Alloy and Temper(s)	Product Form	Product Thickness in inches [mm]	Minimum Tensile Strength in ksi [MPa]
25	5456-0, H111, H112, F	Extrusions	Up thru 5.000 [125]	41 [285]
	5456-0, H112, H116, H321, F	Sheet & Plate	0.051–1.500 [1–38]	42 [285]
		Plate	1.501–3.000 [38–75]	41 [285]
	5456-0, H116, F	Plate	3.001–5.000 [75–125]	40 [270]
	5456-0, F	Plate	5.001–7.000 [125–175]	39 [270]
			7.001–8.000 [175–200]	38 [260]
23	6005-T5, 6005A-T61	Extrusions	Up thru 1.000 [25]	24 [165]
23	6061-T4, T42, T451, T51, T6, T62, T651	All	Up thru 3.000 [75]	24 [165]
	6061-T6, T62, T651	Plate & Forgings	3.001–4.000 [75–100]	24 [165]
	6061-T62, T651	Plate	4.001–6.000 [100–150]	24 [165]
	6061-T6	Forgings	4.001–8.000 [100–200]	24 [165]
23	Alclad 6061-T4, T42, T451, T6, T62, T651	Sheet & Plate	Up thru 3.000 [75]	24 [165]
	Alclad 6061-T62, T651	Plate	3.001–5.000 [75–125]	24 [165]
23	6063-T4, T42, T5, T52, T6, T62, T83, T831, T832	Extrusions	Up thru 1.000 [25]	17 [115]
23	6082-T6, T6511	Extrusions	0.200 to 6.000 [5 to 150]	28 [190]
23	6351-T4, T5, T51, T53, T54, T6	Extrusions	Up thru 1.000 [25]	24 [165]
27	7005-T53	Extrusions	0.125–1.000 [3–25]	40 [275]
26	A201.0-T7	Castings	All	Note a
26	354.0-T61, T62	Castings	All	Note a
26	C355.0-T6, T61	Castings	All	Note a
26	356.0-T6, T7, T71	Castings	All	Note a
26	A356.0-T6, T61	Castings	All	Note a
26	357.0-T6, T7	Castings	All	Note a
26	A357.0-T6, T61	Castings	All	Note a
26	359.0-T61, T62	Castings	All	Note a
26	443.0-F	Castings	All	Note a
26	A444.0-T4	Castings	All	Note a
26	514.0-F	Castings	All	Note a
26	535.0-F	Castings	All	Note a

^a Minimum as-welded tensile strength has not been established for this alloy. The tensile properties must be established by WPS qualification and approved by the Engineer.

Table 3.3
WPS Qualification—Type of Weld and Position Limitations (see 3.13)

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

^a Qualifies for welding pipe or tubing over 24 in [610 mm] in diameter.

^b Qualifies for T-, Y-, and K-connections and for CJP groove welds in all positions.

^c See Figures 3.3, 3.4, 3.5, and 3.6.

^d Also qualifies WPSs for plug and slot welds.

Table 3.4
Number and Type of Test Specimens and Range of Thickness Qualified—
WPS Qualification—CJP Groove Welds [see 3.15.4(1)]
(Dimensions in Inches)

1. Tests on Plate

Nominal Plate Thickness (T) Tested, in	Number of Sample Welds per Position	Visual Inspection (see 3.6)	Number of Specimens Required				Nominal Plate Thickness Qualified, in
			Reduced Section Tension (see Fig. 3.7)	Root Bend (see Figures 3.11, 3.12)	Face Bend (see Figures 3.11, 3.12)	Side Bend (see Figure 3.10)	
T < 1/8	1 ^a	Yes	2	2	2	—	T to 2T
1/8 ≤ T ≤ 3/8	1	Yes	2	2	2	—	1/8 to 2T
Over 3/8 and under 1	1	Yes	2	—	—	4	T/2 to 2T
1 and over	1	Yes	2	—	—	4	T/2 to unlimited

