AWS D1.6/D1.6M:2007
An American National Standard

Structural Welding Code—Stainless Steel

American Welding Society

Approved American National Standard
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Structural Welding Code—
Stainless Steel

2nd Edition

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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 requirements for welding stainless steel structural assemblies.

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Foreword

This foreword is not part of AWS D1.6/D1.6M:2007, *Structural Welding Code—Stainless Steel*, but is included for informational purposes only.

This is the second edition of the AWS D1.6, *Structural Welding Code—Stainless Steel*; the first edition was published in 1999. This code is the product of a pool of experts arriving at a consensus position, in keeping with the American National Standard Institute's requirements.

This code covers the requirements for welding stainless steel components other than pressure vessels or pressure piping. For many years, fabrications involving stainless steel welding have used AWS D1.1/D1.1M, *Structural Welding Code—Steel*, to provide the requirements for quality construction. However, as the AWS D1.1 document is written for the carbon and low alloy steels commonly encountered in structural fabrication, it does not explicitly address the unique requirements of the stainless steels. The AWS Structural Welding Committee thus recognized the industry need for an AWS D1.1 analogue designed for the welding of stainless steel wrought and cast shapes and plates.

The most noticeable feature of D1.6 is the allowance of prequalified Welding Procedure Specifications (WPSs) for the austenitic stainless steels. This exemption from qualification testing is based on considerable experience with the most widely used stainless steels.

Underlined text in the subclauses, tables, or figures indicates an editorial or technical change from the 1999 edition. A vertical line in the margin next to a figure indicates a revision from the 1999 edition. Changes to Clause 2 are not indicated in the chapter since the substantial reorganization of Clause 2 makes it too difficult to identify technical changes.

The following is a summary of the most significant technical revisions contained in D1.6/D1.6M:2007:

Clause 1 was reorganized to add elements found within AWS D1.1/D1.1M.

Terms specific to this code were added in 1.3 for clarity.

Responsibilities of parties involved in structural welding were clarified in 1.4.

Clause 2 was rewritten to bring its design requirements into closer accord with AWS D1.1/D1.1M.

The fatigue provisions in Clause 2 were revised.

Provisions for fillet welds and plug and slot welds were added to Table 2.1 and 2.2.

The provisions for fillet welds and plug and slot welds in holes and slots in Clause 2 were revised.

A comprehensive suggested filler metal chart for various combinations of stainless steels and other ferrous base metals was added as an annex.

New commentary for Clause 2 was added.

Comments and suggestions for the improvement of this standard are welcome. They should be sent to the Secretary, AWS D1 Committee on Structural Welding, American Welding Society, 550 N.W. LeJeune Road, Miami, FL 33126.

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Structural Welding Code—Stainless Steel

1. General Provisions

1.1 Scope

This code covers welding requirements applicable to stainless steel structures and weldments subject to design stress. It shall be used in conjunction with any complementary code or specification for the design or construction of stainless steel structures and weldments. When this code is stipulated in contract documents, conformance with all provisions of the code shall be required, except for those provisions that the Engineer (see 1.4.1) or contract documents specifically modify or exempt. This code is not intended to be used for pressure vessels or pressure piping.

1.2 Base Metals

1.2.1 The base metals to be welded under this code shall be stainless steels with the following chemical composition limits:

(1) Carbon (C) content equal to or less than 0.5%

(2) Chromium (Cr) content equal to or greater than 10.5%

(3) Iron (Fe) content exceeding the content of any other single element

(4) Any combination of the types in 1.2.2 or with weldable carbon steels or low alloy steels. Free machining steels and steels with intentional additions of sulfur (S), selenium (Se), or lead (Pb) shall not be welded.

1.2.2 Stainless steel base metals may include any of the following types:

(1) Austenitic

(2) Ferritic

(3) Martensitic

(4) Precipitation Hardening (austenitic, semi-austenitic, and martensitic)

(5) Duplex

1.2.3 Base metals may be used in assemblies, the parts of which may be composed of:

(1) The same grade of stainless steel,

(2) Different grades of stainless steels belonging to the same type as listed above,

(3) Different types of stainless steels,

(4) Any combination of the types in 1.2.2 or with weldable carbon steels or low alloy steels. See Annex F for suggested filler metals for various combinations of stainless steels and other ferrous base metals.

1.2.4 The stainless steel base metals may be in any of the following forms:

(1) Sheet—cold rolled

(2) Sheet, plate—hot rolled

(3) Shapes

(4) Tubular products

(5) Clad materials

(6) Castings

(7) Forgings

1.2.5 Stainless steels are generally defined by American Iron and Steel Institute (AISI) Numbers, Unified Numbering System (UNS), and by American Society for Testing and Materials (ASTM) Specifications for product form, chemical composition, and mechanical properties. Newer proprietary steels may not be covered by standards and shall be identified by chemical composition or other suitable means which clearly define the steel.

1.2.6 Specified Base Metal. The contract documents shall designate the specifications and grades of base metal to be used. The provisions of this code are not intended to apply to welding base metals thinner than 1/16 in. [1.5 mm] or 16 gage.

1.2.7 Service Temperature Limits. The contract documents shall specify service temperature limits for the weldment.

1.2.8 Base Metal Prequalification. Austenitic stainless steels whose filler metals normally produce a small amount of ferrite (see Table 3.2 for prequalified limits) shall be considered prequalified, provided they are welded with filler metals in accordance with Table 3.3 and the WPSs used conform to all the applicable requirements of this code. All other stainless steels or combinations, and WPSs which are not prequalified, shall be qualified in conformance to this code. Suggested filler metals to weld a number of stainless steels are shown in Annex F.

1.2.9 Use of Unlisted Base Metals. When a stainless steel other than one of those listed in Table 3.2 is proposed for welded construction under this code, WPSs shall be established by qualification in accordance with the requirements of Clause 4, except as permitted in 1.2.9.1. The contractor shall have the responsibility for establishing the WPS by qualification.

1.2.9.1 An unlisted base metal which has the same chemical composition and strength as a listed steel may be welded with a prequalified or qualified WPS for the listed steel.

1.2.9.2 The Engineer may prescribe additional weldability testing of the unlisted steel. The responsibility for determining weldability is assigned to the party who either specifies a material not listed in Table 3.2, except as permitted by 1.2.9.1, or who proposes the use of a substitute material not listed in Table 3.2.

1.3 Terms and Definitions

The welding terms used in this code shall be interpreted in conformance with the definitions given in AWS A3.0:2001, *Standard Welding Terms and Definitions*, supplemented by Annex L of this code. Definitions, which follow, shall also apply:

1.3.1 Authority Having Jurisdiction. The organization, political subdivision, office or individual charged with the administration and enforcement of this standard.

1.3.2 Drawings. Plans, design and detail drawings, and erection plans.

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

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

1.3.5 Inspectors

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

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

1.3.5.3 Inspector. When the term "Inspector" is used without further qualification as the specific Inspector category described above, it applies equally to the Contractor's Inspector and the Verification Inspector within the limits of responsibility described in 6.1.2.

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

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

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

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

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

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

1.4 Responsibilities

1.4.1 Engineer's Responsibilities. The Engineer shall be responsible for the development of the contract documents that govern products or structural assemblies produced under this code. The Engineer may add to, delete from, or otherwise modify, the requirements of this code to meet the particular requirements of a specific structure. If alternate requirements are proposed by other parties such as the Contractor, the Engineer may approve them based on provided documentation. Alternate requirements shall be based upon evaluation of suitability for service using past experience, experimental evidence or engineering analysis considering material type, service load effects, and environmental factors. All requirements that modify this code shall be incorporated into contract documents. The Engineer shall determine the suitability of all joint details to be used in a welded assembly.

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

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

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

(3) Verification inspection, when required by the Engineer.

(4) Weld acceptance criteria other than that specified in Clause 6.

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

(6) Tests for corrosion, carbide sensitization, creep, etc. Standards for test methods and acceptance criteria shall be specified in the contract documents.

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

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

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

1.4.2 Contractor's Responsibilities. The Contractor shall be responsible for establishing WPSs, qualification of welding personnel, the Contractor's inspection, and performing work in conformance with the requirements of this code and contract documents. The Contractor may submit to the Engineer requests to modify the requirements of this code to suit particular conditions related to feasibility and quality of a specific structure.

1.4.3 Inspector's Responsibilities

1.4.3.1 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.

1.4.3.2 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.

1.5 Approval

All references to the need for approval shall be interpreted to mean approval by the Building Commissioner or the Engineer.

1.6 Welding Symbols

Welding symbols shall be those shown in the latest edition of AWS A2.4-98, *Symbols for Welding, Brazing, and Nondestructive Examination*. Special conditions shall be fully explained by added notes or details.

1.7 Safety Precautions

This technical document does not address all welding and health hazards. However, pertinent information can be found in the following documents:

1. ANSI Z49.1:2005, *Safety in Welding, Cutting, and Allied Processes*
2. Manufacturer's safety literature on equipment and materials
3. Other pertinent documents as appropriate.

These documents shall be referred to and followed as required (also see Annex J, Safe Practices).

Note: This code may involve hazardous materials, operations, and equipment. The code does not purport to address all of the safety problems associated with its use. It is the responsibility of the user to establish appropriate safety and health practices. The user should determine the applicability of any regulatory limitations prior to use.

1.8 Standard Units of Measurement

This standard makes use of both U.S. Customary Units and the International System of Units (SI). The measurements may not be exact equivalents; therefore, each system shall be used independently of the other without combining in any way. The standard with the designation D1.6:2007 uses U.S. Customary Units. The standard designation D1.6M:2007 uses SI Units. The latter are shown within brackets [ ] or in appropriate columns in tables and figures.

1.9 Reference Documents

Annex G contains a list of all documents referenced within this code.

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2. Design of Welded Connections

Part A
General Requirements

2.0 General

Stainless steel welded connections shall be designed to meet the loading requirements. However, in order to ensure that the resultant design is fit for the intended purpose, the Engineer shall also consider other factors (see also 1.4.1):

(1) *Corrosion.* Necessary design adjustments shall be made, such as appropriate selection of base and filler metals and application of seal welds.

(2) *Elevated Temperature.* For elevated service temperatures, a decrease in short-term and creep strengths of base and filler metals shall be considered.

(3) *Heat Treatment.* Where necessary, heat treatment shall be prescribed.

(4) *Dissimilar Connections.* The Engineer shall not design welded connections of an austenitic stainless steel member to a ferritic stainless steel, martensitic stainless steel or a carbon/low alloy steel member without due consideration of a judicious choice of filler metal based on metallurgical criteria.

(5) Other factors not mentioned herein, which could adversely affect the welded connection shall be taken into account.

2.1 Contract Plans and Specifications

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

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

2.1.3 Specific Welding Requirements. The Engineer, in the contract documents, and the Contractor, in the shop drawings, shall indicate those joints or groups of joints for which the Engineer or Contractor require a specific assembly order, welding sequence, welding technique or other special precautions.

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

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

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

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

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

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

2.1.5.2 Fillet Welds and Welds in Skewed T-Joints. The following shall be provided on the shop drawings:

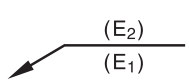
(1) For fillet welds between parts with surfaces meeting at an angle between 80° and 100°, shop drawings shall show the fillet weld leg size,

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

(3) End returns and hold-backs.

2.1.5.3 Symbols. The contract documents shall show complete joint penetration (CJP) or partial joint penetration (PJP) groove weld requirements. Contract documents do not need to show groove type or groove dimensions. The welding symbol without dimensions and with "CJP" in the tail designates a CJP weld as follows:

The welding symbol without dimension and without CJP in the tail designates a weld that will develop the adjacent base metal strength in tension and shear. A welding symbol for a PJP groove weld shall show dimensions enclosed in parentheses below "(E_1)" and/or above "(E_2)" the reference line to indicate the groove weld sizes on the arrow and other sides of the weld joint, respectively, as shown below:



2.1.5.4 Prequalified Detail Dimensions. The joint details described in Clause 3 have repeatedly demonstrated their adequacy in providing the conditions and clearances necessary for depositing and fusing sound weld metal to base metal. However, the use of these details shall not be interpreted as implying consideration of the effects of welding process on base metal beyond the fusion boundary nor suitability of the joint detail for a given application.

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

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

2.2 Eccentricity of Connections

2.2.1 Intersecting Parts. Eccentricity between intersecting parts and members shall be avoided insofar as practicable.

2.2.2 Bending Stresses. Adequate provisions shall be made for bending stresses due to eccentricity resulting from the location and types of welds. Corner and T-joints that are to be subjected to bending about an axis parallel to the joint shall have their welds arranged to avoid concentration of tensile stress at the root of any weld.

2.2.3 Symmetry. For members having symmetrical cross sections, the connection welds shall be arranged symmetrically about the axis of the member, or proper allowance shall be made for asymmetrical distribution of stresses.

2.2.4 Center of Gravity. For axially stressed angles, the center of gravity of the connecting welds shall lie between the line of the center of gravity of the angle's cross section and the centerline of the connected leg. If the center of gravity of the connecting weld lies outside of this zone, the total stresses, including those due to the eccentricity from the center of gravity of the angle, shall not exceed those permitted by the contract specification.

2.3 Allowable Stresses

2.3.1 Allowable Base Metal Stresses. The allowable stresses for the base metals shall be as specified in the applicable contract specifications.

2.3.2 Allowable Stresses in Welds

2.3.2.1 Groove Welds. For allowable stresses in groove welds, see Table 2.1.

2.3.2.2 Fillet Welds and Welds in Skewed T-Joints. Stress on the effective area of fillet welds and of welds in skewed joints shall be considered as shear stress, regardless of the direction of application.

2.3.2.3 Intermittent Fillet Welds. Intermittent fillet welds may be used to carry calculated static stress.

2.3.2.4 Plug and Slot Welds. When used, plug and slot welds shall only transfer shear, prevent bucking, or prevent separation of lapped parts.

2.3.2.5 Bending Stresses. Fiber stresses due to bending shall not exceed the values prescribed for tension and compression.

2.3.2.6 Increased Allowable Stresses. Where permitted in the applicable design specification the allowable stresses, as defined in 2.3, may be increased.

2.3.2.7 Allowable Stresses Established by Testing. Mechanical properties of joints and allowable stresses may be established by testing. These tests shall be agreed between Engineer and Contractor (see Notes in Table 2.1 and Annex I, Clause I2.2).

2.3.3 Fatigue Provisions. Fatigue stress provisions for structures subject to cyclic loading shall be determined by the Engineer and be included in the contract specification.

Contractual fatigue provisions shall be established by the Engineer based on:

(1) Applicable research data.

(2) The environmental conditions such as fluids, temperatures and atmospheres to which the structure will be subjected.

(3) Conditions specific to thin-walled structures, typical for stainless steels, such as load-induced distortion and local stress concentration. Hot spot stress approach may be considered to accommodate these conditions.

(4) Consideration of the stress intensification effects of the weld details.

(5) Fatigue performance of the applicable type and grade of stainless steels.

Part B Weld Lengths and Areas

2.4 Effective Areas

2.4.1 Groove Welds

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

2.4.1.2 Effective Weld Size

(1) In CJP Welds, effective weld size shall be the thickness of the thinner part joined. No weld size increase for weld reinforcement shall be allowed.

(2) In PJP welds, effective weld size shall be as determined in 3.15 for joints with beveled edges and in 3.17 for flare-bevel welds. Larger weld sizes may be established through procedure qualification. No weld size increase for penetration into weld root or for weld reinforcement shall be allowed.

3. For PJP welds with reinforcing fillet welds, see 2.4.2.2(2).

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

2.4.2 Fillet Welds, PJP Welds with Reinforcing Fillet Welds, and Welds in Skewed Joints

2.4.2.1 Effective Area. The effective area shall be the effective weld length multiplied by the effective throat [see also 2.4.2.3(2)].

2.4.2.2 Effective Throat

(1) In fillet welds, the effective throat shall be the shortest distance from the joint root to the weld face of the diagrammatic weld.

(2) In PJP welds with reinforcing fillet welds, the effective throat shall be the shortest distance from the joint root to the weld face of the diagrammatic weld as determined in Annex A. Provisions on root penetration of paragraphs 3.15, 3.17, and 2.4.1.2(2) shall also apply.

(3) In skewed joints having angles between parts of 60° or more, the weld effective throat shall be the shortest distance from the joint root to the face of the diagrammatic weld as determined in Annex B. For angles less than 60°, provisions of 2.16 shall apply.

2.4.2.3 Effective Lengths of Fillet Welds

(1) *Straight Welds.* The effective length of a fillet weld shall be the overall length of the weld, including boxing. No reduction in effective specified length shall be made for either the start or end of the weld.

(2) *Curved Welds.* The effective length of a curved fillet weld shall be measured along the centerline of the effective throat. If the effective area of a fillet weld in a hole or slot calculated from this length is greater than the area calculated from 2.5.4, then this latter area shall be used as the effective area of the fillet weld.

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

The minimum length of an intermittent fillet weld segment shall be 1-1/2 in. [40 mm] unless otherwise shown on approved design drawings.

2.4.3 Length and Spacing of Longitudinal Fillet Welds. If longitudinal fillet welds are used alone in lap joint end connections, the length of each fillet weld shall be no less than the perpendicular distance between the welds. The transverse spacing of longitudinal fillet welds used in end connections shall not exceed 8 in. [200 mm], unless end transverse welds or intermediate plug or slot welds are used. The longitudinal fillet weld may be either at the edges of the member or in the slots.

2.4.4 Fillet Welds Weld Terminations

2.4.4.1 Unless otherwise specified in this code or other contract documents, fillet welds connecting attachments need not start nor terminate less than the weld size from the end of the joint.

2.4.4.2 Boxing. Fillet welds stressed by forces not parallel to the faying surface shall not terminate at corners of parts or members, except as required in 2.4.4.3, but shall be returned continuously, full size, around the corner for a length equal to twice the weld size where such return can be made in the same plane. Boxing shall be indicated on design and detail drawings where required.

2.4.4.3 Opposite Sides of the Common Plane. For cyclically loaded structures, fillet welds deposited on the opposite sides of a common plane of contact between two parts shall be interrupted at a corner common to both welds (see Figure 2.1).

2.4.5 Fillet Welds in Holes or Slots

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

2.4.5.2 Sizes of holes and slots in which fillet welds are to be deposited shall be large enough to ensure that the fillet welds do not overlap, and the base metal at the fillet weld toes is visible.

Should the fillet welds in holes or slots overlap, the welds shall be considered as partially filled plug or slot welds (see 2.5).

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

2.5 Plug and Slot Welds

2.5.1 Plug Weld Spacing. The minimum center-to-center spacing of plug welds shall be four times the diameter of the hole.

2.5.2 Slot Weld Spacing. The minimum spacing of lines of slot welds in a direction transverse to their length shall be four times the width of the slot. The minimum center-to-center spacing in a longitudinal direction on any line shall be two times the length of the slot.

2.5.3 Plug Weld Sizes. The minimum diameter of the hole in which a plug weld is to be deposited shall be the thickness of the part in which it is made plus 5/16 in. [8 mm]. The maximum diameter of the hole shall be the minimum diameter plus 1/8 in. [3 mm] or 2-1/4 times the thickness of the part, whichever is greater.

2.5.4 Slot Weld Sizes and Shape. The minimum width of slot in which a slot weld is to be deposited shall be the thickness of the part in which it is made plus 5/16 in. [8 mm] or 2-1/2 times the thickness of the member, whichever is smaller. The maximum width of the slot shall be the minimum width plus 1/8 in. [3 mm] or 2-1/4 times the thickness of the part, whichever is greater. The ends of the slot shall be semicircular.

2.5.5 Plug and Slot Weld Effective Areas. The effective area shall be the nominal area of the hole or slot in the plane of the faying surface.

2.5.6 Depth of Filling of Plug and Slot Welds. The depth of filling of plug or slot welds in metal 5/8 in. [16 mm] thick or less shall be equal to the thickness of the material. In metal over 5/8 in. [16 mm] thick, it shall be at least one-half the thickness of the material, but no less than 5/8 in. [16 mm]. The Engineer may specify an alternative limit of depth of filling.

Part C
Miscellaneous Structural Details

2.6 General

These provisions define requirements, limitations and prohibitions for typical welded structural details, such as filler plates, lap joints, transitions, connections or splices, stiffeners, built-up members/shapes for statically loaded structures, plug and slot dimensions, specific requirements for cyclically loaded structures, and weld combinations. Details shall promote ductile behavior, minimize restraint, avoid undue concentration of welding, and afford ample access for depositing the weld metal.

2.7 Filler Plates

2.7.1 Filler Plate Usage. Fillers plates may be used in:

(1) Splicing parts of different thicknesses.

(2) Connections that, due to existing geometric alignment, must accommodate offsets to permit simple framing.

2.7.2 Filler Plates Less Than 1/4 in. [6 mm]. Any filler plate less than 1/4 in. [6 mm] thick shall not be used to transfer stress, but shall be kept flush with the welded edges of the stress-carrying part. The sizes of welds along such edges shall be increased over the required sizes by an amount equal to the thickness of the filler plate.

2.7.3 Filler Plates 1/4 in. [6 mm] and Larger. Any filler plate 1/4 in. [6 mm] or more in thickness shall be capable of transferring the stress and shall extend beyond the edges of the splice plate or connection material. It shall be welded to the part on which it is fitted, and the joint shall be of sufficient strength to transmit the splice plate or connection material stress applied at the surface of the filler plate as an eccentric load. The welds joining the splice plate or connection material to the filler plate shall be sufficient to transmit the splice plate or connection material stress and shall be long enough to avoid overstressing the filler plate along the toe of the weld.

2.7.4 Filler Plates Used for Dissimilar Thickness Connections. For assemblies, in which the thickness is less than 1/4 in. [6 mm], the Engineer may specify a limit of filler plate thickness less than 1/4 in. [6 mm] as determined in 2.7.2 and 2.7.3. In no case, however, shall the thickness of filler plate used as per 2.7.3 be less than the thickness of the thinner of the connected parts.

2.8 Lap Joints

2.8.1 Minimum Overlap. The minimum overlap of parts in stress-carrying lap joints shall be five times the thickness of the thinner part joined but not less than 1 in. [25 mm] (see Figures 2.2 and 2.3).

2.8.2 Double Fillet Welded. Lap joints in parts carrying axial stress shall be double-fillet welded (see Figure 2.3), except where deflection of the joint is sufficiently restrained to prevent it from opening under load.

2.8.3 Double Plug or Slot Welds. Unless lateral deflection of the parts is prevented, they are to be connected by at least two transverse lines of plug or slot welds, or by two or more longitudinal slot welds.

2.9 Transitions of Butt Joints in Nontubular Connections

Butt joints between axially aligned members of different thicknesses or widths, or both, and subject to tensile stress greater than one-third the allowable design tensile stress or to fatigue loads, shall have appropriate transition of thickness as per 2.9.1 and of width as per 2.9.2.

2.9.1 Transition of Thicknesses The slope in the transition of thickness shall not exceed 1 in 2-1/2 with the surface of either part (see Figure 2.4). The transition shall be accomplished by chamfering the thicker part, sloping the weld metal, or by any combination of these.

2.9.2 Transition of Width. Parts having different widths shall have a smooth transition between offset edges at a slope of no more than 1 in 2-1/2 with the edge of either part or shall be transitioned with a 2 ft [600 mm] minimum radius tangent to the narrower part of the center of the butt joints.

2.10 Transitions in Tubular Connections

2.10.1 Size Transition. Flared connections and tube size transitions not excepted below shall be checked for local stresses caused by the change in direction [angle (Ψ)] at the transition. Exceptions: Circular tubes having D/t less than 30, box sections having a/t less than 20, and transition slopes for circular tubes and box sections less than 1 in 4.

2.10.2 Transition of Thicknesses. Tension butt joints in axially aligned primary members of different material thicknesses or size shall be made in such a manner that the slope through the transition zone does not exceed 1 in 2-1/2. The transition shall be accomplished by chamfering the thicker part, sloping the weld metal, or by any combination of these methods (see Figure 2.5).

2.11 Connections or Splices

2.11.1 Tension or Compression Members. Connections or splices of tension or compression members made by groove welds shall have CJP welds, except as specified in 2.11.2. Connections or splices made with fillet or plug welds, except as noted in 2.11.2, shall be designed for an average of the calculated stress and the strength of the member, but not less than 75% of the strength of the member; or if there is repeated application of load, the maximum stress or stress range in such connection or splice shall not exceed the fatigue stress permitted by the applicable contract specification.

2.11.2 Compression Members with Milled Joints. If members subject to compression only are spliced and full-milled bearing is provided, the splice material and its welding shall be arranged, unless otherwise stipulated by the applicable general specifications, to hold all parts in alignment and shall be proportioned to carry 50% of the computed stress in the member. Where such members are in full-milled bearing on base plates, there shall be sufficient welding to hold all parts securely in place.

2.11.3 Splices in Girders and Beams

2.11.3.1 Splices between sections of rolled beams or built-up girders shall preferably be made in a single transverse plane. Shop splices of webs and flanges in built-up girders, made before the webs and flanges are joined to each other, may be located in a single transverse plane or multiple transverse planes, but the fatigue stress provisions of the contract specification shall apply.

2.11.3.2 Girders (built-up I sections) shall preferably be made with one plate in each flange, i.e., without cover plates. The unsupported projection of a flange shall be no more than permitted by the applicable contract specification. The thickness and width of a flange may be varied by butt joint welding parts of different thickness or width with transitions conforming to the requirements of 2.9.

2.12 Built-Up Members in Statically Loaded Structures

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

2.12.1.1 Maximum Longitudinal Spacing of Intermittent Welds. The maximum longitudinal spacing of intermittent welds connecting two or more rolled shapes, or a shape and a plate, in contact with one another shall not exceed 24 in. [600 mm].

2.12.1.2 Longitudinal Spacing in Built-Up Tension and Compression Members. In built-up tension and compression members, the longitudinal spacing of intermittent welds connecting a plate component to other components, or connecting two plate components to each other, shall not exceed 12 in. [300 mm] or 24 times the thickness of the thinner plate.

2.12.2 Intermittent or Partial Length Groove Welds. Intermittent or partial length groove welds are not permitted except as specified in 2.12.3.

2.12.3 Groove Welds in Elements Connected by Fillet Welds. Members built-up of elements connected by fillet welds, at points of localized load application, may have groove welds of limited length to participate in the transfer of the localized load. The groove weld shall extend at uniform size for at least the length required to transfer the load. Beyond this length, the groove shall be transitioned in depth to zero over a distance, not less than four times its depth. The groove shall be filled flush before the application of the fillet weld.

2.13 Noncontinuous Beams

The connections at the ends of noncontinuous beams shall be designed with flexibility so as to avoid excessive secondary stresses due to bending. Seated connections with a flexible or guiding device to prevent end twisting are recommended.

2.14 Specific Requirements for Cyclically Loaded Structures

2.14.1 Connections of Components of Built-Up Members. When a member is built up of two or more pieces, the pieces shall be connected along their longitudinal joints by sufficient continuous welds to make the pieces act in unison.

2.14.2 When the offset between surfaces at either side of the joint is greater than the thickness of the thinner part connected, the transition of thicknesses (see Figure 2.4) subject to shear or compressive stress shall be made as specified in 2.9.1. When the offset is equal to or less than the thickness of the thinner part connected, the face of the weld shall be sloped no more than 1 in 2-1/2 from the surface of the thinner part or shall be sloped to the surface of the thicker part if this requires a lesser slope with the following exception: Truss member joints and beam and girder flange joints shall be made with smooth transitions of the type specified in 2.9.1.

2.14.3 Prohibited Types of Joints and Welds

2.14.3.1 In butt joints, PJP welds subject to tension normal to their longitudinal axis are prohibited In other joints, transversely loaded PJP welds are prohibited, unless fatigue design criteria allow for their application.

2.14.3.2 SMAW and SAW CJP groove welds, made from one side only, are prohibited, if the welds are made:

(1) Without any backing, or

(2) With backing, other than stainless steel, that has not been qualified in accordance with Clause 4.

These prohibitions do not apply to:

(1) Secondary or nonstress carrying members and shoes or other nonstressed appurtenances, or,

(2) Corner joints parallel to the direction of computed stress, between components for built-up members designed primarily for axial stress.

2.14.3.3 Intermittent groove welds are prohibited.

2.14.3.4 Intermittent fillet welds are prohibited.

2.14.3.5 Plug and slot welds on primary tension members are prohibited.

2.15 Combinations of Different Types of Welds

If two or more welds of different type (groove, fillet, plug, slot) are combined to share the load in a single connection, the capacity of the connection shall be calculated as the sum of the individual welds determined relative to the direction of applied load. This method of adding individual capacities of welds does not apply to fillet welds reinforcing PJP groove welds (see Annex A).

2.16 Skewed T-Joints (see Annex B, Figure B.1)

Skewed T-joints which have angles between members less than 60° shall be qualified in accordance with Clause 4 to determine effective weld size. Welds in these types of joints should be considered PJP groove welds. Z-loss values for stainless steels have not been determined; therefore, the requirements of 2.16 are necessary in order to find the achievable weld size for given set of procedural conditions.

Table 2.1
Allowable Stresses (see 2.3.2)

Stress in Weld		Allowable Stress[a, b, c, d]
CJP Groove Welds		
Tension normal to the effective area		The lesser of values for base metal or filler metal.
Compression normal to the effective area		The lesser of values for base metal or filler metal.
Tension or compression parallel to the axis of the weld		Same as for base metal.
Shear on the effective area		0.30 × nominal tensile strength of filler metal, except shear stress on base metal shall not exceed 0.40 × yield strength of base metal
PJP Groove Welds		
Tension normal to the effective area		0.30 × nominal tensile strength of filler metal, except tensile stress on base metal shall not exceed 0.60 × yield strength of base metal
Compression normal to the effective area	Joint not designed to bear	0.5 × nominal tensile strength of weld metal, except compression stress on adjacent base metal shall not exceed 0.60 × yield strength of base metal
	Joint designed to bear	The lesser of values for base metal or filler metal
Tension or compression parallel to the axis of the weld		Same as for base metal
Shear parallel to the axis of the weld		0.30 × nominal tensile strength of filler metal, except shear stress on base metal shall not exceed 0.40 × yield strength of base metal
Fillet Welds		
Shear on effective area of weld		0.30 × nominal tensile strength of filler metal, except shear stress on base metal shall not exceed 0.40 × yield strength of base metal
Tension or compression parallel to the axis of the weld		Same as for base metal
Plug and Slot Welds		
Shear parallel to the faying surface on the effective area		0.30 × nominal tensile strength of filler metal, except shear stress on base metal shall not exceed 0.40 × yield strength of base metal

[a] The strength of the various types of stainless steels indicated in Table 3.2 begins to decrease at temperatures over 200ºF [95ºC]. The Engineer should consult strength data that indicate the allowable stress at service temperatures greater than 200ºF [95ºC], e.g., ASME Section II, Part D.

[b] In contrast to carbon steels, where filler metal is selected on the basis of its strength, in stainless steels the selection of filler metal is predominantly based on metallurgical criteria. This may lead to overmatch or undermatch condition of yield and/or tensile strength, which shall be taken into account by Engineer.

[c] Nominal tensile strength of filler metals for stainless steels shall be determined as follows:

(1) for covered electrodes, nominal tensile strength shall be that required in AWS A5.9/A5.9M:2006,
(2) for flux cored filler metals, nominal tensile strength shall be that required in AWS A5.22-95R,
(3) for solid and metal cored filler metals, nominal tensile strength shall be that required in AWS A5.4/A5.4M:2006 for covered electrodes of corresponding composition of weld metal,
(4) for filler metals which are not covered in AWS A5.4/A5.4M:2006, AWS A5.9/A5.9M:2006, or A5.22-95R, nominal tensile strength shall be assessed by Engineer.

[d] Yield strength of filler metals for stainless steels is not specified in pertinent AWS A5 specifications. For design based on yield criteria, Engineer shall assess yield stress values for filler metals selected.

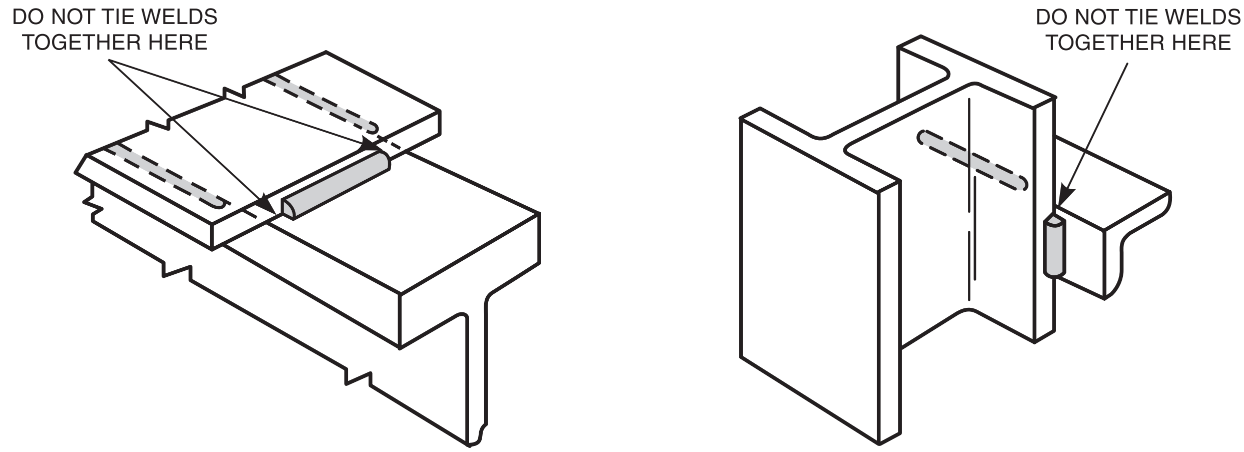
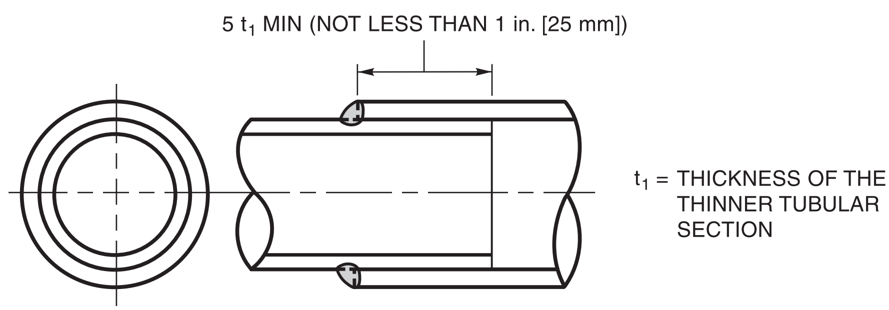
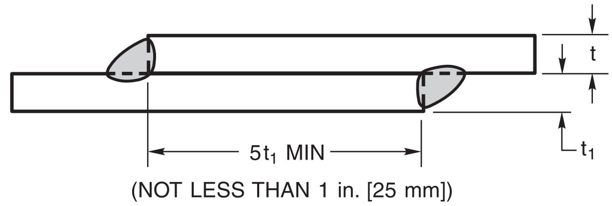


Figure 2.1—Fillet Welds on Opposite Sides of a Common Plane of Contact for Cyclically Loaded Structures (see 2.4.4.3)



Note: L = size as required.

Figure 2.2—Fillet Welded Lap Joint in Tubular Connections (see 2.8.1)



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

Figure 2.3—Double-Fillet Welded Lap Joint (see 2.8.2)

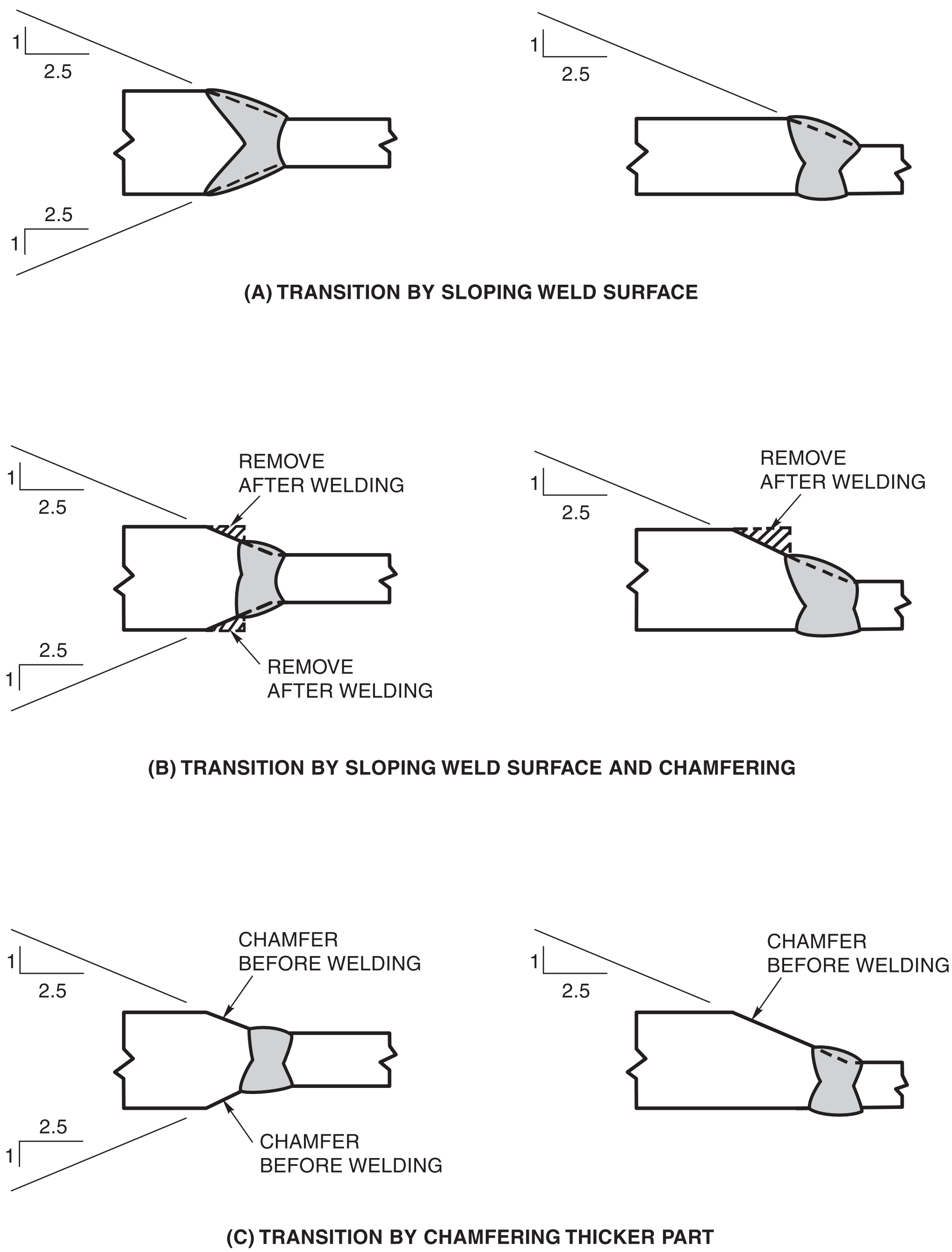
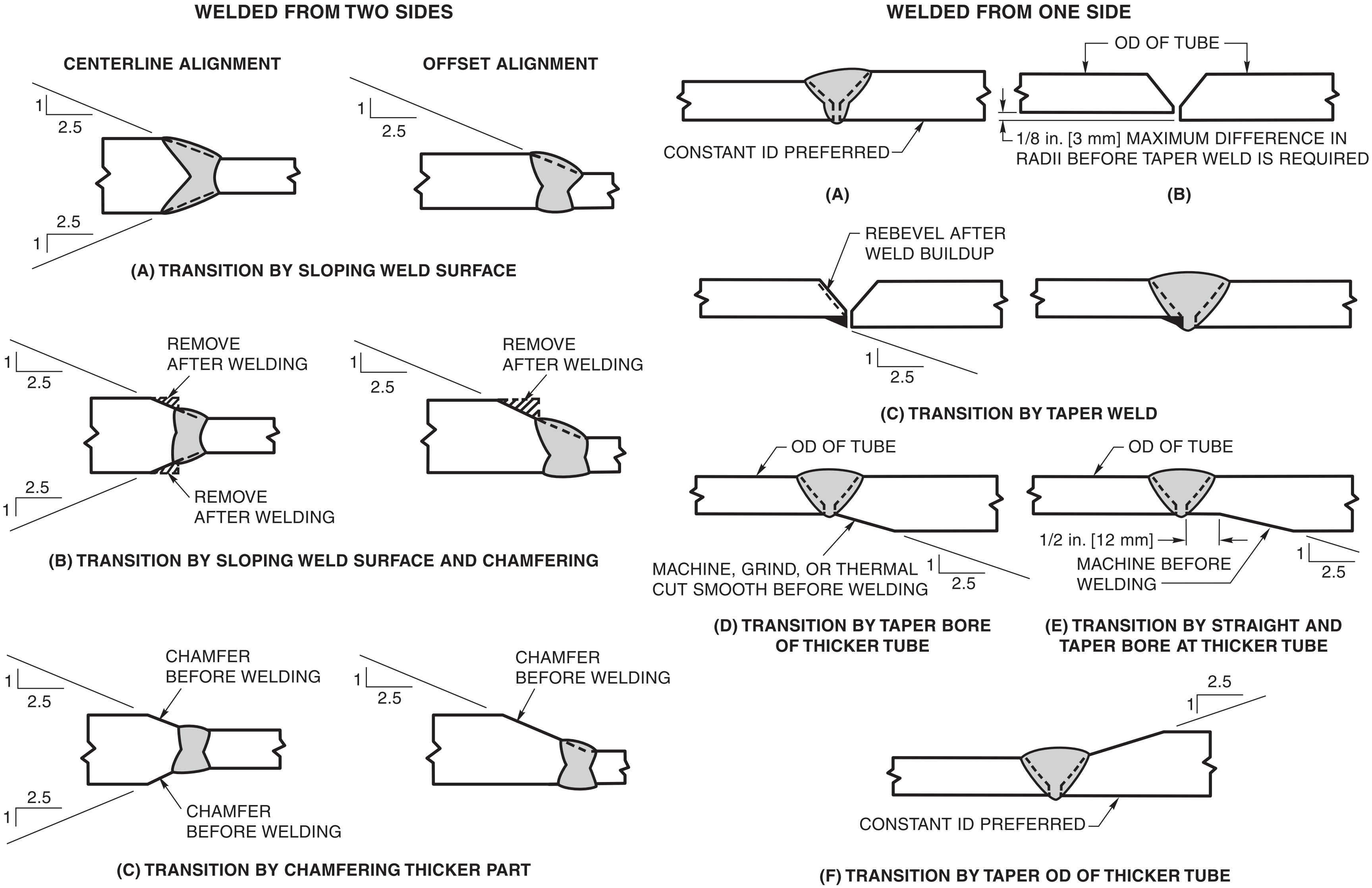


Figure 2.4—Transition of Butt Joints in Nontubular Connections of Unequal Thickness (see 2.9.1)



Notes:
1. Groove may be of any allowed or qualified type and detail.
2. Transition slopes shown are the maximum allowed.
3. In (B), (D), and (E) groove may be any allowed or qualified type and detail. Transition slopes shown are maximum allowed.