2. Tests on Statically Loaded Tubular Structures

Weld Type	Pipe or Tube Size of Sample Weld			Number of Specimens Required					Min.	Max.	Min.	Max.
	Nominal Diam., in	Nominal Wall Thickness, T, of Wrought, in	Number of Sample Welds per Position	Visual Inspection (see 3.6)	Nick-Break Fracture Test (see Fig. 3.16)	Tension Test (see Figs. 3.7, 3.8, 3.9)	Root Bend (see Fig. 3.12)	Face Bend (see Fig. 3.12)				
Wrought to Wrought	6 through 8	1/8–3/8	1	Yes	—	2	2	2	3/4	16	1/8	2T
Cast to Wrought or Cast to Cast	3 through 5	3/16	1	Yes	2	2	—	—	2	16	1/8	1/2

3. Tests on Cyclically Loaded Tubular Structures

Nomi- nal Diam.	Pipe Size of Sample Weld		Number of Sample Welds per Position	Visual Inspection (see 3.6)	Number of Specimens Required				Diam.	Min.	Max.
	Nominal Wall Thickness, T				Tension Test (see Figs. 3.7, 3.8, 3.9)	Root Bend (see Fig. 3.12)	Face Bend (see Fig. 3.12)	Side Bend (see Fig. 3.10)			
2 in	Sch. 80	2	Yes	2	2	2	—	3/4	1/8	1/2	
3 in	Sch. 40							through 4			
6 in	Sch. 120	1	Yes	2	—	—	4	4	0.187	Un-	
8 in	Sch. 80							and over		limited	

(Continued)

Table 3.4 (Continued)
Number and Type of Test Specimens and Range of Thickness Qualified—
WPS Qualification—CJP Groove Welds [see 3.15.4(1)]
(Dimensions in Inches)

3. Tests on Cyclically Loaded Tubular Structures (Continued)

Nomi- nal Diam.	Pipe Size of Sample Weld	Number of Sample Welds per Position	Visual Inspection (see 3.6)	Number of Specimens Required				Diam.	Min.	Max.
	Nominal Wall Thickness, T			Reduced Section Tension (see Figs. 3.7, 3.8, 3.9)	Root Bend (see Fig. 3.12)	Face Bend (see Fig. 3.12)	Side Bend (see Fig. 3.10)			
Job Size Pipe or Tubing										
<24 in	T < 1/8	1 ^a	Yes	2	2	2	—	Test diam. & over	T	2T
	1/8 ≤ T ≤ 3/8 in	1 ^a	Yes	2	2	2	—	Test diam. & over	1/8	2T
	3/8 < T < 3/4 in	1 ^a	Yes	2	—	—	4	Test diam. & over	T/2	2T
	T ≥ 3/4 in	1 ^a	Yes	2	—	—	4	Test diam. & over	T/2	2T
≥24 in	1/8 ≤ T ≤ 3/8 in	1	Yes	2	2	2	—	Test diam. & over	1/8	2T
	3/8 < T < 3/4 in	1	Yes	2	—	—	4	24 & over	T/2	2T
	T ≥ 3/4 in	1	Yes	2	—	—	4	24 & over	0.375	Un- limited

^a Adequate number of test welds per position must be made to obtain required test specimens.

Table 3.4 (Continued)
Number and Type of Test Specimens and Range of Thickness Qualified—
WPS Qualification—CJP Groove Welds [see 3.15.4(1)]
(Dimensions in Millimeters)

1. Tests on Plate

Nominal Plate Thickness (T) Tested, mm	Number of Sample Welds per Position	Visual Inspection (see 3.6)	Number of Specimens Required				Nominal Plate Thickness Qualified, mm
			Reduced Section Tension (see Fig. 3.7)	Root Bend (see Figures 3.11, 3.12)	Face Bend (see Figures 3.11, 3.12)	Side Bend (see Figure 3.10)	
T < 3	1 ^a	Yes	2	2	2	—	T to 2T
3 ≤ T ≤ 10	1	Yes	2	2	2	—	3 to 2T
Over 10 and under 25	1	Yes	2	—	—	4	T/2 to 2T
25 and over	1	Yes	2	—	—	4	T/2 to unlimited