Figure 2.5—Transition of Butt Joints in Tubular Connections of Unequal Thickness (see 2.10.2)

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3. Prequalification

3.0 Scope

The provisions of this clause cover the requirements for the use of prequalified WPSs. WPSs that conform to this clause, or to standardized WPSs of AWS B2.1:2005, *Standard for Welding Procedure and Performance Qualification*, shall be exempt from qualification. Prequalification covers weldments in thicknesses of 1/16 in. [2 mm] or 16 gage and greater, designed for supporting mechanical loads under normal atmospheric corrosion conditions, or under conditions of comparable severity in a temperature range of –100°F to +800°F [–75°C to +430°C]. It applies only to nominally austenitic stainless steel base metals and filler metals whose as-welded fusion zones normally contain a small amount of delta ferrite (see 3.29). Filler metals used for prequalified WPSs shall equal or exceed the corresponding minimum specified base metal strength and provide resistance to normal atmospheric corrosion. Atmospheric exposure may not require stainless steel; however, some industrial and sea coast environments may require additional corrosion mitigation which is not anticipated in this section or code. For corrosion conditions significantly more severe than normal atmospheric exposure, the Engineer shall determine appropriate base and filler metals.

Prequalification may still be applicable if the selected materials are listed in Tables 3.2 and 3.3 and as permitted by 1.2.3.1. Any other materials shall be qualified per the requirements of Clause 4.

Note: The use of prequalified joints or a prequalified WPS is not intended as a substitute for engineering judgment in the suitability of application to a welded assembly or connection.

Part A
General Requirements

3.1 Limitation of Variables for Prequalified WPSs

All prequalified WPSs to be used shall be prepared, approved, and controlled by the manufacturer, fabricator, or contractor as written prequalified WPSs, and shall be available to those authorized to use or examine them. The written WPSs shall specify the welding variables for each process. The welding variables set forth in (1) through (7) of this subclause shall be specified on the written WPSs within the limitation of variables prescribed in Table 3.1 for each applicable process. For an example of a WPS, see Annex M. Changes in these variables, beyond those specified on the written WPS, shall be considered essential changes, and shall require a new or revised prequalified written WPS, or possibly a WPS qualification.

(1) Amperage (wire feed speed)

(2) Voltage

(3) Travel speed

(4) Shielding gas composition and flow rate

(5) Position of welding

(6) SAW flux trade designation

(7) Welding filler metal classification(s) and size(s).

3.2 Combination of WPSs

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

Part B
Prequalified Processes

3.3 General

The following fabrication processes have prequalified status and do not require testing to demonstrate applicability.

However, WPSs using these processes which do not conform to the requirements of Clause 3 shall be qualified in conformance with Clause 4. See Annex B for non-prequalified stainless steel qualification guidelines.

3.4 Welding Processes

3.4.1 Prequalified Welding Processes. Shielded metal arc welding (SMAW), gas metal arc welding (GMAW), gas tungsten arc welding (GTAW) (including autogenous GTAW), and flux cored arc welding (FCAW) WPSs which conform to the provisions of Clause 3, Parts C, D, E, F, G, and H, may be used for prequalified WPSs, and therefore approved for use without WPS qualification tests (see limitations of Table 3.5).

3.4.2 Submerged Arc Welding (SAW). Fluxes for SAW of stainless steels are not presently classified by AWS. Accordingly, fluxes cannot be prequalified by their classification. However, SAW with a flux of a particular trade designation and a specific wire classification shall be considered prequalified for welding prequalified base metals (see 3.6) under the following conditions:

(1) Test welds are made under production conditions or are actual production welds, and

(2) Test welds are made with that classification of filler metal, and flux of the particular trade designation, and

(3) Test welds exhibit at least a 4.0 Ferrite Number (FN) along the top centerline of the weld bead, and a strength (see Table 3.3) not less than corresponding base metal. Measurements of the FN shall be made with an instrument calibrated according to the latest edition of AWS A4.2M:2006, *Standard Procedures for Calibrating Magnetic Instruments to Measure the Delta Ferrite Content of Austenitic and Duplex Austenitic-Ferritic Stainless Steel Weld Metal*.

Otherwise, SAW with a particular filler metal and flux shall be qualified as prescribed in Clause 4 and approved by the Engineer.

3.5 Other Welding Processes

Other welding processes may be used, provided they are qualified by applicable tests as prescribed in Clause 4 and approved by the Engineer.

Part C
Base Metals

3.6 Base Metals for Prequalified WPSs

3.6.1 Exempt Base Metal. The base metals listed in Table 3.2 may be used in prequalified WPSs; however, WPSs using these base metals which do not conform to the requirements of Clause 3 shall be qualified by test in conformance with Clause 4.

3.7 Auxiliary Component Base Metals

The Engineer may approve unlisted materials for auxiliary attachments or components which fall within the chemical composition range of a listed material to be welded with prequalified WPSs. The filler metal shall belong to the corresponding filler metal group (Table 3.3) based upon equal or greater minimum tensile strength of the filler metal.

3.8 Base Metal for Weld Tabs and Backing

Weld tabs shall be of any base metal group in Table 3.2. Backings may be used provided they are approved by the Engineer. Steel for backing shall be of the same base metal group (Table 3.2) as the base metal, unless otherwise approved.

Part D
Prequalified Filler Metals, Fluxes, and Gases

3.9 Filler Metals

3.9.1 Filler Metals for Prequalified WPS. Table 3.3 lists filler metal groups, based upon strength, which are prequalified for the corresponding prequalified base metal groups of Table 3.2. In the event that base metals from two different base metal groups in Table 3.2 are to be joined, filler metal from the filler metal group in Table 3.3 corresponding to the lower strength of the two base metal groups in Table 3.2 shall be considered prequalified.

3.9.2 Electrode or Electrode-Flux Combinations. The electrode, including electrodes for SAW, shall be as specified in Table 3.3. SAW electrode-flux combinations can be prequalified as prescribed in 3.4.2. Other SAW electrode-flux combinations shall be qualified according to Clause 4.

3.9.3 Filler Metal Removed from Packages. After filler metal has been removed from its original package, it shall be protected or stored so that its characteristics or welding properties are not adversely affected. Filler metals of different classifications shall not be mixed in one container.

3.10 Electrodes for SMAW

3.10.1 Purchasing Requirements. Electrodes for SMAW shall conform to the requirements of the latest edition of AWS A5.4/A5.4M:2006, *Specification for Stainless Steel Welding Electrodes for Shielded Metal Arc Welding*.

3.10.2 Electrode Storage and Drying Conditions. Electrodes supplied in hermetically sealed containers may remain in the container, once opened, provided that the container is reclosed at once. Otherwise, once the container is opened, the electrodes shall be stored in an oven at 250°F to 300°F [120°C to 150°C]. Electrodes received in containers which are not hermetically sealed, whether by design or by damage, shall be redried according to the manufacturer's instructions, then stored until use in an oven at 250°F to 300°F [120°C to 150°C].

3.10.3 Manufacturer's Certification. When requested by the Engineer, the contractor or fabricator shall furnish an electrode manufacturer's certification that the electrode will meet the requirements of the classification, and will provide at least 3.0 Ferrite Number in undiluted weld metal when tested with an instrument calibrated according to AWS A4.2M:2006.

3.11 Electrodes and Fluxes for SAW

3.11.1 Purchasing Requirements. The bare electrodes (solid or composite) for SAW of stainless steels shall conform to the requirements in the latest edition of AWS A5.9/A5.9M:2006, *Specification for Bare Stainless Steel Welding Electrodes and Rods*.

3.11.2 Manufacturer's Certification. When requested by the Engineer, the contractor or fabricator shall furnish an electrode manufacturer's certification that the electrode will meet the requirements of the classification or grade, and a flux manufacturer's certification of the composition, Ferrite Number, and mechanical properties obtained with the particular flux formulation and an electrode of the same classification (see 3.9.2).

3.11.3 Storage Conditions. Flux used for SAW shall be dry and free of contamination from dirt, mill scale, or other foreign material. All flux shall be purchased in packages that can be stored under normal conditions, for at least six months, without such storage affecting its welding characteristics or weld properties. Flux from damaged packages shall be discarded or shall be dried at a minimum temperature of 500°F [260°C] for one hour before use. Flux shall be placed in the dispensing system immediately upon opening a package or withdrawal from an oven, or, if used from an opened package, the top 1 in. [25 mm] shall be discarded or dried as above. Flux that has been wet shall not be used.

3.11.4 Flux Reclamation

3.11.4.1 Unmelted Flux. SAW flux that has not been melted during the welding operation may be reused after recovery by vacuuming, catch pans, sweeping, or other means. The welding fabricator shall have a system for collecting unmelted flux, adding new flux, and welding with the mixture of these two, such that the flux composition and particle size distribution at the welding arc are relatively constant.

3.11.4.2 Melted Flux (Crushed Slag). Crushed slag shall not be considered prequalified. Melted flux or slag removed from a weld deposit may be crushed and used as a SAW flux again. However, it must be recognized that this crushed slag is likely to be a chemically and physically different flux from the unmelted virgin flux. It shall therefore require separate certification testing for the particular dry mix or lot of crushed slag, according to the requirements of 3.4.2. The crusher, not the original flux manufacturer, shall be considered the manufacturer of flux made from crushed slag, or from mixtures of crushed slag with virgin flux. The crusher shall provide certification in accordance with 3.11.2.

3.12 Consumables for GMAW, GTAW, and FCAW

3.12.1 Purchasing Requirements. The filler metals for GMAW, GTAW, or FCAW shall conform to the requirements of the latest edition of AWS A5.9/A5.9M:2006, *Specification for Bare Stainless Steel Welding Electrodes and Rods*, AWS A5.22-95R, *Specification for Stainless Steel Electrodes for Flux Cored Arc Welding and Stainless Steel Flux Cored Rods for Gas Tungsten Arc Welding*, or AWS A5.30-97, *Specification for Consumable Inserts*, as applicable.

3.12.2 Electrode Manufacturer's Certification. When requested by the Engineer, the contractor or fabricator shall furnish the electrode manufacturer's certification that the electrode will meet the requirements of the classification or grade. In addition, if requested by the Engineer for electrodes for GMAW, and for rods or consumable inserts for GTAW welding, the certification shall include typical mechanical properties of the all-weld metal. For electrodes and rods classified according to AWS A5.22-95R, certification shall indicate that the specimen for the all-weld-metal test will contain at least 3.0 Ferrite Number when tested with an instrument calibrated according to AWS A4.2M:2006. For filler metals classified according to AWS A5.9/A5.9M:2006 or A5.30-97, certification shall indicate a calculated Ferrite Number of at least 3.0 FN using the filler metal composition and Figure 3.1.

3.12.3 Shielding Gas for GMAW, GTAW, and FCAW. A gas or gas mixture used for shielding in GMAW, GTAW, or FCAW shall be of a welding grade having a dew point of –40°F [–40°C] or lower. When requested by the Engineer, the contractor or fabricator shall furnish the gas manufacturer's certification that the gas or gas mixture composition and dew point meet applicable requirements.

Part E
Weld Sizes for Prequalified Joints

3.13 General

The provisions of Part E shall be complied with for the determination of weld size and effective throat of welds made with a prequalified WPS. Joint details that depart from the details prescribed in this clause shall be qualified in accordance with the requirements of Clause 4 of this code and their conformance with applicable provisions of Clause 5.

Note: The use of weld sizes or effective throats other than those defined in Part E shall be determined by the use of qualifying tests found in Clause 4, Qualification.

3.14 Prequalified Fillet Welds

The provisions of this subclause shall apply to joints where the minimum angle between the joined pieces is 60° and the maximum angle is 135°.

3.14.1 Maximum Leg Sizes. The maximum fillet weld size (see Figure 3.2) 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 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. In the as-welded condition, the distance between the edge of the base metal and the toe of the weld may be less than 1/16 in. [2 mm], provided the weld size is clearly verifiable.

3.14.2 Effective Throat. The effective throat of skewed T-joint welds (see Annex B) is dependent upon the minimum angle between members to be joined and the magnitude of the root opening. Joints with angles between members to be welded of less than 60° are not prequalified. These joints shall be qualified per Clause 4 based upon the WPS, the minimum joint angle and the minimum root face or distance between members (see Figure 3.3).

3.15 Prequalified Partial Joint Penetration (PJP) Groove Welds in Nontubular Connections

The weld size of a PJP groove weld shall be the depth of bevel less 1/8 in. [3 mm] for grooves having a groove angle less than 60°, but not less than 45°, at the root of the groove, when made by SMAW or GTAW in any position, by SAW in the flat position, or when made in the vertical or overhead welding positions by GMAW or FCAW. The weld size of a PJP groove weld shall be the depth of bevel, without reduction, for grooves having the following as detailed angles:

(1) A groove angle of 60° or greater at the root of the groove when made by any of the following welding processes: SMAW, SAW, GMAW, GTAW, or FCAW.

(2) A groove angle not less than 45° at the root of the groove when made in flat or horizontal positions by GMAW or FCAW.

The design weld size of a prequalified PJP groove weld shall not be greater than that shown in Figures 3.4 and 3.6 for the particular welding process, joint designation, groove angle, and welding position proposed for use in welding fabrication.

3.15.1 Combined Welds. The effective throat of a combination PJP groove weld and a fillet weld shall be the shortest distance from the joint root to the weld face of the diagrammatic weld (see Annex A).

3.16 Prequalified Partial Joint Penetration (PJP) Groove Welds in Tubular Connections

The weld sizes for tubular connections shall be determined from Figure 3.6.

3.17 Prequalified Flare-Bevel Groove Weld Sizes

The effective weld size for flare groove welds when filled flush to the surface of a round bar, a 90° bend in a formed section, or a rectangular tube shall be as shown in Table 3.4.

3.18 Prequalified Skewed Joints

The effective weld size of skewed joints are dependent upon the minimum angle between members to be joined and the magnitude of the root opening (see Annex B).

3.18.1 Exceptions. Joints with angles between members to be welded of less than 60° are not prequalified.

3.18.1.1 Qualifications. Joints with angles less than 60° and more than 30° shall be qualified by macroetch examination in accordance with 4.3.2. The weld size acceptance criteria shall be established by the Engineer.

3.19 Prequalified Plug and Slot Weld Sizes

3.19.1 Plug Welds. The minimum hole diameter shall be the thickness of the member containing it plus 5/16 in. [8 mm]. The maximum hole diameter shall be the minimum diameter plus 1/8 in [3 mm] or 2-1/4 times the thickness of the member, whichever is greater.

3.19.2 Slot Welds. The minimum slot width shall be the thickness of the member containing it plus 5/16 in. [8 mm] or 2-1/2 times the thickness of the member, whichever is smaller. The maximum slot width shall be the minimum width plus 1/8 in. [3 mm] or 2-1/4 times the thickness of the member, whichever is greater. The ends of the slot shall be semicircular.

3.20 Prequalified Complete Joint Penetration (CJP) Groove Welds in Nontubular Connections

The joints shown in Figure 3.5 for CJP groove welds may be welded without performing the tests described in Clause 4, provided the allowable joint configurations are maintained.

3.21 Prequalified Complete Joint Penetration (CJP) Groove Welds in Tubular Connections

The weld size of a CJP groove weld shall be the thickness of the thinner part joined. No increase shall be permitted for weld reinforcement (see Figure 3.5).

Part F
Prequalified Nontubular Joint Details

3.22 General

The provisions of this subclause cover the requirements for prequalified status for joints with fillet, PJP, CJP, plug, slot, or flare-bevel groove welds in nontubular connections.

3.22.1 Minimum Joint Requirements. Joints meeting the following requirements are designated as prequalified:

(1) Conformance with the details in Table 3.4 and Figures 3.2, 3.4, and 3.5.

(2) Use of one of the following welding processes in accordance with the requirements of Clause 3: SMAW, SAW, GMAW, GTAW, or FCAW.

3.22.1.1 Joints meeting these requirements may be used without performing the WPS qualification tests prescribed in Clause 4.

3.22.1.2 The WPS for all joints not meeting these requirements shall be qualified by tests prescribed in Clause 4.

3.23 Partial Joint Penetration (PJP) Groove Welds

3.23.1 Prequalified PJP Groove Welds. PJP groove welds are detailed in Figure 3.4.

3.23.1.1 Definition. Except as provided in Figure 3.5, groove welds without steel backing, welded from one side, and groove welds welded from both sides, but without back gouging, are considered PJP groove welds for purposes of prequalification.

3.23.2 Dimensions of Groove Welds. Dimensions of groove welds specified in 3.23.1 may vary on design or detail drawings within the limits or tolerances shown in the "As Detailed" column in Figure 3.4. Fit up tolerances of 5.4 may be applied to the dimensions shown on the detail drawing. J- and U-grooves may be prepared before or after assembly.

3.23.3 Groove Preparation. Groove preparations detailed for prequalified SMAW and SAW may be used for prequalified GMAW, GTAW, or FCAW.

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

3.24 Complete Joint Penetration (CJP) Groove Welds

3.24.1 Prequalified CJP Groove Welds. CJP groove welds are detailed in Figure 3.5 and are subject to the limitations specified in 3.24.2.

3.24.2 Dimensions of Groove Welds. Dimensions of groove welds specified in 3.24.1 may vary on design or detail drawings within the limits or tolerances shown in the "As Detailed" column in Figure 3.5. Fit up tolerance of 5.4 may be applied to the dimensions shown on the detail drawing. J- and U-grooves and the other side of partially welded double-V and double-bevel grooves may be prepared before or after assembly. After back-gouging, the other side of partially welded double-V or double-bevel joints should resemble a prequalified U- or J-joint configuration at the joint root.

3.24.3 Groove Preparations. Groove preparations detailed for prequalified SMAW and SAW joints may be used for prequalified GMAW, GTAW, or FCAW.

3.24.4 Joint Root Openings. Joint root openings may vary as noted in Figure 3.5. However, for automatic or machine welding using FCAW, GMAW, GTAW, and SAW processes, the maximum root opening variation (minimum to maximum opening as fit up) may not exceed 1/8 in. [3 mm]. Variations greater than 1/8 in. [3 mm] shall be locally corrected prior to automatic or machine welding.

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

3.25 Plug and Slot Welds

The details of plug and slot welds made by the SMAW, GMAW, GTAW, or FCAW welding processes are listed in 2.5, 2.13, and 3.19, and may be used without performing the WPS qualification prescribed in Clause 4, provided the technique provisions of 3.30 are complied with.

3.26 Flare-Bevel Groove Welds

The joint detail requirements for a prequalified flare-bevel groove weld are given in 3.17, Figure 3.6, and Table 3.4.

Part G
Prequalified Tubular Joint Details

3.27 General

The provisions of this subclause cover the requirements for prequalified status for joints with fillet, PJP, CJP, plug, slot or flare-bevel groove welds in tubular connections. The provisions of 3.28 shall apply to prequalification of tubular joints.

3.28 Prequalified Joints

Any production joint that cannot be welded in accordance with a prequalified WPS shall be qualified by testing in accordance with Clause 4.

3.28.1 CJP Tubular Groove Welds

(1) A prequalified WPS for production joints welded from one side with backing, or both sides with backgouging, shall use the appropriate Figure 3.5 detail and shall conform with Clause 3. However, nominal pipe diameters less than 12 in. [300 mm] and welded with SAW shall require WPS qualification in accordance with Clause 4.

(2) A prequalified WPS for tubular CJP butt joints welded from one side without backing shall use Detail B-L6 or B-L2b of Figure 3.5, whichever is appropriate, and shall conform with Clause 3.

(3) This code does not address welded T-, Y-, or K-connections.

3.28.2 PJP Tubular Groove Welds. A prequalified WPS for circular or box section PJP butt joints shall use the appropriate Figure 3.6 detail and shall conform with Clause 3.

3.28.3 Fillet Welded Tubular Connection. A prequalified WPS for fillet welded tubular connections shall use the appropriate Figure 3.3 details and conform with Clause 3.

Part H
Prequalified WPS Requirements

3.29 General

The following provisions pertain to the requirements for the technique employed in the performance of prequalified welds of austenitic stainless steels. Prequalified welding applies only to the nominally austenitic stainless steels listed in Table 3.2 (comparable to ASME *Boiler and Pressure Vessel Code*, Section IX P8 and AWS B2.1:2005 M8) welded with filler metals whose weld metal is expected to contain delta ferrite of at least 3.0 FN as determined according to the latest edition of AWS A4.2M:2006. For all processes:

(1) The base metal shall be clean and free of moisture.

(2) The filler metals shall be clean and dry.

(3) The minimum preheat shall be sufficient to remove moisture from the work, unless other means are used to keep moisture away from the weld puddle area.

(4) The maximum interpass temperature shall be 350°F [175°C].

(5) The work shall be positioned for flat position welding whenever practicable.

(6) The classification and size of electrode, arc length, voltage, and amperage shall be suited to the thickness of the material, type of groove, welding positions, and other circumstances attending the work. The welding current, arc voltage, gas flow, and speed of travel shall be such that each pass will have complete fusion with adjacent base metal and weld metal, and there will be no overlap or excessive porosity or undercutting.

(7) The minimum size of a root pass shall be sufficient to prevent cracking.

(8) The progression for all passes in vertical position welding shall be upward, except that GTAW, GMAW-S, and FCAW-G are prequalified vertical down for base metal of 3/16 in. [5 mm] maximum thickness. Undercut may be repaired vertically downwards on the joint faces only, by any prequalified welding process listed in 3.4.1, without base thickness limitation, within the limits of 5.11.1.

(9) CJP groove welds made without the use of backing shall have the root backgouged to sound metal before welding is started from the second side, except as permitted by Figure 3.5, Joint B-L1-S and B-L2-b.

(10) Roots of groove or fillet welds may be backed by copper, flux, glass tape, or backing bars of prequalified stainless steel to prevent melting through (see 3.8). Copper shall not be melted. Copper backing shall be removed and the root visually inspected. Roots may also be sealed by means of root passes deposited by other arc welding processes.