2. Tests on Statically Loaded Tubular Structures

Weld Type	Pipe or Tube Size of Sample Weld		Number of Specimens Required							Min.	Max.	Min.	Max.
	Nominal Diam., mm	Nominal Wall Thickness, T, of Wrought, mm	Number of Sample Welds per Position	Visual Inspection (see 3.6)	Nick-Break Fracture Test (see Fig. 3.16)	Reduced Section Tension (see Figs. 3.7, 3.8, 3.9)	Root Bend (see Fig. 3.12)	Face Bend (see Fig. 3.12)					
Wrought to Wrought	150 through 200	3–10	1	Yes	—	2	2	2	19	410	3	2T	
Cast to Wrought or Cast to Cast	75 through 130	5	1	Yes	2	2	—	—	50	410	3	13	

3. Tests on Cyclically Loaded Tubular Structures

Nominal Diam.	Pipe Size of Sample Weld		Number of Sample Welds per Position	Visual Inspection (see 3.6)	Number of Specimens Required				Diam.	Min.	Max.
	Nominal Thickness, T, mm	Wall			Reduced Section Tension (see Figs. 3.7, 3.8, 3.9)	Root Bend (see Fig. 3.12)	Face Bend (see Fig. 3.12)	Side Bend (see Fig. 3.10)			
50 or 75	5.5		2	Yes	2	2	2	—	19 through 100	3	13
150 or 200	14.3 or 12.7		1	Yes	2	—	—	4	100 and over	5	Un-limited

(Continued)

Table 3.4 (Continued)
Number and Type of Test Specimens and Range of Thickness Qualified—
WPS Qualification—CJP Groove Welds [see 3.15.4(1)]
(Dimensions in Millimeters)

3. Tests on Cyclically Loaded Tubular Structures (Continued)

Nominal Diam.	Pipe Size of Sample Weld	Number of Sample Welds per Position	Visual Inspection (see 3.6)	Number of Specimens Required				Nominal Pipe or Tubing Diameter Qualified, mm Diam.	Min.	Max.
	Nominal Wall Thickness, T			Reduced Section Tension (see Figs. 3.7, 3.8, 3.9)	Root Bend (see Fig. 3.12)	Face Bend (see Fig. 3.12)	Side Bend (see Fig. 3.10)			
Job Size Pipe or Tubing										
<610 mm	T < 3 mm	1 ^a	Yes	2	2	2	—	Test diam. & over	T	2T
	3 ≤ T ≤ 10 mm	1 ^a	Yes	2	2	2	—	Test diam. & over	3	2T
	10 < T < 19 mm	1 ^a	Yes	2	—	—	4	Test diam. & over	T/2	2T
	T ≥ 19 mm	1 ^a	Yes	2	—	—	4	Test diam. & over	10	Un- limited
≥610 mm	3 ≤ T ≤ 10 mm	1	Yes	2	2	2	—	Test diam. & over	3	2T
	10 < T < 19 mm	1	Yes	2	—	—	4	610 & over	T/2	2T
	T ≥ 19 mm	1	Yes	2	—	—	4	610 & over	10	Un- limited

^a Adequate number of test welds per position must be made to obtain required test specimens.

Table 3.5
Number and Type of Test Specimens and Range of Thickness Qualified—
WPS Qualification—PJP Groove Welds [see 3.15.4(2)]

Groove Type	Groove Depth, Max.	Number of Sample Welds	Number of Specimens Required			
			Macroetch for Weld Size (E)	Tension and Bend Test		
				Reduced Section Tension (see Figures 3.7 and 3.8)	Side Bend (see Figure 3.10)	Plate Thickness Qualified, Max.
Same as used in construction ^a	1 in [25 mm]	1	1	2	4	Unlimited

^a If a PJP 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.