(11) Neither the depth nor the maximum width in the cross section of weld metal deposited in each weld pass shall exceed the width at the surface of the weld pass (see Figure 3.7). This requirement may be waived only if the testing of a WPS to the satisfaction of the Engineer has demonstrated that such welds exhibit freedom from cracks, and the same WPS and filler metal classifications are used in construction.

(12) For welding processes with external gas shielding, welding shall not be done in a draft or wind unless the weld is protected by a shelter. Such shelter shall be of material and shape appropriate to reduce wind velocity in the vicinity of the weld to a maximum of 5 mph [8 km/h],

or, in lieu of velocity requirements, such that the weld beads are free of porosity.

(13) Prequalified GMAW in the spray transfer mode is limited to welds in the flat position and fillet welds in the horizontal position.

Further requirements are listed in Table 3.5.

3.30 Plug and Slot Welds

The technique used to make plug welds when using SMAW, GMAW, GTAW, or FCAW shall be as follows:

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

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

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

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

Table 3.1
Prequalified Variables to be Specified in the WPS[a] (see 3.1)

	Welding Variable Range Limits				
Welding Process	Amperage or Wire Feed Speed	Voltage	Travel Speed	Shielding Gas Flow Rate	Gas Composition or Flux Trade Designation
SMAW	MR	DCEP, not restricted	Not restricted	—	—
SAW	Mean ±10% for each diameter	Mean ±7% for each diameter	Mean ±15% for each diameter	—	Flux trade designation
FCAW	Mean ±10% for each diameter	Mean ±7% for each diameter	Mean ±25% for each diameter	Rate +25%, –10%	Nominal gas composition, if used
GMAW	Mean ±10% for each diameter	Mean ±7% for each diameter	Mean ±25% for each diameter	Rate +25%, –10%	Nominal gas composition
GTAW	Mean ±25%	Mean ±25%	Not restricted	Rate +50%, –25%	Nominal gas composition

[a] Position shall be specified for all WPSs. "MR" = electrode manufacturer's recommended range.

Table 3.2
Prequalified Austenitic Stainless Steels (see 3.6.1)

Minimum Tensile Strength ksi (MPa)	Minimum Yield Strength ksi (MPa)	Base Metal Group[a]	Alloy Designation[a]	UNS Number	ASTM Specification				
					Plate, Sheet, Strip	Tubes	Plate, Sheet, Strip	Tubes	Bars, Shapes
70 (490)	25 (170)	A	304L	S30403	A167	A213	A240	A249	A276
70 (490)	25 (170)	A	316L	S31603	A167		A240	A249	A276
75 (520)	30 (200)	B	301	S30100	A167				
75 (520)	30 (200)	B	302	S30200	A167		A240		A276
75 (520)	30 (200)	B	304	S30400	A167	A213	A240	A249	A276
75 (520)	30 (200)	B	304H	S30409		A213	A240	A249	
75 (520)	30 (200)	B	308	S30880	A167				A276
75 (520)	30 (200)	B	309	S30900	A167				A276
75 (520)	30 (200)	B	309Cb	S30940	A167	A213	A240	A249	A276
75 (520)	30 (200)	B	309H	S30909			A240	A249	
75 (520)	30 (200)	B	309HCb	S30941		A213		A249	
75 (520)	30 (200)	B	309HCb	S30949			A240		
75 (520)	30 (200)	B	309S	S30908	A167	A213	A240		A276
75 (520)	30 (200)	B	316	S31600	A167	A213	A240	A249	A276
75 (520)	30 (200)	B	316Cb	S31640	A167		A240		A276
75 (520)	30 (200)	B	316H	S31609		A213	A240	A249	
75 (520)	30 (200)	B	316Ti	S31635	A167		A240		A276
75 (520)	30 (200)	B	317	S31700	A167	A213	A240	A249	A276
75 (520)	30 (200)	B	317L	S31703	A167	A213	A240	A249	
75 (520)	30 (200)	B	321	S32100	A167	A213	A240	A249	A276
75 (520)	30 (200)	B	321H	S32109	A167	A213	A240	A249	A276
75 (520)	30 (200)	B	347	S34700	A167	A213	A240	A249	A276
75 (520)	30 (200)	B	347H	S34709		A213	A240	A249	
75 (520)	30 (200)	B	348	S34800	A167	A213	A240	A249	A276
75 (520)	30 (200)	B	348H	S34809		A213	A240	A249	
75 (520)	40 (280)	B	202	S20200					A276
75 (520)	40 (280)	B	201	S20100					A276
90 (620)	38 (260)	D	202	S20200			A240	A249	
90 (620)	45 (310)	D	202	S20200		A213			
90 (620)	50 (345)	D	XM-11	S21904					A276
90 (620)	50 (345)	D	XM-10	S21900					A276
95 (660)	35 (245)	E	201	S20100				A249	
95 (660)	38 (260)	E	201	S20100		A213			
95 (660)	38 (260)	E	201-1	S20100			A240		
95 (660)	45 (310)	E	201-2	S20100			A240		
100 (690)	55 (380)	E	XM-29	S24000			A240	A249	A276
100 (690)	55 (380)	E	XM-28	S24100					A276
100 (690)	55 (380)	E	XM-19	S20910			A240	A249	A276
100 (690)	60 (415)	E	205	S20500					A276

[a] Several alloy designations appear in both Base Metal Group A and Group B. The correct Base Metal Group for a given base metal depends upon the ASTM Specification to which it was purchased.

Note: Prequalified filler metals for each Base Metal Group are given in the corresponding Filler Metal Group of Table 3.3.

Table 3.2 (Continued) Prequalified Austenitic Stainless Steels (see 3.6.1)

Minimum Tensile Strength ksi (MPa)	Minimum Yield Strength ksi (MPa)	Base Metal Group[a]	Alloy Designation[a]	UNS Number	ASTM Specification					
					Pipe	Castings	Pipe	Fittings	Pipe	Pipe
70 (490)	25 (170)	A	304L	S30403	A 312			A 403	A 409	
70 (490)	25 (170)	A	316L	S31603	A 312			A 403	A 409	
70 (490)	30 (200)	A	16 8-2H							A 430
70 (490)	30 (200)	A	304							A 430
70 (490)	30 (200)	A	304H							A 430
70 (490)	30 (200)	A	316							A 430
70 (490)	30 (200)	A	316H							A 430
70 (490)	30 (200)	A	321							A 430
70 (490)	30 (200)	A	321H							A 430
70 (490)	30 (200)	A	347							A 430
70 (490)	30 (200)	A	347H							A 430
70 (490)	30 (200)	A	CF-10			A 351				
70 (490)	30 (200)	A	CF-10M			A 351				
70 (490)	30 (200)	A	CF-3			A 351				
70 (490)	30 (200)	A	CF-3M			A 351				
70 (490)	30 (200)	A	CF-8			A 351				
70 (490)	30 (200)	A	CF-8C			A 351				
70 (490)	30 (200)	A	CH-20			A 351				
75 (520)	30 (200)	B	16 8-2H				A 376			
75 (520)	30 (200)	B	304	S30400	A 312		A 376	A 403	A 409	
75 (520)	30 (200)	B	304H	S30409	A 312		A 376	A 403		
75 (520)	30 (200)	B	309	S30900				A 403		
75 (520)	30 (200)	B	309Cb	S30940	A 312				A 409	
75 (520)	30 (200)	B	309H	S30909	A 312					
75 (520)	30 (200)	B	309HCb	S30941	A 312					
75 (520)	30 (200)	B	309S	S30908	A 312				A 409	
75 (520)	30 (200)	B	316	S31600	A 312		A 376	A 403	A 409	
75 (520)	30 (200)	B	316H	S31609	A 312		A 376	A 403		
75 (520)	30 (200)	B	317	S31700	A 312			A 403	A 409	
75 (520)	30 (200)	B	317L	S31703	A 312			A 403		
75 (520)	30 (200)	B	321	S32100	A 312		A 376	A 403	A 409	
75 (520)	30 (200)	B	321H	S32109	A 312		A 376	A 403		
75 (520)	30 (200)	B	347	S34700	A 312		A 376	A 403	A 409	
75 (520)	30 (200)	B	347H	S34709	A 312		A 376	A 403		
75 (520)	30 (200)	B	348	S34800	A 312		A 376	A 403	A 409	
75 (520)	30 (200)	B	348H	S34809	A 312			A 403		
75 (520)	35 (200)	B	CG-8M			A 351				
77 (530)	35 (245)	C	CF-3A			A 351				
77 (530)	35 (245)	C	CF-8A			A 351				
80 (550)	37 (255)	C	CF-3MA			A 351				
90 (620)	50 (345)	D	XM-11	S21903	A 312					
90 (620)	50 (345)	D	XM-10	S21900	A 312					
100 (690)	55 (380)	E	XM-29	S24000	A 312					
100 (690)	55 (380)	E	XM-19	S20910	A 312			A 403		

[a] Several alloy designations appear in both Base Metal Group A and Group B. The correct Base Metal Group for a given base metal depends upon the ASTM Specification to which it was purchased.

Note: Prequalified filler metals for each Base Metal Group are given in the corresponding Filler Metal Group of Table 3.3.

Table 3.2 (Continued)
Prequalified Austenitic Stainless Steels (see 3.6.1)

Minimum Tensile Strength ksi (MPa)	Minimum Yield Strength ksi (MPa)	Base Metal Group[a]	Alloy Designation[a]	UNS Number	ASTM Specification: Cast Pipe	Pipe	Forgings	Bars, Shapes	Tube	Tube	Plate, Sheet, Bars, Strips	Castings
65 (450)	25 (170)	A	304L	S30403			A 473					
65 (450)	25 (170)	A	316L	S31603			A 473					
65 (450)	28 (195)	A	CPH8		A 451							
70 (490)	25 (170)	A	304L	S30403				A 479			A 666	
70 (490)	25 (170)	A	316L	S31603				A 479			A 666	
70 (490)	28 (195)	A	CG-12									A 743
70 (490)	30 (200)	A	CF-20									A 743
70 (490)	30 (200)	A	CF-3									A 743
70 (490)	30 (200)	A	CF-3M									A 743
70 (490)	30 (200)	A	CF-8									A 743
70 (490)	30 (200)	A	CF-8C									A 743
70 (490)	30 (200)	A	CF-8M									A 743
70 (490)	30 (200)	A	CH-20									A 743
70 (490)	30 (200)	A	CPF3		A 451							
70 (490)	30 (200)	A	CPF3M		A 451							
70 (490)	30 (200)	A	CPF8		A 451							
70 (490)	30 (200)	A	CPF8C		A 451							
70 (490)	30 (200)	A	CPF8M		A 451							
70 (490)	30 (200)	A	CPH10		A 451							
70 (490)	30 (200)	A	CPH20		A 451							
75 (520)	30 (200)	B	201	S20100			A 473					
75 (520)	30 (200)	B	301	S30100						A 554	A 666	
75 (520)	30 (200)	B	302	S30200			A 473	A 479	A 511	A 554	A 666	
75 (520)	30 (200)	B	304	S30400			A 473	A 479	A 511	A 554	A 666	
75 (520)	30 (200)	B	304H	S30409		A 452		A 479				
75 (520)	30 (200)	B	304L						A 511	A 554		
75 (520)	30 (200)	B	308	S30880			A 473	A 479				
75 (520)	30 (200)	B	309	S30900			A 473					
75 (520)	30 (200)	B	309Cb	S30940				A 479				
75 (520)	30 (200)	B	309H	S30909				A 479				
75 (520)	30 (200)	B	309S	S30908			A 473	A 479	A 511	A 554		
75 (520)	30 (200)	B	309S-Cb							A 554		
75 (520)	30 (200)	B	316	S31600				A 479	A 511	A 554	A 666	
75 (520)	30 (200)	B	316Cb	S31640				A 479				
75 (520)	30 (200)	B	316H	S31609		A 452		A 479				
75 (520)	30 (200)	B	316L						A 511	A 554		
75 (520)	30 (200)	B	316Ti	S31635				A 479				
75 (520)	30 (200)	B	317	S31700			A 473		A 511	A 554		
75 (520)	30 (200)	B	321	S32100			A 473	A 479	A 511	A 554		
75 (520)	30 (200)	B	321H	S32109				A 479				
75 (520)	30 (200)	B	347	S34700			A 473	A 479	A 511	A 554		
75 (520)	30 (200)	B	347H	S34709		A 452		A 479				
75 (520)	30 (200)	B	348	S34800			A 473	A 479				
75 (520)	30 (200)	B	348H	S34809				A 479				
75 (520)	35 (245)	B	CG-8M									A 743
77 (530)	35 (245)	C	CF-3A		A 451							
90 (620)	38 (260)	D	202	S20200							A 666	

[a] Several alloy designations appear in both Base Metal Group A and Group B. The correct Base Metal Group for a given base metal depends upon the ASTM Specification to which it was purchased.

Note: Prequalified filler metals for each Base Metal Group are given in the corresponding Filler Metal Group of Table 3.3.

Table 3.2 (Continued)
Prequalified Austenitic Stainless Steels (see 3.6.1)

Minimum Tensile Strength ksi (MPa)	Minimum Yield Strength ksi (MPa)	Base Metal Group[a]	Alloy Designation[a]	UNS Number	ASTM Specification							
					Cast Pipe	Pipe	Forgings	Bars, Shapes	Tube	Tube	Plate, Sheet, Bars, Strips	Castings
90 (620)	45 (310)	D	202	S20200			A 473					
90 (620)	50 (345)	D	205	S20500			A 473					
90 (620)	50 (345)	D	XM-11	S21904			A 473	A 479			A 666	
90 (620)	50 (345)	D	XM-10	S21900			A 473					
90 (620)	50 (345)	D	XM-17	S21600				A 479				
90 (620)	50 (345)	D	XM-18	S21603				A 479				
95 (660)	38 (260)	E	201-1	S20100							A 666	
95 (660)	45 (310)	E	201-2	S20100							A 666	
100 (690)	55 (380)	E	XM-29	S24000				A 479				
100 (690)	55 (380)	E	XM-19	S20910				A 479				

[a] Several alloy designations appear in both Base Metal Group A and Group B. The correct Base Metal Group for a given base metal depends upon the ASTM Specification to which it was purchased.

Note: Prequalified filler metals for each Base Metal Group are given in the corresponding Filler Metal Group of Table 3.3.

Table 3.2 (Continued)
Prequalified Austenitic Stainless Steels (see 3.6.1)

Minimum Tensile Strength ksi (MPa)	Minimum Yield Strength ksi (MPa)	Base Metal Group[a]	Alloy Designation[a]	UNS Number	ASTM Specification						
					Castings	Fittings	Tube	Pipe	Pipe	Bars, Billets, Forgings	Tube
70 (490)	25 (170)	A	304L	S30403		A 774	A 778	A 813	A 814		A 851
70 (490)	25 (170)	A	316L	S31603		A 774	A 778	A 813	A 814		
70 (490)	30 (200)	A	CF-3		A 744						
70 (490)	30 (200)	A	CF-3M		A 744						
70 (490)	30 (200)	A	CF-8		A 744						
70 (490)	30 (200)	A	CF-8C		A 744						
70 (490)	30 (200)	A	CF-8M		A 744						
75 (520)	30 (200)	B	304	S30400				A 813	A 814		A 851
75 (520)	30 (200)	B	304H	S30409				A 813	A 814		
75 (520)	30 (200)	B	309Cb	S30940				A 813	A 814		
75 (520)	30 (200)	B	309S	S30908				A 813	A 814		
75 (520)	30 (200)	B	316	S31600				A 813	A 814	A 831	
75 (520)	30 (200)	B	316H	S31609				A 813	A 814		
75 (520)	30 (200)	B	317	S31700				A 813	A 814		
75 (520)	30 (200)	B	317L	S31703		A 774	A 778	A 813	A 814		
75 (520)	30 (200)	B	321	S32100		A 774	A 778	A 813	A 814		
75 (520)	30 (200)	B	321H	S32109				A 813	A 814		
75 (520)	30 (200)	B	347	S34700		A 774	A 778	A 813	A 814		
75 (520)	30 (200)	B	347H	S34709				A 813	A 814		
75 (520)	30 (200)	B	348	S34800				A 813	A 814		
75 (520)	30 (200)	B	348H	S34809				A 813	A 814		
75 (520)	35 (245)	B	CG 8M		A 744						
90 (620)	50 (345)	D	XM-11	S21903				A 813	A 814		
90 (620)	50 (345)	D	XM-10	S21900				A 813	A 814		
100 (690)	55 (380)	E	XM-29	S24000				A 813	A 814		
100 (690)	55 (380)	E	XM-19	S20910				A 813	A 814		

[a] Several alloy designations appear in both Base Metal Group A and Group B. The correct Base Metal Group for a given base metal depends upon the ASTM Specification to which it was purchased.

Note: Prequalified filler metals for each Base Metal Group are given in the corresponding Filler Metal Group of Table 3.3.

Table 3.3
Prequalified Filler Metal Classifications[a] (see 3.9.1)

AWS A5.4/A5.4M:2006	AWS A5.9/A5.9M:2006	AWS A5.22-95R	AWS A5.30-97
Filler Metal Group A—70 ksi [490 MPa] Minimum Tensile Strength			
E316L-XX	ER316L ER316LSi EC316L	E316LTX-X R316LT1-5	IN316L
Filler metals of Groups B, C, D, and E are also prequalified for Group A base metals			
Filler Metal Group B—75 ksi [520 MPa] Minimum Tensile Strength			
E308L-XX E308MoL-XX E309L-XX E309MoL-XX E316-XX E316H-XX E317L-XX E347-XX	ER308L ER308MoL ER309L ER309MoL ER316 ER316H ER317L ER347	E308LTX-X E308LMoTX-X E309LTX-X E309LMoTX-X E309LCbTX-X E316TX-X E317LTX-X E347TX-X R308LT1-5 R309LT1-5 R347T1-5	IN308L IN316
Filler metals of Groups C, D, and E are also prequalified for Group B base metals			
Filler Metal Group C—80 ksi [550 MPa] Minimum Tensile Strength			
E307-XX E308-XX E308H-XX E308Mo-XX E309-XX E309Cb-XX E309Mo-XX E317-XX E318-XX E16-8-2-XX	ER307 ER308 ER308H ER308Mo ER309 ER309Mo ER317 ER318 ER16-8-2	E307TX-X E308TX-X E308MoTX-X E309TX-X E309MoTX-X	IN308
Filler metals of Groups D and E are also prequalified for Group C base metals			
Filler Metal Group D—90 ksi [620 MPa] Minimum Tensile Strength			
E219-XX	ER219		
Filler metals of Group E are also prequalified for Group D base metals			
Filler Metal Group E—100 ksi [690 MPa] Minimum Tensile Strength			
E209-XX E240-XX	ER209 ER240		

[a] Electrode classifications with high silicon modifications (indicated by inclusion of "Si" in the classification designation) are prequalified along with the corresponding lower silicon version. Thus, the ER308Si classification is prequalified for the same base metals as is the ER308 classification, and so forth. Metal cored electrodes, indicated by a "C" in place of the "R," are prequalified only for GMAW and SAW processes, along with the corresponding solid wire classifications. Thus, the EC308L classification is prequalified with GMAW and SAW for the same base metals as is the ER308L classification, and so forth.

Table 3.4
Effective Weld Sizes of
Flare-Groove Welds (see 3.17)

Flare-Bevel-Groove Welds	Flare-V-Groove Welds
5/16 R	1/2 R[a]

Note: R = radius of outside surface.

[a] Use 3/8 in. [10 mm] for GMAW. Effective size shall be qualified for the GMAW short circuiting transfer process.