Table 3.6
Number and Type of Test Specimens and Range of Thickness Qualified—
WPS Qualification—Fillet Welds [see 3.15.4(3)]

			Number of Specimens Required ^a			Sizes Qualified	
Test Specimen	Fillet Weld Size	Number of Welds per Procedure	Macroetch	Fracture Test (see Figures 3.17 and 3.18)	Root Bend (see Figure 3.19)	Plate Thickness	Fillet Weld Size
1. Tests of Plate							
Fillet Weld Test Option 1 (see Figure 3.17)	Single pass, max. size to be used in construction	1 in each position to be used	2 faces	2	—	Unlimited	Max. tested single pass and smaller
	Multiple pass, min. size to be used in construction	1 in each position to be used	2 faces	2	—	Unlimited	Min. tested multiple pass and larger
Fillet Weld Test Option 2 (see Figure 3.19)	Max. size to be used in construction	1 in each position to be used	—	—	2	Unlimited	All
2. Tests on Pipe and Tubing							
Fillet Weld Test—Pipe Option 1 (see Figure 3.18)	Single pass, max. size to be used in construction	1 in each position to be used	2	4 or more	—	Unlimited	Max. tested single pass and smaller
	Multiple pass, min. size to be used in construction	1 in each position to be used	2	4 or more	—	Unlimited	Min. tested multiple pass and larger

^a All welded test specimens shall be visually inspected (see 3.6).

Table 3.7
Welder Performance Qualification—Type of Weld and Position Limitations (see 3.17.4)

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

^a Qualifies for welding pipe or tube over 24 in [610 mm] in diameter.

^b Qualifies all positions and T-, Y-, and K-connections.

^c See Figures 3.1, 3.2, 3.3, 3.4, 3.5, and 3.6.

^d Also qualifies welder to make plug and slot welds.

Table 3.8
Number and Type of Test Specimens and Range of Thickness Qualified—
Welder and Welding Operator Qualification (see 3.19 and 3.19.3)
(Dimensions in Inches)

1. Tests on Plate

Type of Weld	Nominal Thickness T of Test Plate as Welded	Visual Inspection	Number of Specimens Required					Nominal Plate Thickness Qualified	
			Bend Tests All Positions ^b			Fillet Weld Fracture	Macroetch Test		
			Face	Root	Side				
			Min.	Max. ^c					
Groove	T < 1/8	Yes	1	1	—	—	—	T	2T
Groove	1/8 ≤ T ≤ 3/8	Yes	1	1	—	—	—	1/8	2T
Groove	3/8 < T < 1	Yes	—	—	2	—	—	1/8	2T
Groove	≥ 1	Yes	—	—	2	—	—	1/8	Unlimited
Fillet ^a	≤ 1/8	Yes	—	—	—	1	1	T	Larger of 2T or 3/16 2T Unlimited ^c
	1/8 < T < 3/8	Yes	—	—	—	1	1	T/2	
	≥ 3/8	Yes	—	—	—	1	1	T/2	

2. Tests on Statically Loaded Tubular Structures

Material Type	Pipe or Tube Size of Sample Weld			Number of Specimens Required							
	Nominal Pipe Size	Nominal Wall Thickness T of Wrought	Number of Sample Welds per Position	Visual Inspection	Macroetch Test	Root Bend (see Fig. 3.12) ^b	Face Bend (see Fig. 3.12) ^b	Min.	Max.	Min.	Max. ^c
Wrought to Wrought	6 through 8	$1/8 \leq T \leq 3/8$	1	Yes	—	2	2	3/4	16	1/8	2T
Cast to Wrought or Cast to Cast	3 through 5	3/16	1	Yes	2	—	—	2	16	1/8	1/2

3. Tests on Cyclically Loaded Tubular Structures

Type of Weld	Pipe or Tubing Size as Welded			Number of Specimens Required						Pipe Diameter or Tube Size Qualified	Pipe or Tube Nominal Wall Thickness Qualified	
				All Positions Except 5G and 6G ^b			5G and 6G Positions Only ^b				Min.	Max ^c
	Face Bend	Root Bend	Side Bend	Face Bend	Root Bend	Side Bend	Nominal					
	Nominal Pipe Size	Nominal Wall Thickness	Visual Inspection									
Groove	2	Schedule 80	Yes	1	1	—	2	2	—	≤4	0.063	0.674
	3	Schedule 40										
Groove	6	Schedule 120	Yes	—	—	2	—	—	4	>4	0.187	Unlimited
	8	Schedule 80										

(Continued)

Table 3.8 (Continued)
Number and Type of Test Specimens and Range of Thickness Qualified—
Welder and Welding Operator Qualification (see 3.19 and 3.19.3)
(Dimensions in Inches)