Table 3.5
Prequalified WPS Requirements (see 3.29)

<table>
<tr><th>Variable</th><th>Position</th><th>Weld Type</th><th>SMAW</th><th>SAW[b]</th><th>GMAW[c, d]</th><th>FCAW[c, e]</th><th>GTAW[c, g, h]</th></tr>
<tr><td rowspan="7">Maximum Electrode Diameter in. [mm]</td><td rowspan="3">Flat</td><td>Fillet</td><td>1/4 [6.4]</td><td>5/16 [8.0]</td><td rowspan="7">1/16 [1.6]</td><td rowspan="7">3/32 [2.4]</td><td rowspan="7">5/32 [4.0]</td></tr>
<tr><td>Groove</td><td>1/4 [6.4]</td><td>5/16 [8.0]</td></tr>
<tr><td>Root Pass</td><td>1/4 [6.4][a]</td><td>5/16 [8.0]</td></tr>
<tr><td rowspan="2">Horizontal</td><td>Fillet</td><td>1/4 [6.4]</td><td>5/16 [8.0]</td></tr>
<tr><td>Groove</td><td>3/16 [4.8]</td><td>5/16 [8.0]</td></tr>
<tr><td>Vertical</td><td rowspan="2">All</td><td rowspan="2">5/32 [4.0]</td><td rowspan="2">NA</td></tr>
<tr><td>Overhead</td></tr>
<tr><td rowspan="5">Maximum Current (A)</td><td>All</td><td>Fillet</td><td rowspan="5">Within the range of recommended operation by the filler metal manufacturer</td><td>600 (H)
800 (F)</td><td rowspan="5">Within the range of recommended operation by the filler metal manufacturer</td><td rowspan="5">Within the range of recommended operation by the filler metal manufacturer</td><td rowspan="5">See Note g</td></tr>
<tr><td rowspan="4">All</td><td>Groove Weld Root Pass With Opening</td><td rowspan="3">600</td></tr>
<tr><td>Groove Weld Root Pass Without Opening</td></tr>
<tr><td>Groove Weld Fill Passes</td></tr>
<tr><td>Groove Weld Cap Passes</td><td>800</td></tr>
<tr><td rowspan="4">Maximum Root Pass Thickness in. [mm][f]</td><td>Flat</td><td rowspan="4">All</td><td>1/4 [6]</td><td>1/2 [12]</td><td>3/16 [5]</td><td>1/4 [6]</td><td rowspan="4">3/16 [5]</td></tr>
<tr><td>Horizontal</td><td>1/4 [6]</td><td>3/8 [10]</td><td>3/16 [5]</td><td>1/4 [6]</td></tr>
<tr><td>Vertical</td><td>1/4 [6]</td><td rowspan="2">NA</td><td>3/16 [5]</td><td>1/4 [6]</td></tr>
<tr><td>Overhead</td><td>1/4 [6]</td><td>3/16 [5]</td><td>1/4 [6]</td></tr>
<tr><td rowspan="4">Maximum Fill Pass Thickness in. [mm]</td><td>Flat</td><td rowspan="4">All</td><td>1/8 [3]</td><td>1/4 [6]</td><td rowspan="4">1/4 [6]</td><td rowspan="4">1/4 [6]</td><td rowspan="4">1/8 [3]</td></tr>
<tr><td>Horizontal</td><td>3/16 [5]</td><td>5/16 [8]</td></tr>
<tr><td>Vertical</td><td>3/16 [5]</td><td rowspan="2">NA</td></tr>
<tr><td>Overhead</td><td>3/16 [5]</td></tr>
<tr><td rowspan="4">Maximum Single Pass Fillet Weld Size in. [mm]</td><td>Flat</td><td rowspan="4">Fillet</td><td>3/8 [10]</td><td>1/2 [12]</td><td>1/2 [12]</td><td>1/2 [12]</td><td>1/4 [6]</td></tr>
<tr><td>Horizontal</td><td>5/16 [8]</td><td>5/16 [8]</td><td>5/16 [8]</td><td>5/16 [8]</td><td>3/16 [5]</td></tr>
<tr><td>Vertical</td><td>1/2 [12]</td><td rowspan="2">NA</td><td>1/2 [12]</td><td>1/2 [12]</td><td>3/16 [5]</td></tr>
<tr><td>Overhead</td><td>5/16 [8]</td><td>1/4 [6]</td><td>5/16 [8]</td><td>3/16 [5]</td></tr>
<tr><td>Maximum Single Pass Layer Width in. [mm][i]</td><td>All (for SMAW, GMAW, FCAW, GTAW)
F & H (for SAW)</td><td>Any individual layer of width w</td><td>1/2 [12]</td><td>5/8 [16]</td><td>1/2 [12]</td><td>1/2 [12]</td><td>1/2 [12]</td></tr>
</table>

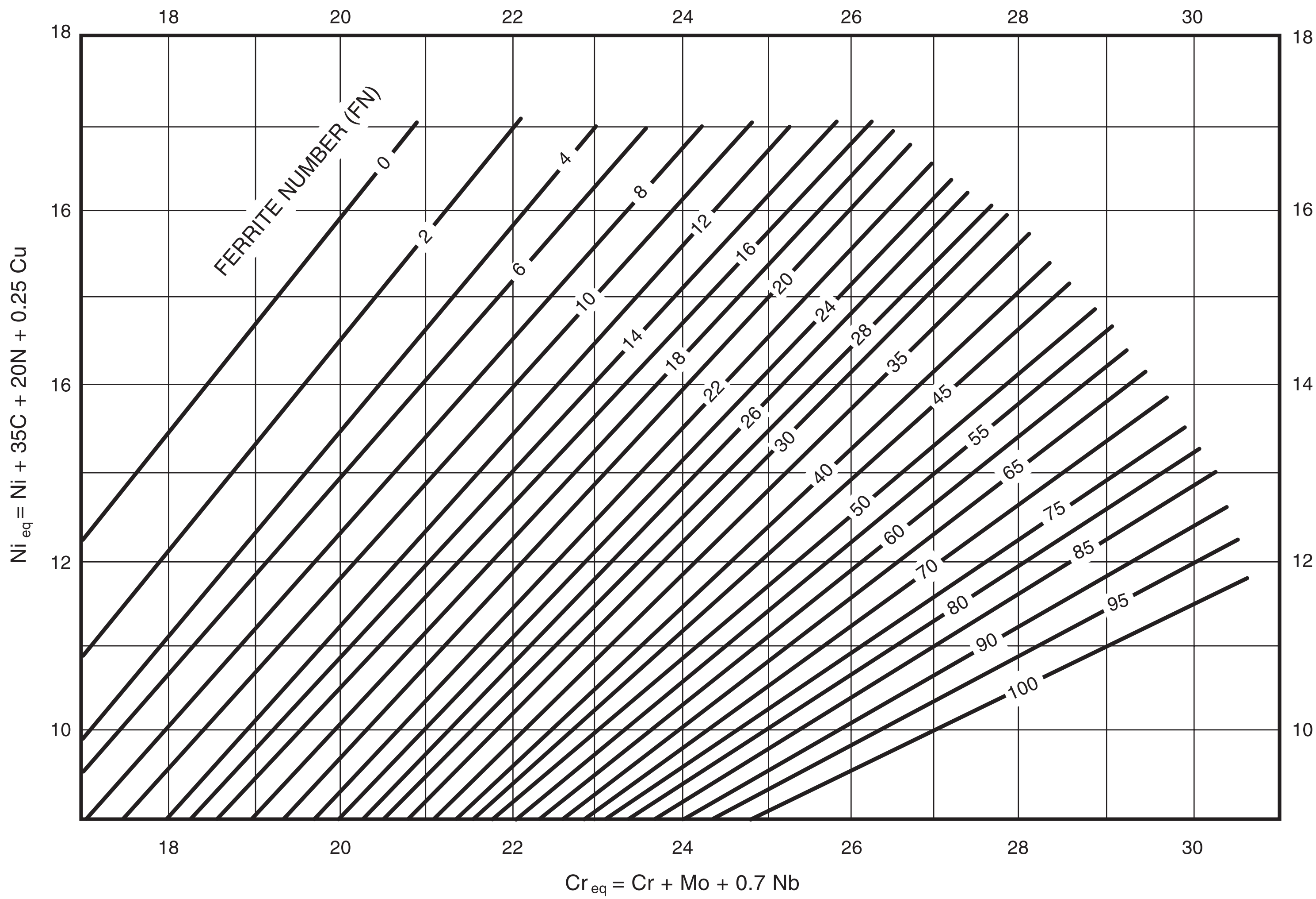
(Continued)

Table 3.5 (Continued)
Prequalified WPS Requirements (see 3.29)

[a] 1/4 in. [6 mm] for fillet welds and groove welds with backing and a root opening of 1/4 in. [6 mm] or more.
[b] Single electrode.
[c] See 3.29(8).
[d] Pulsed GMAW is prequalified in all positions except vertical down. Prequalification of short circuiting transfer GMAW is limited to helium base shielding gas mixes (at least 85% He by volume), extends to all positions, but is limited to 3/16 in. [5 mm] maximum base metal thickness. Prequalified shielding gases for all GMAW are argon and/or helium-based and limited to those containing at least 0.5%, but not more than 6% total, by volume, of oxygen plus carbon dioxide, including no more than 3% carbon dioxide.
[e] Gas shielded FCAW is prequalified in all positions, except that vertical-down prequalification is limited to 3/16 in. [5 mm] maximum base metal thickness. Self-shielded FCAW is prequalified in the flat and horizontal positions only. Prequalified shielding gases for electrodes classified with gas shielding are limited to welding grade carbon dioxide and mixes of argon with not less than 20%, by volume, carbon dioxide. Self-shielded electrodes are prequalified only without external shielding gas.
[f] See Figure 3.7 for Width-to-Depth limitations.
[g] GTAW and Pulse GTAW is prequalified in all welding positions, DCEN only. Prequalified shielding gases are restricted to welding grade (or higher purity) argon, helium, and argon-helium mixes. Prequalified current range depends upon tungsten electrode diameter (size) as follows:

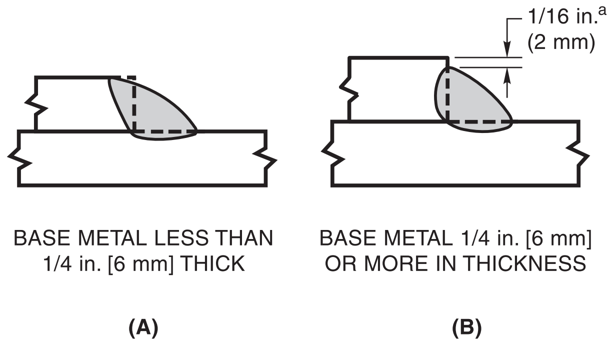
Electrode Diameter		
in.	mm	Current Range, DCEN
0.060 (1/16)	1.60	40–150
0.093 (3/32)	2.40	60–250
	2.50	70–250
	3.00	90–350
0.125 (1/8)	3.20	100–400
0.156 (5/32)	4.00	150–500

[h] For GTAW the electrode is per AWS A5.12/A5.12M-98, *Specification for Tungsten and Tungsten-Alloy Electrodes for Arc Welding and Cutting*.
[i] Split layers when the maximum single pass layer width is exceeded.
H = Horizontal
F = Flat



Note: This diagram is identical to the WRC-1992 Diagram, except that the solidification mode lines have been removed for ease of use.

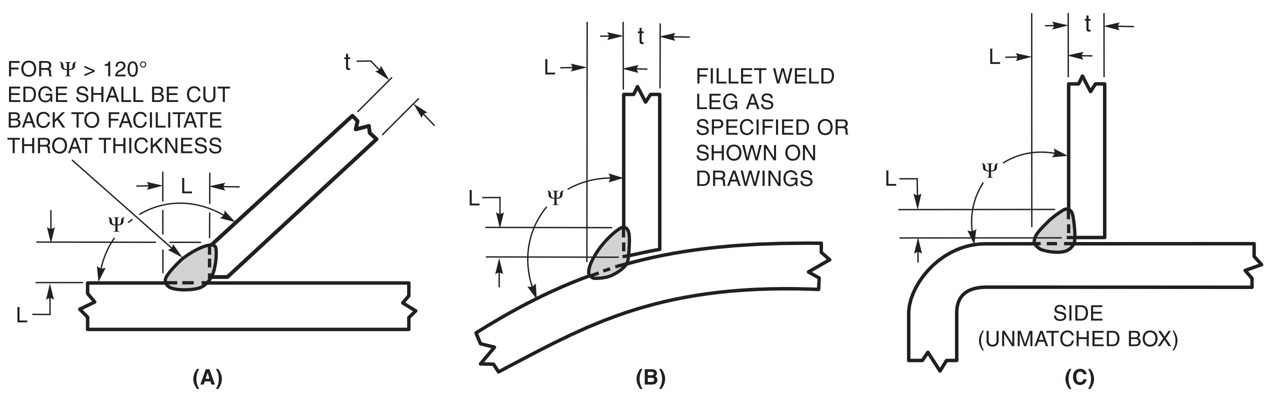
Figure 3.1—Weld Metal Delta Ferrite Content (see 3.12.2)

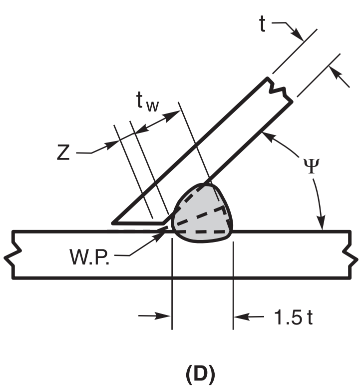


Maximum detailed size of fillet weld along edges

[a]The 1/16 in. [2 mm] distance need not be maintained provided that the effective weld size can be determined.

Figure 3.2—Details for Prequalified Fillet Welds (see 3.14.1)





DIHEDRAL ANGLE = Ψ	MIN L FOR		
	E = 0.7t	E = t	E = 1.07t
SIDE ≤ 100°	t	1.4t	1.5t
SIDE 100°–110°	1.1t	1.6t	1.75t
SIDE 110°–120°	1.2t	1.8t	2.0t
TOE > 120°	t BEVEL	1.4t BEVEL	FULL BEVEL 60°–90° GROOVE

Notes:
1. t = thickness of thinner part.
2. L = minimum size.
3. Root opening 0 to 3/16 in. [5 mm]—see 5.4.
4. Not prequalified for Ψ < 60°.
5. Z—see 2.16.

Figure 3.3—Fillet Welded Prequalified Joints (see 3.28.3)

Legend for Figures 3.4 and 3.5

Symbols for joint types

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

Symbols for base metal thickness and penetration

L — limited thickness–complete joint penetration
U — unlimited thickness–complete joint penetration
P — partial joint penetration

Symbol for weld types

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

Symbols for welding processes if not shielded metal arc

S — submerged arc welding
G — gas metal arc welding
F — flux cored arc welding

Welding processes

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

Welding positions

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

Dimensions

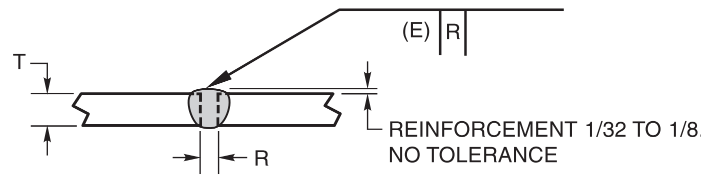
R = Root Opening
α, β = Groove Angles
f = Root Face
r = J- or U-groove Radius
S, S_1, S_2 = PJP Groove Weld Depth of Groove
E, E_1, E_2 = PJP Groove Weld Sizes corresponding to S, S_1, S_2, respectively

Joint Designation

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

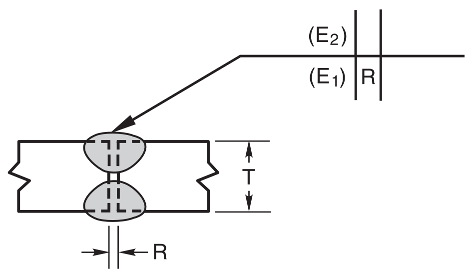
See Notes on Page 70

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



Welding Process	Joint Designation	Base Metal Thickness T	Groove Preparation: Root Opening	Tolerances: As Detailed (see 3.23.2)	Tolerances: As Fit-Up (see 5.4)	Permitted Welding Positions	Weld Size (E)	Notes
SMAW GTAW FCAW GMAW	B-P1a	16 ga to 1/8	R = 0 to T/2	+T/2, –0	±T/2	All	3T/4	a, b, o
	B-P1c	1/8 to 1/4 max.	R = T/2 min.	+1/16, –0	±1/16	All	T/2	a, b, o

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



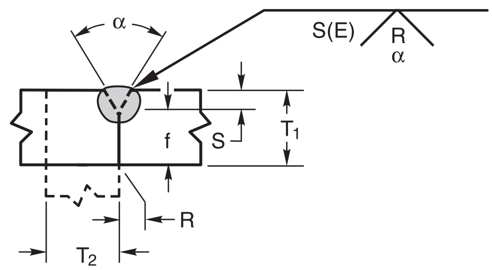
$E_1 + E_2$ MUST NOT EXCEED 3T/4

Welding Process	Joint Designation	Base Metal Thickness T	Groove Preparation: Root Opening	Tolerances: As Detailed (see 3.23.2)	Tolerances: As Fit-Up (see 5.4)	Permitted Welding Positions	Total Weld Size $(E_1 + E_2)$	Notes
SMAW GTAW FCAW GMAW	B-P1b	1/4 max.	R = T/2	+T/4, –0	±T/4	All	T/4	a, o

Figure 3.4—Prequalified PJP Groove Welded Joints—Nontubular (see 3.23.1)

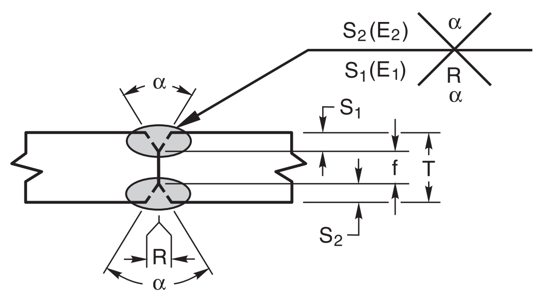
See Notes on Page 70

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



Welding Process	Joint Designation	Base Metal Thickness (U = Unlimited) T_1	T_2	Groove Preparation: Root Opening Root Face Groove Angle	Tolerances: As Detailed (see 3.23.2)	As Fit-Up (see 5.4)	Permitted Welding Positions	Weld Size (E)	Notes
SMAW GTAW	BC-P2	1/8 min.	U	R = 0 f = 1/32 min. α = 60°	0, +1/16 +U, –0 +10°, –0°	$+T_1/2$, –1/16 ±1/16 +10°, –5°	All	S	f, l, o
FCAW GMAW GTAW	BC-P2-GF	1/4 min.	U	R = 0 f = 1/8 min. α = 60°	0, +1/16 +U, –0 +10°, –0°	+1/8, –1/16 ±1/16 +10°, –5°	All	S	a, f, l, o
GMAW SAW	BC-P2-a	7/16 min.	U	R = 0 f = 1/4 min. α = 60°	±0 +U, –0 +10°, –0°	+1/16, –0 ±1/16 +10°, –5°	F	S	a, l

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

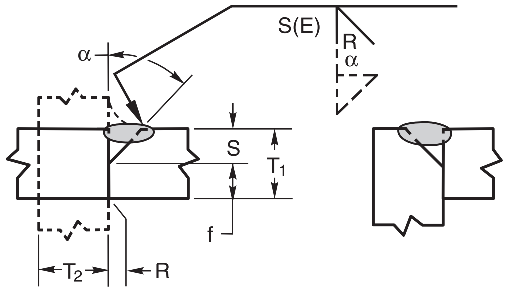


Welding Process	Joint Designation	Base Metal Thickness T	Groove Preparation: Root Opening Root Face Groove Angle	Tolerances: As Detailed (see 3.23.2)	As Fit-Up (see 5.4)	Permitted Welding Positions	Total Weld Size ($E_1 + E_2$)	Notes
GTAW SMAW	B-P3	3/16 min.	R = 0 f = 1/16 min. α = 60°	+1/16, –0 +U, –0 +10°, –0°	+T/2, –1/16 ±1/16 +10°, –5°	All	$S_1 + S_2$	f, j, l, o
FCAW GMAW GTAW	B-P3-GF	3/16 min.	R = 0 f = 1/8 min. α = 60°	+1/16, –0 +U, –0 +10°, –0°	+1/8, –1/16 ±1/16 +10°, –5°	All	$S_1 + S_2$	a, f, j, l, o
GMAW SAW	B-P3-a	3/4 min.	R = 0 f = 1/4 min. α = 60°	±0 +U, –0 +10°, –0°	+1/16, –0 ±1/16 +10°, –5°	F	$S_1 + S_2$	a, j, l

Figure 3.4 (Continued)—Prequalified PJP Groove Welded Joints—Nontubular (see 3.23.1)

See Notes on Page 70

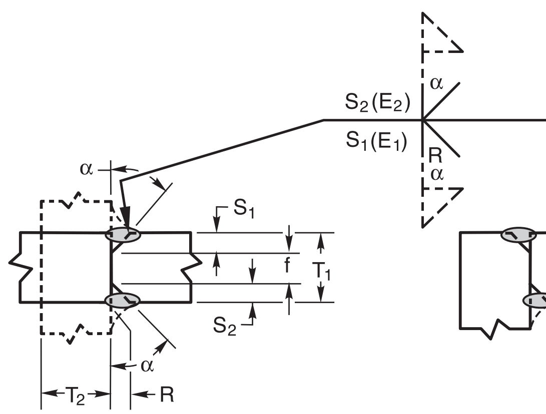
Single-bevel-groove (4)
Butt joint (B)
T-joint (T)
Corner joint (C)



Welding Process	Joint Designation	Base Metal Thickness (U = Unlimited) T_1	T_2	Groove Preparation: Root Opening Root Face Groove Angle	Tolerances: As Detailed (see 3.23.2)	As Fit-Up (see 5.4)	Permitted Welding Positions	Weld Size (E)	Notes
SMAW GTAW	BTC-P4	3/16 min.	U	R = 0 f = 1/16 min. α = 45°	+1/16, –0 Unlimited[a] +10°, –0°	+1/8, –1/16 ±1/16 +10°, –5°	All	S–1/8	f, g, l, n, o
GMAW FCAW	BTC-P4-GF	3/8 min.	U	R = 0 f = 1/8 min. α = 45°	+1/16, –0 Unlimited[a] +10°, –0°	+1/8, –1/16 ±1/16 +10°, –5°	F, H	S	a, g, l, n
							n, OH	S–1/8	
GMAW SAW	TC-P4-S	7/16 min.	U	R = 0 f = 1/4 min. α = 60°	±0 +U, –0 +10°, –0°	+1/16, –0 ±1/16 +10°, –5°	F	S	a, g, l, n

[a]For flat and horizontal position: f = +U, –0.