4. Tests on Job Size Pipe or Tubing

Type of Weld	Pipe or Tubing Size as Welded		Visual Inspection	Number of Specimens Required						Nominal Pipe Diameter or Tube Size Qualified	Pipe or Tube Nominal Wall Thickness Qualified	
				All Positions Except 5G and 6G ^b			5G and 6G Positions Only ^b				Min.	Max. ^c
	Nominal Pipe Size	Nominal Wall Thickness		Face Bend	Root Bend	Side Bend	Face Bend	Root Bend	Side Bend			
Groove	≤4	Any	Yes	1	1	—	2	2	—	≤4	0.063	0.674
	≤4	<0.063	Yes	1	1	—	2	2	—	≤4	T	2T
Groove	>4	Any	Yes	—	—	2	—	—	4	1/2 test diameter or 4 min through unlimited (for maximum size qualified) ^e	0.187	Unlimited
Fillet ^d	3-1/2 welded to 4	Schedule 40 Schedule 40	Yes	Fillet Weld Fracture Test			Macroetch Test			All	Unlimited ^c	
				2			2					

^a See Figure 3.32.

^b RT of the welder or welding operator test plate may be made in lieu of the bend test (see 3.5.3 and 3.11).

^c Qualifies for welding fillet welds on material of unlimited thickness.

^d See Figure 3.33. Pipe sizes can be used to make a lap joint or a backed-up groove weld [see 3.19.3.(3) and Figure 3.31].

^e Minimum pipe size qualified shall not be less than 4 in or $d/2$, whichever is greater, where d is diameter of test pipe.

Table 3.8 (Continued)
Number and Type of Test Specimens and Range of Thickness Qualified—
Welder and Welding Operator Qualification (see 3.19 and 3.19.3)
(Dimensions in Millimeters)

1. Tests on Plate

Type of Weld	Nominal Thickness T of Test Plate as Welded	Visual Inspection	Number of Specimens Required					Nominal Plate Thickness Qualified	
			Bend Tests All Positions ^b			Fillet Weld Fracture	Macroetch Test		
			Face	Root	Side			Min.	Max. ^c
Groove	T < <u>3</u>	Yes	1	1	—	—	—	T	2T
Groove	3 ≤ T ≤ 10	Yes	1	1	—	—	—	3	2T
Groove	10 < T < 25	Yes	—	—	2	—	—	3	2T
Groove	≥25	Yes	—	—	2	—	—	3	Unlimited
Fillet ^a	≤3	Yes	—	—	—	1	1	T	Larger of 2T or 5 2T
	3 < T < 10	Yes	—	—	—	1	1	T/2	
	≥10	Yes	—	—	—	1	1	T/2	Unlimited ^ε

2. Tests on Tests on Statically Loaded Tubular Structures

Material Type	Pipe or Tube Size of Sample Weld			Number of Specimens Required							
	Nominal Pipe Size	Nominal Wall Thickness T of Wrought	Number of Sample Welds per Position	Visual Inspection	Macroetch Test	Root Bend (see Fig. 3.12) ^b	Face Bend (see Fig. 3.12) ^b	Min.	Max.	Min.	Max.
Wrought to Wrought	150 through 200	$3 \leq T \leq 10$	1	Yes	—	2	2	19	410	3	2T
Cast to Wrought or Cast to Cast	75 through 130	5	1	Yes	2	—	—	50	410	3	13

3. Tests on Cyclically Loaded Tubular Structures

Type of Weld	Pipe or Tubing Size as Welded		Visual Inspection	Number of Specimens Required						Nominal Pipe Diameter or Tube Size Qualified	Pipe or Tube Nominal Wall Thickness Qualified	
				All Positions Except 5G and 6G ^b			5G and 6G Positions Only ^b				Min.	Max. ^c
	Face Bend	Root Bend		Side Bend	Face Bend	Root Bend	Side Bend					
Groove	50	5	Yes	1	1	—	2	2	—	≤100	2	17.1
	75	5										
Groove	150	14	Yes	—	—	2	—	—	4	>100	5	Unlimited
	200	13										

(Continued)