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

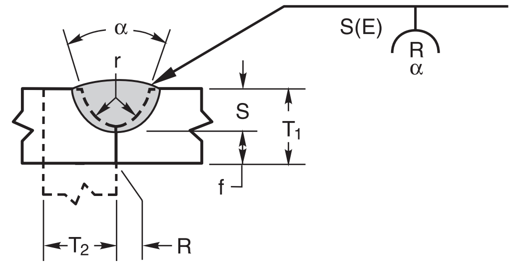


Welding Process	Joint Designation	Base Metal Thickness (U = Unlimited) T_1	T_2	Groove Preparation: Root Opening Root Face Groove Angle	Tolerances: As Detailed (see 3.23.2)	As Fit-Up (see 5.4)	Permitted Welding Positions	Total Weld Size ($E_1 + E_2$)	Notes
SMAW GTAW	BTC-P5	5/16 min.	U	R = 0 f = 1/16 min. α = 45°	+1/16, –0 Unlimited + 10°, –0°	+1/8, –1/16 ±1/16 +10°, –5°	All	($S_1 + S_2$) –1/4	f, g, h, j, l, n, o
GMAW	BTC-P5-G	3/8 min.	U	R = 0 f = 1/8 min. α = 45°	+1/16, –0 Unlimited +10°, –0°	+1/8, –1/16 ±1/16 +10°, –5°	F, H	$S_1 + S_2$	a, g, h, j, l, n
FCAW	BTC-P5-F	5/8 min.					n, OH	($S_1 + S_2$) –1/4	
GMAW SAW	TC-P5	3/4 min.	U	R = 0 f = 1/4 min. α = 60°	±0 +U, –0 +10°, –0°	+1/16, –0 ±1/16 +10°, –5°	F	$S_1 + S_2$	a, g, h, j, l, n

Figure 3.4 (Continued)—Prequalified PJP Groove Welded Joints—Nontubular (see 3.23.1)

See Notes on Page 70

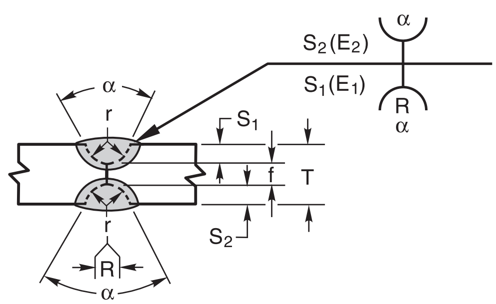
Single-U-groove weld (6)
Butt joint (B)
Corner joint (C)



Welding Process	Joint Designation	Base Metal Thickness (U = Unlimited) T1	T2	Groove Preparation: Root Opening Root Face Groove Radius Groove Angle	Tolerances: As Detailed (see 3.23.2)	Tolerances: As Fit-Up (see 5.4)	Permitted Welding Positions	Weld Size (E)	Notes
SMAW GTAW GMAW	BC-P6	1/8 min.	U	R = 0 f = 1/32 min. r = T/2[a] α = 45°	+1/16, –0 +U, –0 +1/4, –0 + 10°, –0°	+1/8, –1/16 ±1/16 ±1/16 +10°, –5°	All	S	a, l, o
FCAW	BC-P6-F	1/4 min.	U	R = 0 f = 1/8 min. r = T/2[a] α = 20°	+1/16, –0 +U, –0 +1/4, –0 + 10°, –0°	+1/8, –1/16 ±1/16 ±1/16 +10°, –5°	All	S	l, o
GMAW SAW	BC-P6-a	7/16 min.	U	R = 0 f = 1/4 min. r = T/2 α = 20°	±0 +U, –0 +1/4, –0 +10°, –0°	+1/16, –0 ±1/16 ±1/16 +10°, –5°	F	S	a, l

[a] But not greater than 1/4 in.

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



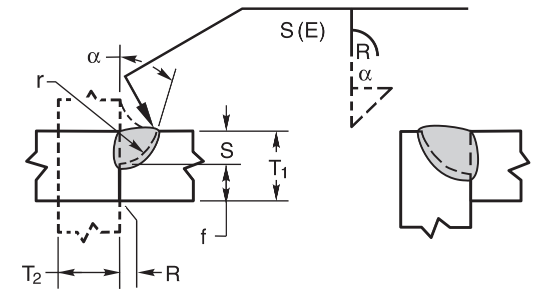
Welding Process	Joint Designation	Base Metal Thickness T	Groove Preparation: Root Opening Root Face Groove Radius Groove Angle	Tolerances: As Detailed (see 3.23.2)	Tolerances: As Fit-Up (see 5.4)	Permitted Welding Positions	Total Weld Size ($E_1 + E_2$)	Notes
SMAW GTAW GMAW	B-P7	1/4 min.	R = 0 f = 1/16 min. r = T/2[a] α = 45°	+1/16, –0 +U, –0 +T/4, –0 + 10°, –0°	+1/8, –1/16 ±1/16 ±1/16 +10°, –5°	All	$S_1 + S_2$	a, j, l, o
FCAW	B-P7-F	3/8 min.	R = 0 f = 1/8 min. r = T/2[a] α = 20°	+1/16, –0 +U, –0 +T/4, –0 + 10°, –0°	+1/8, –1/16 ±1/16 ±1/16 +10°, –5°	All	$S_1 + S_2$	j, l, o
GMAW SAW	B-P7-a	5/8 min.	R = 0 f = 1/4 min. r = 1/4 α = 20°	±0 +U, –0 +1/4, –0 +10°, –0°	+1/16, –0 ±1/16 ±1/16 +10°, –5°	F	$S_1 + S_2$	a, j, l

[a] But not greater than 1/4 in.

Figure 3.4 (Continued)—Prequalified PJP Groove Welded Joints—Nontubular (see 3.23.1)

See Notes on Page 70

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



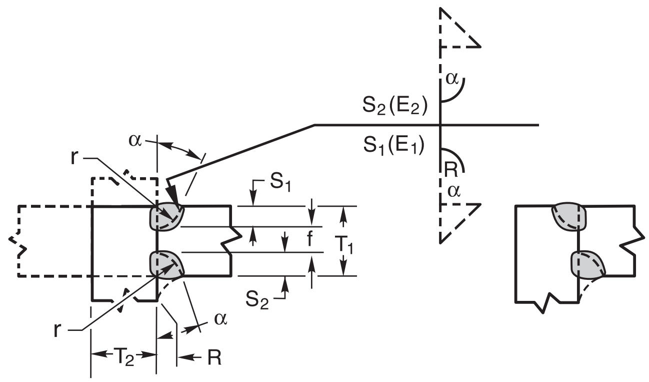
Welding Process	Joint Designation	Base Metal Thickness (U = Unlimited)		Groove Preparation			Permitted Welding Positions	Weld Size (E)	Notes
		T_1	T_2	Root Opening Root Face Groove Radius Groove Angle	Tolerances: As Detailed (see 3.23.2)	Tolerances: As Fit-Up (see 5.4)			
SMAW GTAW	TC-P8[a]	3/16 min.	U	R = 0 f = 1/16 min. r = T/2 min.[c] α = 45°	+1/16, –0 +U, –0 +1/4, –0 + 10°, –0°	+1/8, –1/16 ±1/16 ±1/16 +10°, –5°	All	S	f, g, l, o
SMAW GTAW	BC-P8[b]	3/16 min.	U	R = 0 f = 1/16 min. r = T/2[c] α = 30°	+1/16, –0 +U, –0 +1/4, –0 + 10°, –0°	+1/8, –1/16 ±1/16 ±1/16 +10°, –5°	All	S	f, g, l, n, o
FCAW	TC-P8-F[a]	1/4 min.	U	R = 0 f = 1/8 min. r = T/2[c] α = 45°	+1/16, –0 +U, –0 +1/4, –0 + 10°, –0°	+1/8, –1/16 ±1/16 ±1/16 +10°, –5°	All	S	g, l, o
FCAW	BC-P8-F[b]	1/4 min.	U	R = 0 f = 1/8 min. r = T/2[c] α = 30°	+1/16, –0 +U, –0 +1/4, –0 + 10°, –0°	+1/8, –1/16 ±1/16 ±1/16 +10°, –5°	All	S	g, l, n, o
GMAW SAW	TC-P8-a	7/16 min.	U	R = 0 f = 1/4 min. r = 1/2 α = 45°	±0 +U, –0 +1/4, –0 +10°, –0°	+1/16, –0 ±1/16 ±1/16 +10°, –5°	F	S	a, g, l
GMAW SAW	C-P8	7/16 min.	U	R = 0 f = 1/4 min. r = 1/2 α = 20°	±0 +U, –0 +1/4, –0 +10°, –0°	+1/16, –0 ±1/16 ±1/16 +10°, –5°	F	S	a, g, l, n

[a] Applies to inside corner joints.
[b] Applies to outside corner joints.
[c] Need not be more than 1/2 in.

Figure 3.4 (Continued)—Prequalified PJP Groove Welded Joints—Nontubular (see 3.23.1)

See Notes on Page 70

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



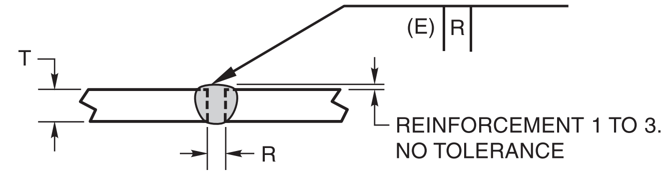
Welding Process	Joint Designation	Base Metal Thickness (U = Unlimited) T1	T2	Groove Preparation: Root Opening, Root Face, Groove Radius, Groove Angle	Tolerances: As Detailed (see 3.23.2)	Tolerances: As Fit-Up (see 5.4)	Permitted Welding Positions	Total Weld Size ($E_1 + E_2$)	Notes
SMAW GTAW	BTC-P9	1/4 min.	U	R = 0 f = 1/16 min. r = T/2[b] α = 45°	+1/16, –0 +U, –0 +1/4, –0 + 10°, –0°	+1/8, –1/16 ±1/16 ±1/16 +10°, –5°	All	$S_1 + S_2$	f, g, j, l, n, o
FCAW GMAW	BTC-P9-GF[b]	1/2 min.	U	R = 0 f = 1/8 min. r = T/2[c] α = 30°[b] α = 45°[a]	+1/16, –0 +U, –0 +1/4, –0 + 10°, –0°	+1/8, –1/16 ±1/16 ±1/16 +10°, –5°	All	$S_1 + S_2$	a, g, j, l, n, o
FCAW GMAW	BTC-P9a-GF[b]	3/4 min.	U	R = 0 f = 1/4 min. r = 1/2 α = 45°	±0 +U, –0 +1/4, –0 + 10°, –0°	+1/16, –0 ±1/16 ±1/16 +10°, –5°	F	$S_1 + S_2$	a, g, j, l, n
SAW	C-P9-S[a]								
GMAW FCAW SAW	C-P9-S[b]	3/4 min.	U	R = 0 f = 1/4 min. r = 1/2 α = 20°	±0 +U, –0 +1/4, –0 +10°, –0°	+1/16, –0 ±1/16 ±1/16 +10°, –5°	F	$S_1 + S_2$	a, g, j, l, n
SAW	T-P9-S	3/4 min.	U	R = 0 f = 1/4 min. r = 1/2 α = 45°	±0 +U, –0 +1/4, –0 +10°, –0°	+1/16, –0 ±1/16 ±1/16 +10°, –5°	F	$S_1 + S_2$	g, j, l

[a] Applies to inside corner joints.
[b] Applies to outside corner joints.
[c] Need not be more than 1/2 in.

Figure 3.4 (Continued)—Prequalified PJP Groove Welded Joints—Nontubular (see 3.23.1)

See Notes on Page 70

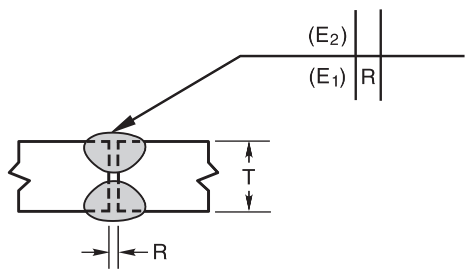
Square-groove weld (1)
Butt joint (B)



ALL DIMENSIONS IN mm

Welding Process	Joint Designation	Base Metal Thickness	Groove Preparation			Permitted Welding Positions	Weld Size (E)	Notes
				Tolerances				
		T	Root Opening	As Detailed (see 3.23.2)	As Fit-Up (see 5.4)			
SMAW GTAW FCAW GMAW	B-P1a	16 ga to 3	R = 0 to T/2	+T/2, –0	±T/2	All	3T/4	a, b, o
	B-P1c	3 to 6 max.	R = T/2 min.	+2, –0	±2	All	T/2	a, b, o

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



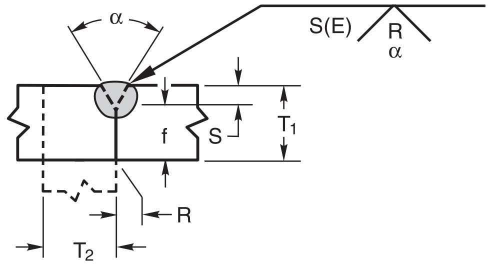
$E_1 + E_2$ MUST NOT EXCEED 3T/4
ALL DIMENSIONS IN mm

Welding Process	Joint Designation	Base Metal Thickness	Groove Preparation			Permitted Welding Positions	Total Weld Size ($E_1 + E_2$)	Notes
				Tolerances				
		T	Root Opening	As Detailed (see 3.23.2)	As Fit-Up (see 5.4)			
SMAW GTAW FCAW GMAW	B-P1b	6 max.	R = T/2	+T/4, –0	±T/4	All	T/4	a, o

Figure 3.4 (Continued)—Prequalified PJP Groove Welded Joints—Nontubular (see 3.23.1) (Dimensions in Millimeters)

See Notes on Page 70

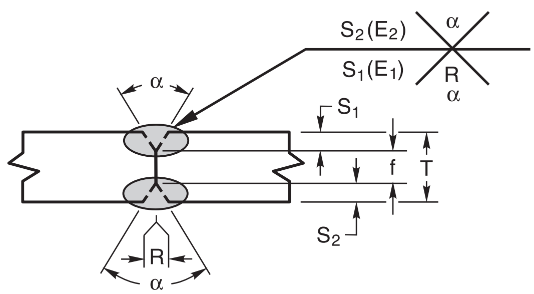
Single-V-groove weld (2)
Butt joint (B)
Corner joint (C)



ALL DIMENSIONS IN mm

Welding Process	Joint Designation	Base Metal Thickness (U = Unlimited)		Groove Preparation			Permitted Welding Positions	Weld Size (E)	Notes
				Root Opening Root Face Groove Angle	Tolerances				
		T_1	T_2		As Detailed (see 3.23.2)	As Fit-Up (see 5.4)			
SMAW GTAW	BC-P2	3 min.	U	R = 0 f = 1 min. α = 60°	0, +2 +U, –0 +10°, –0°	$+T_1/2$, –2 ±2 +10°, –5°	All	S	f, l, o
FCAW GMAW GTAW	BC-P2-GF	6 min.	U	R = 0 f = 3 min. α = 60°	0, +2 +U, –0 +10°, –0°	+3, –2 ±2 +10°, –5°	All	S	a, f, l, o
GMAW SAW	BC-P2-a	11 min.	U	R = 0 f = 6 min. α = 60°	±0 +U, –0 +10°, –0°	+2, –0 ±2 +10°, –5°	F	S	a, l

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



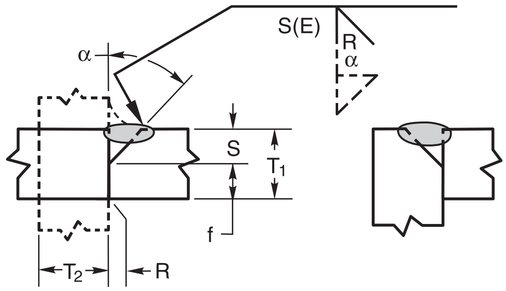
ALL DIMENSIONS IN mm

Welding Process	Joint Designation	Base Metal Thickness	Groove Preparation			Permitted Welding Positions	Total Weld Size ($E_1 + E_2$)	Notes
			Root Opening Root Face Groove Angle	Tolerances				
		T		As Detailed (see 3.23.2)	As Fit-Up (see 5.4)			
GTAW SMAW	B-P3	5 min.	R = 0 f = 2 min. α = 60°	+2, –0 +U, –0 +10°, –0°	+T/2, –2 ±2 +10°, –5°	All	$S_1 + S_2$	f, j, l, o
FCAW GMAW GTAW	B-P3-GF	5 min.	R = 0 f = 3 min. α = 60°	+2, –0 +U, –0 +10°, –0°	+3, –2 ±2 +10°, –5°	All	$S_1 + S_2$	a, f, j, l, o
GMAW SAW	B-P3-a	20 min.	R = 0 f = 6 min. α = 60°	±0 +U, –0 +10°, –0°	+2, –0 ±2 +10°, –5°	F	$S_1 + S_2$	a, j, l

Figure 3.4 (Continued)—Prequalified PJP Groove Welded Joints—Nontubular (see 3.23.1) (Dimensions in Millimeters)

See Notes on Page 70

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

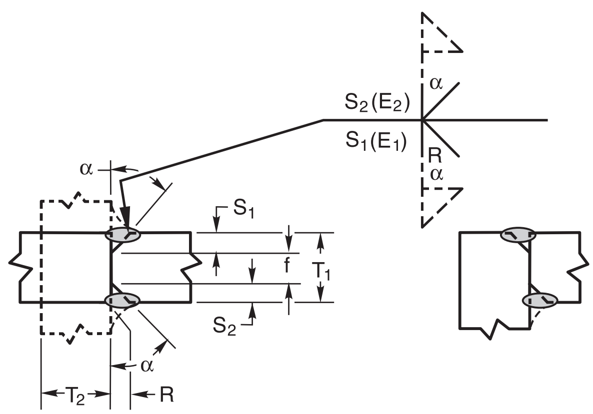


ALL DIMENSIONS IN mm

Welding Process	Joint Designation	Base Metal Thickness (U = Unlimited)		Groove Preparation			Permitted Welding Positions	Weld Size (E)	Notes
		T_1	T_2	Root Opening Root Face Groove Angle	Tolerances: As Detailed (see 3.23.2)	Tolerances: As Fit-Up (see 5.4)			
SMAW GTAW	BTC-P4	5 min.	U	R = 0 f = 2 min. α = 45°	+2, –0 Unlimited[a] +10°, –0°	+3, –2 ±2 +10°, –5°	All	S–3	f, g, l, n, o
GMAW FCAW	BTC-P4-GF	10 min.	U	R = 0 f = 3 min. α = 45°	+2, –0 Unlimited[a] +10°, –0°	+3, –2 ±2 +10°, –5°	F, H	S	a, g, l, n
							n, OH	S–3	
GMAW SAW	TC-P4-S	11 min.	U	R = 0 f = 6 min. α = 60°	±0 +U, –0 +10°, –0°	+2, –0 ±2 +10°, –5°	F	S	a, g, l, n

[a] For flat and horizontal position: f = +U, –0.

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



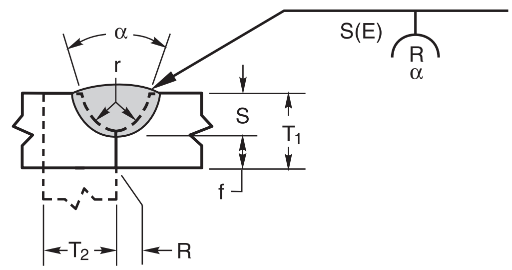
ALL DIMENSIONS IN mm

Welding Process	Joint Designation	Base Metal Thickness (U = Unlimited)		Groove Preparation			Permitted Welding Positions	Total Weld Size ($E_1 + E_2$)	Notes
		T_1	T_2	Root Opening Root Face Groove Angle	Tolerances: As Detailed (see 3.23.2)	Tolerances: As Fit-Up (see 5.4)			
SMAW GTAW	BTC-P5	8 min.	U	R = 0 f = 2 min. α = 45°	+2, –0 Unlimited + 10°, –0°	+3, –2 ±2 +10°, –5°	All	($S_1 + S_2$) –6	f, g, h, j, l, n, o
GMAW	BTC-P5-G	10 min.	U	R = 0 f = 3 min. α = 45°	+2, –0 Unlimited +10°, –0°	+3, –2 ±2 +10°, –5°	F, H	$S_1 + S_2$	a, g, h, j, l, n
FCAW	BTC-P5-F	16 min.					n, OH	($S_1 + S_2$) –6	
GMAW SAW	TC-P5	20 min.	U	R = 0 f = 6 min. α = 60°	±0 +U, –0 +10°, –0°	+2, –0 ±2 +10°, –5°	F	$S_1 + S_2$	a, g, h, j, l, n

Figure 3.4 (Continued)—Prequalified PJP Groove Welded Joints—Nontubular (see 3.23.1) (Dimensions in Millimeters)

See Notes on Page 70

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

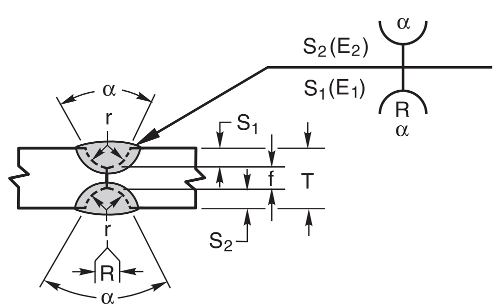


ALL DIMENSIONS IN mm

Welding Process	Joint Designation	Base Metal Thickness (U = Unlimited)		Groove Preparation			Permitted Welding Positions	Weld Size (E)	Notes
		T_1	T_2	Root Opening Root Face Groove Radius Groove Angle	Tolerances: As Detailed (see 3.23.2)	Tolerances: As Fit-Up (see 5.4)			
SMAW GTAW GMAW	BC-P6	3 min.	U	R = 0 f = 1 min. r = T/2[a] α = 45°	+2, –0 +U, –0 +6, –0 + 10°, –0°	+3, –2 ±2 ±2 +10°, –5°	All	S	a, l, o
FCAW	BC-P6-F	6 min.	U	R = 0 f = 3 min. r = T/2[a] α = 20°	+2, –0 +U, –0 +6, –0 + 10°, –0°	+3, –2 ±2 ±2 +10°, –5°	All	S	l, o
GMAW SAW	BC-P6-a	11 min.	U	R = 0 f = 6 min. r = T/2 α = 20°	±0 +U, –0 +6, –0 +10°, –0°	+2, –0 ±2 ±2 +10°, –5°	F	S	a, l

[a]But not greater than 6 mm.

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



ALL DIMENSIONS IN mm

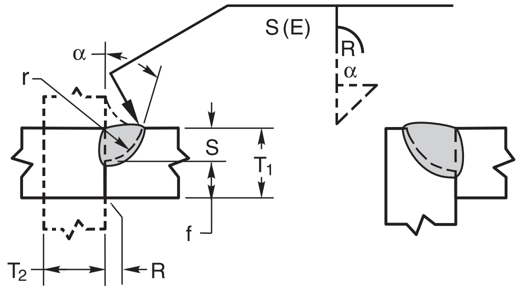
Welding Process	Joint Designation	Base Metal Thickness	Groove Preparation			Permitted Welding Positions	Total Weld Size ($E_1 + E_2$)	Notes
		T	Root Opening Root Face Groove Radius Groove Angle	Tolerances: As Detailed (see 3.23.2)	Tolerances: As Fit-Up (see 5.4)			
SMAW GTAW GMAW	B-P7	6 min.	R = 0 f = 2 min. r = T/2[a] α = 45°	+2, –0 +U, –0 +T/4, –0 + 10°, –0°	+3, –2 ±2 ±2 +10°, –5°	All	$S_1 + S_2$	a, j, l, o
FCAW	B-P7-F	10 min.	R = 0 f = 3 min. r = T/2[a] α = 20°	+2, –0 +U, –0 +T/4, –0 + 10°, –0°	+3, –2 ±2 ±2 +10°, –5°	All	$S_1 + S_2$	j, l, o
GMAW SAW	B-P7-a	16 min.	R = 0 f = 6 min. r = 6 α = 20°	±0 +U, –0 +6, –0 +10°, –0°	+2, –0 ±2 ±2 +10°, –5°	F	$S_1 + S_2$	a, j, l

[a]But not greater than 6 mm.

Figure 3.4 (Continued)—Prequalified PJP Groove Welded Joints—Nontubular (see 3.23.1) (Dimensions in Millimeters)

See Notes on Page 70

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



ALL DIMENSIONS IN mm

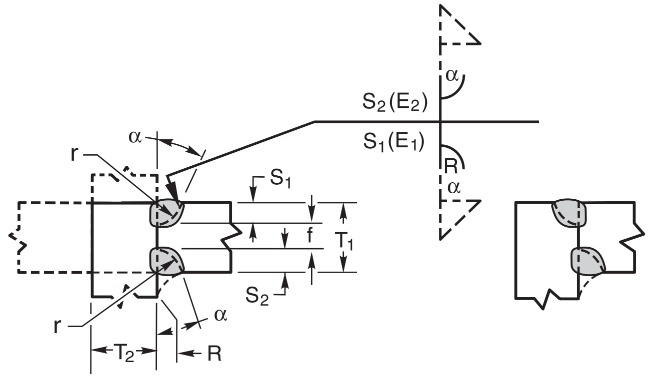
Welding Process	Joint Designation	Base Metal Thickness (U = Unlimited) T_1	T_2	Groove Preparation: Root Opening Root Face Groove Radius Groove Angle	Tolerances: As Detailed (see 3.23.2)	As Fit-Up (see 5.4)	Permitted Welding Positions	Weld Size (E)	Notes
SMAW GTAW	TC-P8[a]	5 min.	U	R = 0 f = 2 min. r = T/2 min.[c] α = 45°	+2, –0 +U, –0 +6, –0 + 10°, –0°	+3, –2 ±2 ±2 +10°, –5°	All	S	f, g, l, o
SMAW GTAW	BC-P8[b]	5 min.	U	R = 0 f = 2 min. r = T/2[c] α = 30°	+2, –0 +U, –0 +6, –0 + 10°, –0°	+3, –2 ±2 ±2 +10°, –5°	All	S	f, g, l, n, o
FCAW	TC-P8-F[a]	6 min.	U	R = 0 f = 3 min. r = T/2[c] α = 45°	+2, –0 +U, –0 +6, –0 + 10°, –0°	+3, –2 ±2 ±2 +10°, –5°	All	S	g, l, o
FCAW	BC-P8-F[b]	6 min.	U	R = 0 f = 3 min. r = T/2[c] α = 30°	+2, –0 +U, –0 +6, –0 + 10°, –0°	+3, –2 ±2 ±2 +10°, –5°	All	S	g, l, n, o
GMAW SAW	TC-P8-a	11 min.	U	R = 0 f = 6 min. r = 12 α = 45°	±0 +U, –0 +6, –0 +10°, –0°	+2, –0 ±2 ±2 +10°, –5°	F	S	a, g, l
GMAW SAW	C-P8	11 min.	U	R = 0 f = 6 min. r = 12 α = 20°	±0 +U, –0 +6, –0 +10°, –0°	+2, –0 ±2 ±2 +10°, –5°	F	S	a, g, l, n

[a] Applies to inside corner joints.
[b] Applies to outside corner joints.
[c] Need not be more than 12 mm.

Figure 3.4 (Continued)—Prequalified PJP Groove Welded Joints—Nontubular (see 3.23.1) (Dimensions in Millimeters)

See Notes on Page 70

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



ALL DIMENSIONS IN mm

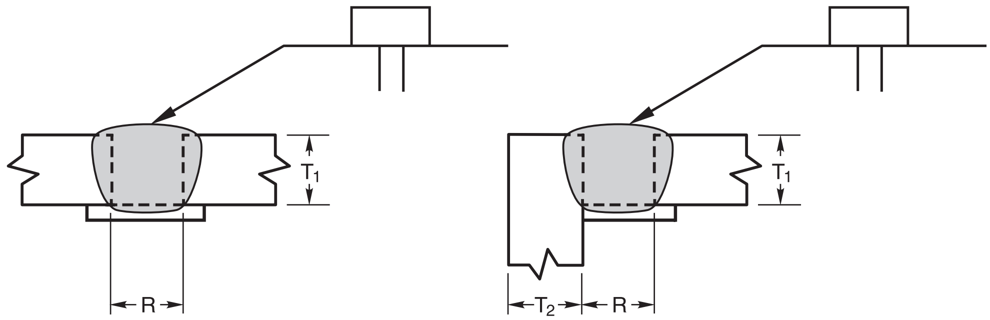
Welding Process	Joint Designation	Base Metal Thickness (U = Unlimited)		Groove Preparation			Permitted Welding Positions	Total Weld Size ($E_1 + E_2$)	Notes
		T_1	T_2	Root Opening Root Face Groove Radius Groove Angle	Tolerances: As Detailed (see 3.23.2)	Tolerances: As Fit-Up (see 5.4)			
SMAW GTAW	BTC-P9	6 min.	U	R = 0 f = 2 min. r = T/2[b] α = 45°	+2, –0 +U, –0 +6, –0 + 10°, –0°	+3, –2 ±2 ±2 +10°, –5°	All	$S_1 + S_2$	f, g, j, l, n, o
FCAW GMAW	BTC-P9-GF[b]	12 min.	U	R = 0 f = 3 min. r = T/2[c] α = 30°[b] α = 45°[a]	+2, –0 +U, –0 +6, –0 + 10°, –0°	+3, –2 ±2 ±2 +10°, –5°	All	$S_1 + S_2$	a, g, j, l, n, o
FCAW GMAW	BTC-P9a-GF[b]	20 min.	U	R = 0 f = 6 min. r = 12 α = 45°	±0 +U, –0 +6, –0 + 10°, –0°	+2, –0 ±2 ±2 +10°, –5°	F	$S_1 + S_2$	a, g, j, l, n
SAW	C-P9-S[a]								
GMAW FCAW SAW	C-P9-S[b]	20 min.	U	R = 0 f = 6 min. r = 12 α = 20°	±0 +U, –0 +6, –0 +10°, –0°	+2, –0 ±2 ±2 +10°, –5°	F	$S_1 + S_2$	a, g, j, l, n
SAW	T-P9-S	20 min.	U	R = 0 f = 6 min. r = 12 α = 45°	±0 +U, –0 +6, –0 +10°, –0°	+2, –0 ±2 ±2 +10°, –5°	F	$S_1 + S_2$	g, j, l

[a] Applies to inside corner joints.
[b] Applies to outside corner joints.
[c] Need not be more than 12 mm.

Figure 3.4 (Continued)—Prequalified PJP Groove Welded Joints—Nontubular (see 3.23.1) (Dimensions in Millimeters)

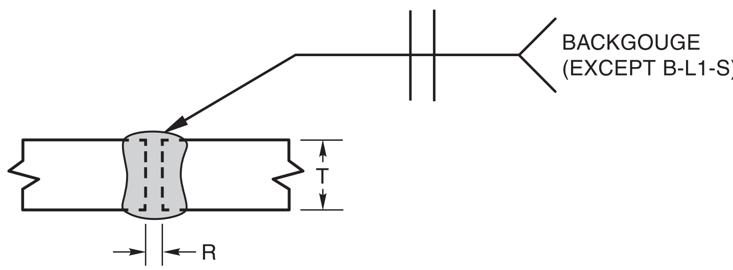
See Notes on Page 70

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



Welding Process	Joint Designation	Base Metal Thickness (U = Unlimited)		Groove Preparation			Permitted Welding Positions	Notes
					Tolerances			
		T_1	T_2	Root Opening	As Detailed (see 3.24.2)	As Fit-Up (see 5.4)		
SMAW GMAW	B-L1a C-L1a	1/4 max.	—	R = T_1	+T/4 ≤ 1/16, –0	+T/4 ≤ 1/4, –T/4 ≤ 1/16	All	a, k, o
GTAW		1/4 max.	U	R = T_1	+T/4 ≤ 1/16, –0	+T/4 ≤ 1/4, –T/4 ≤ 1/16	All	k, o
FCAW	B-L1a-F	3/8 max.	—	R = T_1	+1/16, –0	+T/4 ≤ 1/4, –T/4 ≤ 1/16	All	k, o
SAW	B-L1-S	3/8 max.	—	R = T_1	+1/16, –0	+T/4 ≤ 1/4, –T/4 ≤ 1/16	F	k

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

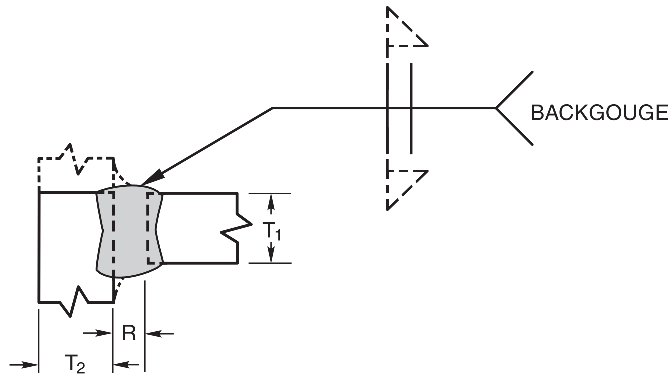


Welding Process	Joint Designation	Base Metal Thickness	Groove Preparation			Permitted Welding Positions	Notes
				Tolerances			
		T	Root Opening	As Detailed (see 3.24.2)	As Fit-Up (see 5.4)		
SMAW GTAW	B-L1b	1/4 max.	R = T/2	+T/4 ≤ 1/16, –0	+1/16, –T/2 ≤ 1/8	All	d, k, o
FCAW	B-L1b-F	3/8 max.	R = 0 to 1/8	+1/16, –0	+1/16, –T/2 ≤ 1/8	All	d, k, o
GMAW	B-L1b-G	3/8 max.	R = 0 to 1/8	+1/16, –0	+1/16, –T/2 ≤ 1/8	All	a, d, k
SAW	B-L1-S	3/8 max.	R = 0	±0	+1/16, –0	F	k
SAW	B-L1a-S	5/8 max.	R = 0	±0	+1/16, –0	F	d, k

Figure 3.5—Prequalified CJP Groove Welded Joints—Nontubular (see 3.24.1)

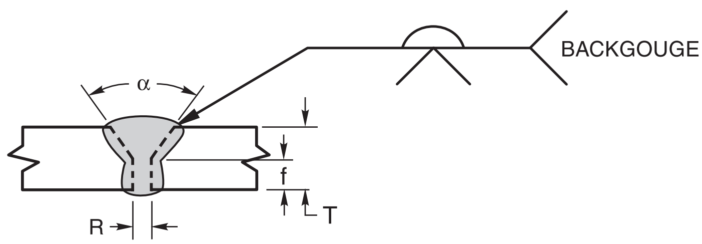
See Notes on Page 70

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



Welding Process	Joint Designation	Base Metal Thickness (U = Unlimited) T_1	T_2	Groove Preparation Root Opening	Tolerances As Detailed (see 3.24.2)	As Fit-Up (see 5.4)	Permitted Welding Positions	Notes
SMAW GTAW	TC-L1b	1/4 max.	U	$R = T_1/2$	+T/4 ≤ 1/16, –0	+1/16, –T/2 ≤ 1/8	All	d, g, o
GMAW FCAW	TC-L1-GF	3/8 max.	U	R = 0 to 1/8	+1/16, –0	+1/16, –T/2 ≤ 1/8	GMAW—F	a, d, g
							FCAW—All	a, d, g, o
SAW	TC-L1-S	3/8 max.	U	R = 0	±0	+1/16, –0	F	d, g

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



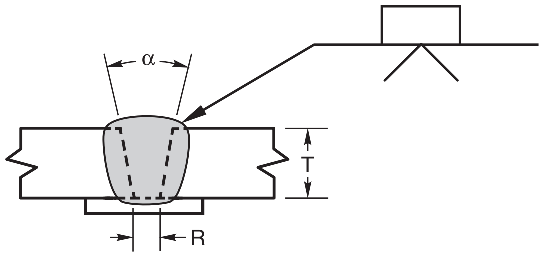
Welding Process	Joint Designation	Base Metal Thickness (U = Unlimited) T	Groove Preparation Root Opening Root Face Groove Angle	Tolerances As Detailed (see 3.24.2)	As Fit-Up (see 5.4)	Permitted Welding Positions	Notes
SMAW GTAW	B-U2	U	R = 0 to T/2 ≤ 1/8 f = 0 to T/2 ≤ 1/8 α = 60°	+T/4 ≤ 1/16, –0 +T/4 ≤ 1/16, –0 + 10°, –0°	+1/16, –T/2 ≤ 1/8 Not limited[a] +10°, –5°	All	d, k, o
	B-L2	2 max.					
GMAW FCAW	B-U2-GF	U	R = 0 to T/2 ≤ 1/8 f = 0 to T/2 ≤ 1/8 α = 45°	+T/4 ≤ 1/16, –0 +T/4 ≤ 1/16, –0 + 10°, –0°	+1/16, –T/2 ≤ 1/8 Not limited[a] +10°, –5°	All	a, d, k, o
SAW	B-L2c-S	Over 1/2 to 1	R = 0 f = 1/4 max. α = 60°	R = ±0 f = +0, –1/16 α = +10°, –0°	+1/16, –0 ±1/16 +10°, –5°	F	d, k
		Over 1 to 1-1/2	R = 0 f = 1/2 max. α = 60°				
		Over 1-1/2 to 2	R = 0 f = 5/8 max. α = 60°				

[a] Limited by a minimum groove depth.

Figure 3.5 (Continued)—Prequalified CJP Groove Welded Joints—Nontubular (see 3.24.1)

See Notes on Page 70

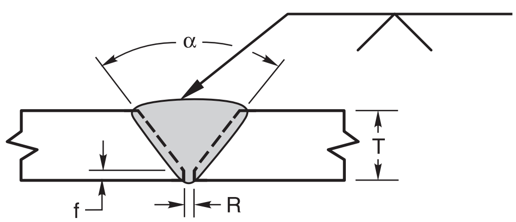
Single-V-groove weld (2)
Butt joint (B)



Tolerances	
As Detailed (see 3.24.2)	As Fit-Up (see 5.4)
R = +1/16, –0	+1/4, –1/16
α = +10°, –0°	+10°, –5°

Welding Process	Joint Designation	Base Metal Thickness (U = Unlimited) T	Groove Preparation: Root Opening	Groove Preparation: Groove Angle	Permitted Welding Positions	Notes
SMAW	B-U2a	U	R = 1/4	α = 45°	All	k, o
GTAW	B-L2a	1 max.	R = 3/8	α = 30°	All	k, o
			R = 1/2	α = 20°	All	k, o
GMAW FCAW	B-U2a-GF	U	R = 3/16	α = 30°	All	a, k, o
			R = 3/8	α = 30°	All	a, k, o
			R = 1/4	α = 45°	All	a, k, o
SAW	B-L2a-S	2 max.	R = 1/4	α = 30°	F	N
SAW	B-U2-S	U	R = 5/8	α = 20°	F	N

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

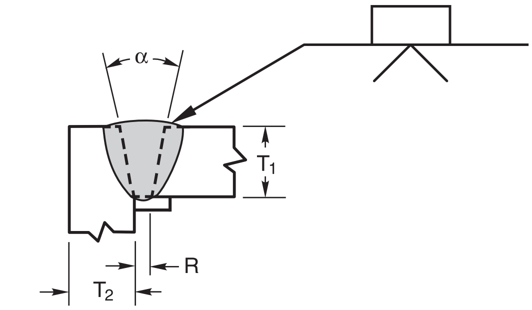


Welding Process	Joint Designation	Base Metal Thickness Max. T	Groove Preparation: Root Opening Root Face Groove Angle	Tolerances: As Detailed (see 3.24.2)	Tolerances: As Fit-Up (see 5.4)	Permitted Welding Positions	Notes
GTAW	B-L2b	1/16 min. to 1	R = 0 to T/2 ≤ 1/8 f = 0 to T/2 ≤ 1/16 α = 75°	+T/4 ≤ 1/16, –0 +T/4 ≤ 1/32, –0 0°, –10°	+1/16, –T/2 ≤ 1/32 +0, –T/2 ≤ 1/32 ±5%	All	e, o, p, q

Figure 3.5 (Continued)—Prequalified CJP Groove Welded Joints—Nontubular (see 3.24.1)

See Notes on Page 70

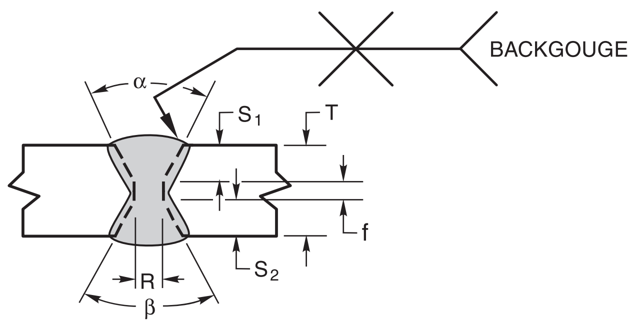
Single-V-groove weld (2)
Corner joint (C)



Tolerances	
As Detailed (see 3.24.2)	As Fit-Up (see 5.4)
R = +1/16, –0	+1/4, –1/16
α = +10°, –0°	+10°, –5°

Welding Process	Joint Designation	Base Metal Thickness (U = Unlimited) T_1	Base Metal Thickness (U = Unlimited) T_2	Groove Preparation: Root Opening	Groove Preparation: Groove Angle	Permitted Welding Positions	Notes
SMAW	C-U2a	U	U	R = 1/4	α = 45°	All	l, o
GTAW	C-L2a	1 max.		R = 3/8	α = 30°	All	l, o
				R = 1/2	α = 20°	All	l, o
GMAW FCAW	C-U2a-GF	U	U	R = 3/16	α = 30°	All	a, o
				R = 3/8	α = 30°	All	a, l, o
				R = 1/4	α = 45°	All	a, l, o
SAW	C-L2a-S	2 max.	U	R = 1/4	α = 30°	F	l
SAW	C-U2-S	U	U	R = 5/8	α = 20°	F	l

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



For B-U3c-S only		
T Over	T to	S_1
2	2-1/2	1-3/8
2-1/2	3	1-3/4
3	3-5/8	2-1/8
3-5/8	4	2-3/8
4	4-3/4	2-3/4
4-3/4	5-1/2	3-1/4
5-1/2	6-1/4	3-3/4
For T > 6-1/4 or T ≤ 2 S_1 = 2/3 (T – 1/4)		

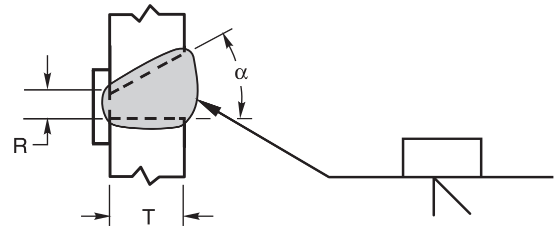
Welding Process	Joint Designation	Base Metal Thickness Max. (U = Unlimited) T	Groove Preparation: Root Opening Root Face Groove Angle	Groove Preparation: Tolerances As Detailed (see 3.24.2)	Groove Preparation: Tolerances As Fit-Up (see 5.4)	Permitted Welding Positions	Notes
SMAW	B-U3b	U	R = 0 to T/2 ≤ 1/8 f = 0 to T/2 ≤ 1/8 α = β = 60°	+T/2 ≤ 1/16, –0 +T/2 ≤ 1/16, –0 +10°, –0°	+1/16, –T/2 ≤ 1/8 Not limited[a] +10°, –5°	All	d, i, k, o
GTAW	B-L3b	2				All	a, d, i, k, o
GMAW FCAW	B-U3-GF	U					
SAW	B-U3c-S	1/2 min. to U —	R = 0 f = 1/4 min. α = β = 60°	+1/16, –0 +1/4, –0 +10°, –5°	+1/16, –0 +1/4, –0 +10°, –0°	F	d, i, k
			To find S_1 see table above: $S_2 = T - (S_1 + f)$				

[a] Limited by a minimum groove depth.

Figure 3.5 (Continued)—Prequalified CJP Groove Welded Joints—Nontubular (see 3.24.1)

See Notes on Page 70

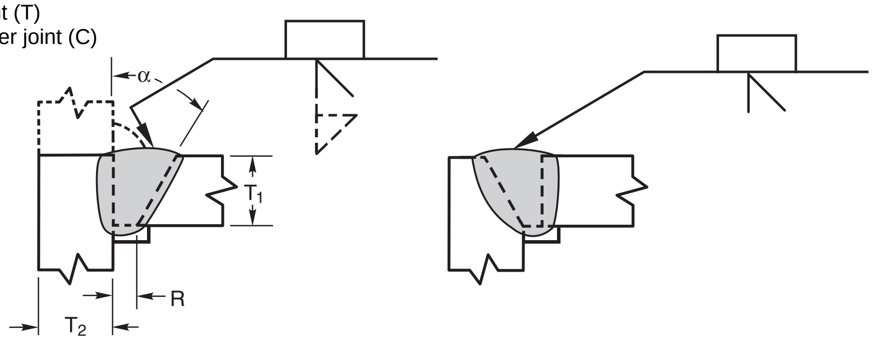
Single-bevel-groove weld (4)
Butt joint (B)



Tolerances	
As Detailed (see 3.24.2)	As Fit-Up (see 5.4)
R = +1/16, –0	+1/4, –1/16
α = +10°, –0°	+10°, –5°

Welding Process	Joint Designation	Base Metal Thickness (U = Unlimited)	Groove Preparation		Permitted Welding Positions	Notes
		T	Root Opening	Groove Angle		
SMAW	B-U4a	1/4 min. to U	R = 1/4	α = 45°	All	c, k, o
GTAW	B-L4a	1/4 min. to 1	R = 3/8	α = 30°	All	c, k, o
GMAW FCAW	B-U4a-GF	1/4 min. to U	R = 3/16	α = 30°	All	a, c, k, o
			R = 1/4	α = 45°	All	a, c, k, o
			R = 3/8	α = 30°	F	c, k
SAW	B-U4a-S	1/4 min. to U	R = 1/4	α = 45°	F	c, k
			R = 3/8	α = 30°		

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



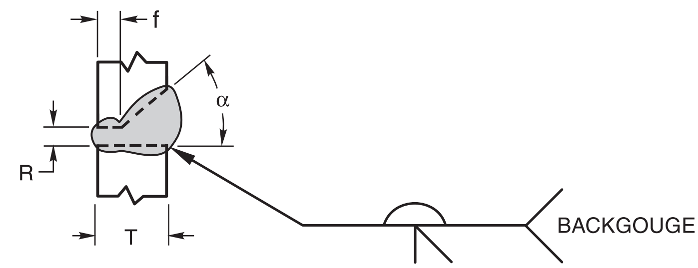
Tolerances	
As Detailed (see 3.24.2)	As Fit-Up (see 5.4)
R = +1/16, –0	+1/4, –1/16
a = +10°, –0°	+10°, –5°

Welding Process	Joint Designation	Base Metal Thickness (U = Unlimited)		Groove Preparation		Permitted Welding Positions	Notes
		T_1	T_2	Root Opening	Groove Angle		
SMAW	TC-U4a	1/4 min. to U	1/4 min. to U	R = 1/4	α = 45°	All	g, l, n, o
GTAW	TC-L4a	1/4 min. to 1		R = 3/8	α = 30°	All	g, l, n, o
GMAW FCAW	TC-U4a-GF	3/16 min. to U	3/16 min. to U	R = 3/16	α = 30°	All	a, g, l, n, o
				R = 1/4	α = 45°	F	a, g, l, n
				R = 3/8	α = 30°	All	a, g, l, n, o
SAW	TC-U4a-S	3/8 min. to U	3/8 min. to U	R = 3/8	α = 30°	F	g, l, n
				R = 1/4	α = 45°		

Figure 3.5 (Continued)—Prequalified CJP Groove Welded Joints—Nontubular (see 3.24.1)

See Notes on Page 70

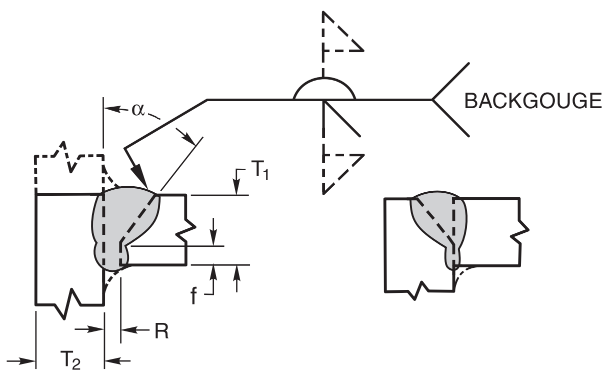
Single-bevel-groove weld (4)
Butt joint (B)



Welding Process	Joint Designation	Base Metal Thickness Max. (U = Unlimited) T	Groove Preparation: Root Opening Root Face Groove Angle	Tolerances: As Detailed (see 3.24.2)	Tolerances: As Fit-Up (see 5.4)	Permitted Welding Positions	Notes
SMAW	B-U4b	1/16 min. to U	R = 0 to T/2 ≤ 1/8 f = 0 to T/2 ≤ 1/8 α = 45°	+T/4 ≤ 1/16, –0 +T/4 ≤ 1/16, –0 +10°, –0°	+1/16, –T/2 ≤ 1/8 Not limited[a] 10°, –5°	All	c, d, k, o
GTAW	B-L4b	1/16 min. to 1					
GMAW FCAW	B-U4b-GF	1/8 min. to U	R = 0 to T/2 ≤ 1/8 f = 0 to T/2 ≤ 1/8 α = 45°	+T/4 ≤ 1/16, –0 +T/4 ≤ 1/16, –0 +10°, –0°	+1/16, –T/2 ≤ 1/8 Not limited[a] 10°, –5°	All	a, c, d, k, o
SAW	B-U4b-S	3/8 min. to U	R = 0 f = 1/4 max. α = 60°	±0 +0, –1/8 +10°, –0°	+1/4, –0 ±1/16 10°, –5°	F	c, d

[a] Limited by a minimum groove depth.

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



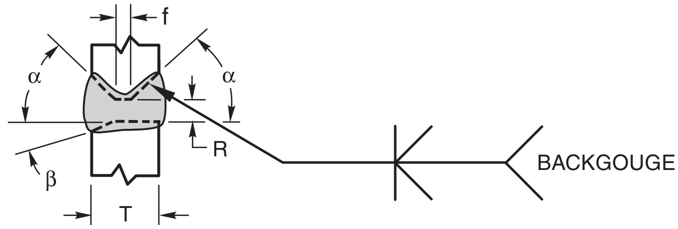
Welding Process	Joint Designation	Base Metal Thickness Max. (U = Unlimited) T_1	T_2	Groove Preparation: Root Opening Root Face Groove Angle	Tolerances: As Detailed (see 3.24.2)	Tolerances: As Fit-Up (see 5.4)	Permitted Welding Positions	Notes
SMAW	TC-U4b	1/16 min. to U	1/16 min. to U	R = 0 to T/2 ≤ 1/8 f = 0 to T/2 ≤ 1/8 α = 45°	+T/4 ≤ 1/16, –0 +T/4 ≤ 1/16, –0 +10°, –0°	+1/16, –T/2 ≤ 1/8 Not limited[a] +10°, –5°	All	d, g, m, n, o
GTAW	TC-L4b	1/16 min. to 1	1/16 min. to 1					
GMAW FCAW	TC-U4b-GF	1/8 min. to U	1/8 min. to U	R = 0 to T/2 ≤ 1/8 f = 0 to T/2 ≤ 1/8 α = 45°	+T/4 ≤ 1/16, –0 +T/4 ≤ 1/16, –0 +10°, –0°	+1/16, –T/2 ≤ 1/8 Not limited[a] +10°, –5°	All	a, d, g, m, n, o
SAW	TC-U4b-S	3/8 min. to U	3/8 min. to U	R = 0 f = 1/4 max. α = 60°	±0 +0, –1/8 +10°, –0°	+1/4, –0 ±1/16 +10°, –5°	F	d, g, m, n

[a] Limited by a minimum groove depth.

Figure 3.5 (Continued)—Prequalified CJP Groove Welded Joints—Nontubular (see 3.24.1)

See Notes on Page 70

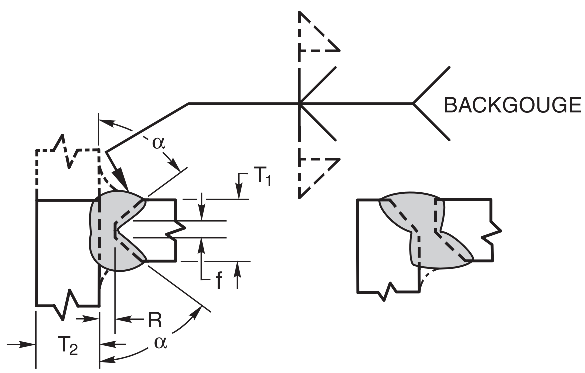
Double-bevel-groove weld (5)
Butt joint (B)



Welding Process	Joint Designation	Base Metal Thickness Max. (U = Unlimited) T	Groove Preparation: Root Opening Root Face Groove Angle	Tolerances: As Detailed (see 3.24.2)	Tolerances: As Fit-Up (see 5.4)	Permitted Welding Positions	Notes
SMAW GMAW	B-U5a	1/8 min. to U	R = 0 to T/2 ≤ 1/8 f = 0 to T/2 ≤ 1/8 α = 45° β = 0° to 15°	+T/4 ≤ 1/16, –0 +T/4 ≤ 1/16, –0 α + β = +10°, –0°	+1/16, –T/2 ≤ 1/8 Not limited[a] α + β = +10°, –5°	All	a, c, d, i, k, o
GTAW	B-L5a	1/8 min. to 2					
FCAW	B-U5-F	3/16 min. to U	R = 0 to T/2 ≤ 1/8 f = 0 to T/2 ≤ 1/8 α = 45° β = 0° to 15°	+T/4 ≤ 1/16, –0 +T/4 ≤ 1/16, –0 α + β = +10°, –0°	+1/16, –T/2 ≤ 1/8 Not limited α + β = +10°, –5°	All	c, d, i, k, o

[a] Limited by a minimum groove depth.

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



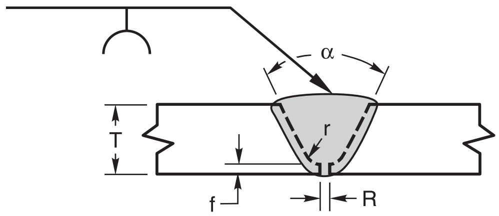
Welding Process	Joint Designation	Base Metal Thickness Max. (U = Unlimited) T_1	T_2	Groove Preparation: Root Opening Root Face Groove Angle	Tolerances: As Detailed (see 3.24.2)	Tolerances: As Fit-Up (see 5.4)	Permitted Welding Positions	Notes
SMAW GMAW	TC-U5b	1/8 min. to U	1/8 min. to U	R = 0 to T/2 ≤ 1/8 f = 0 to T/2 ≤ 1/8 α = 45°	+T/4 ≤ 1/16, –0 +T/4 ≤ 1/16, –0 +10°, –0°	+1/16, –T/2 ≤ 1/8 Not limited[a] +10°, –5°	All	a, d, g, i, m, n, o
GTAW	TC-L5b	1/8 min. to 2	1/8 min. to 2					
FCAW	TC-U5-F	1/8 min. to U	1/8 min. to U	R = 0 to T/2 ≤ 1/8 f = 0 to T/2 ≤ 1/8 α = 45°	+T/4 ≤ 1/16, –0 +T/4 ≤ 1/16, –0 +10°, –0°	+1/16, –T/2 ≤ 1/8 Not limited[a] +10°, –5°	All	d, g, i, m, n, o
SAW	TC-U5-S	3/8 min. to U	3/8 min. to U	R = 0 f = 1/4 max. α = 60°	±0 +0, –1/8 +10°, –0°	+1/4, –0 ±1/16 +10°, –5°	F	d, g, i, m, n

[a] Limited by a minimum groove depth.

Figure 3.5 (Continued)—Prequalified CJP Groove Welded Joints—Nontubular (see 3.24.1)

See Notes on Page 70

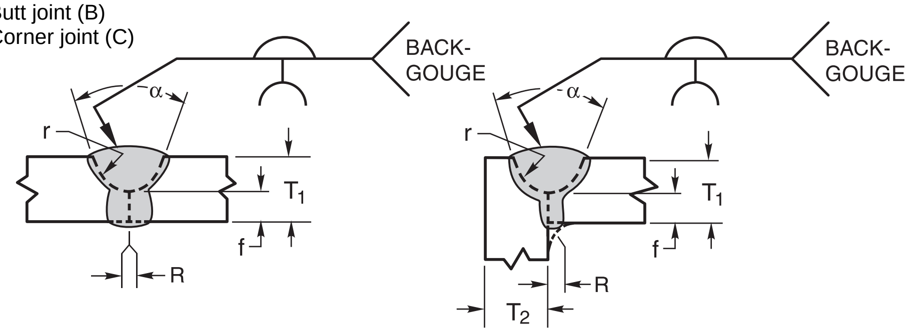
Single-U-groove weld (6)
Butt joint (B)



Tolerances	
As Detailed (see 3.24.2)	As Fit-Up (see 5.4)
R = ±T/4 ≤ 1/16	+1/16, –T/2 ≤ 1/32
α = ±5°	±5°
f = ±T/4 ≤ 1/16	+0, –T/2 ≤ 1/32
r = +T/2 ≤ 1/8, –0	+1/16, –1/32

Welding Process	Joint Designation	Base Metal Thickness Max. T	Groove Preparation: Root Opening	Groove Angle	Root Face	Groove Radius	Permitted Welding Positions	Notes
GTAW	B-L6	1/16 min. to 1	R = 0 to T/2 ≤ 1/8	α = 45°	f = T/2 ≤ 1/8	r = T/2 ≤ 1/4	All	e, o, p, q

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



Tolerances	
As Detailed (see 3.24.2)	As Fit-Up (see 5.4)
R = +T/4 ≤ 1/16, –0	+1/16, –T/2 ≤ 1/8
α = +10°, –0°	+10°, –5°
f = ±T/4 ≤ 1/16	Not limited[a]
r = +T/2 ≤ 1/8, –0	+1/8, –0

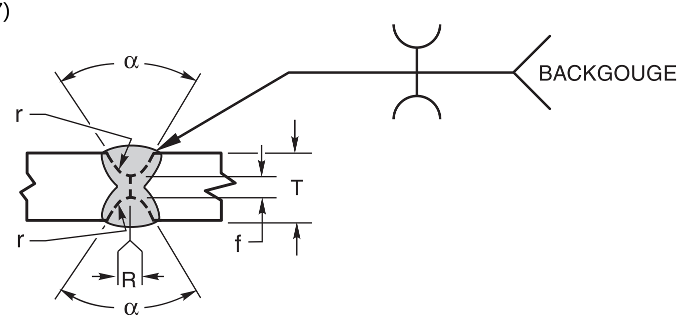
Welding Process	Joint Designation	Base Metal Thickness (U = Unlimited) T_1	T_2	Groove Preparation: Root Opening	Groove Angle	Root Face	Groove Radius	Permitted Welding Positions	Notes
SMAW GTAW	B-U6	3/32 min. to U	3/32 min. to U	R = 0 to T/2 ≤ 1/8	α = 45°	f = T/2 ≤ 1/8	r = T/2 ≤ 1/4	All	d, f, k, o
				R = 0 to T/2 ≤ 1/8	α = 20°	f = T/2 ≤ 1/8	r = T/2 ≤ 1/4	F, OH	d, f, k
	C-U6	3/32 min. to U	3/32 min. to U	R = 0 to T/2 ≤ 1/8	α = 45°	f = T/2 ≤ 1/8	r = T/2 ≤ 1/4	All	d, f, g, m, o
				R = 0 to T/2 ≤ 1/8	α = 20°	f = T/2 ≤ 1/8	r = T/2 ≤ 1/4	F, OH	d, f, g, m
GMAW FCAW	B-U6-GF	1/8 min. to U	1/8 min. to U	R = 0 to T/2 ≤ 1/8	α = 20°	f = T/2 ≤ 1/8	r = T/2 ≤ 1/4	All	a, d, k, o
	C-U6-GF	1/8 min. to U	1/8 min. to U	R = 0 to T/2 ≤ 1/8	α = 20°	f = T/2 ≤ 1/8	r = T/2 ≤ 1/4	All	a, d, g, m, o
SAW	BC-U6-S	1/2 min. to U	1/2 min. to U	R = 0	α = 20°	f = 1/4 min.	r = 1/4 min.	F	d, g, m

[a]Limited by a minimum groove depth.

Figure 3.5 (Continued)—Prequalified CJP Groove Welded Joints—Nontubular (see 3.24.1)

See Notes on Page 70

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

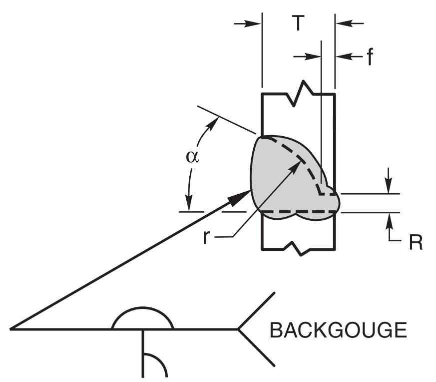


Tolerances	
As Detailed (see 3.24.2)	As Fit-Up (see 5.4)
For B-U7 and B-U7-GF	
R = +T/4 ≤ 1/16, –0	+1/16, –1/8
α = +10°, –0°	+10°, –5°
f = +T/4 ≤ 1/16, –0	Not limited[a]
R = +T/2 ≤ 1/4, –0	±1/16
For B-U7-S	
R = +0	+1/16, –0
f = +0, –1/4	±1/16

Welding Process	Joint Designation	Base Metal Thickness (U = Unlimited)	Groove Preparation				Permitted Welding Positions	Notes
		T	Root Opening	Groove Angle	Root Face	Groove Radius		
SMAW GTAW	B-U7	5/32 min. to U	R = 0 to T/2 ≤ 1/8	α = 45°	f = T/2 ≤ 1/8	r = T/2 ≤ 1/4	All	d, f, i, k, o
			R = 0 to T/2 ≤ 1/8	α = 20°	f = T/2 ≤ 1/8	r = T/2 ≤ 1/4	F, OH	d, f, i, k
GMAW FCAW	B-U7-GF	3/8 min. to U	R = 0 to T/2 ≤ 1/8	α = 20°	f = 1/8	r = 1/4 min.	All	a, d, k, i, o
SAW	BC-U7-S	1/2 min. to U	R = 0	α = 20°	f = 1/4 max.	r = 1/4 min.	F	d, i, k

[a]Limited by a minimum groove depth.

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



Tolerances	
As Detailed (see 3.24.2)	As Fit-Up (see 5.4)
R = +T/4 ≤ 1/16, –0	+1/16, –0
α = +10°, –0°	+10°, –5°
f = +T/4 ≤ 1/16, –0	Not limited[a]
r = +T/2 ≤ 1/8, –0	±1/16

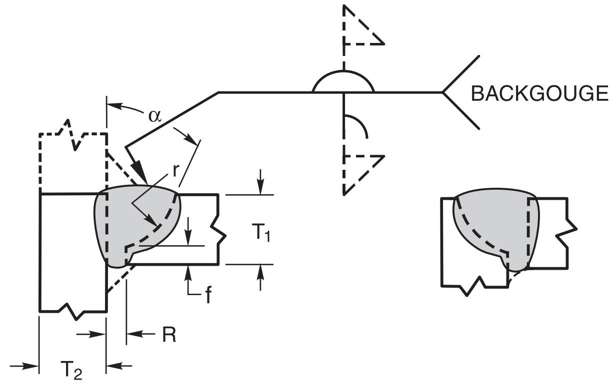
Welding Process	Joint Designation	Base Metal Thickness (U = Unlimited)	Groove Preparation				Permitted Welding Positions	Notes
		T	Root Opening	Groove Angle	Root Face	Groove Radius		
SMAW	B-U8	3/32 min. to U	R = 0 to T/2 ≤ 1/8	α = 45°	f = T/2 ≤ 1/8	r = 3T/4 ≤ 3/8	All	c, d, k, o
GTAW	B-L8	3/32 min. to 1						
GMAW FCAW	B-U8-GF	1/8 min. to U	R = 0 to T/2 ≤ 1/8	α = 30°	f = T/2 ≤ 1/8	r = 3T/4 ≤ 3/8	All	a, c, d, k, o
SAW	B-U8-S	3/8 min. to U	R = 0	α = 45°	f = 1/4 max.	r = 3/8	F	c, d, k

[a]Limited by a minimum groove depth.

Figure 3.5 (Continued)—Prequalified CJP Groove Welded Joints—Nontubular (see 3.24.1)

See Notes on Page 70

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

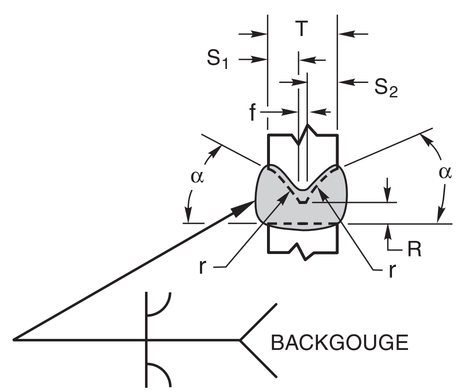


Tolerances	
As Detailed (see 3.24.2)	As Fit-Up (see 5.4)
R = +T/4 ≤ 1/16	+1/16, –0
α = +10°, –0°	+10°, –5°
f = +1/16, –0	Not limited[a]
r = +1/4, –0	±1/16

Welding Process	Joint Designation	Base Metal Thickness (U = Unlimited)		Groove Preparation				Permitted Welding Positions	Notes
		T_1	T_2	Root Opening	Groove Angle	Root Face	Groove Radius		
SMAW	TC-U8a	3/32 min. to U	3/32 min. to U	R = 0 to T/2 ≤ 1/8	α = 45°	f = T/2 ≤ 1/8	r = 3T/4 ≤ 3/8	All	d, g, m, n, o
GTAW	TC-L8a	3/32 min. to U	3/32 min. to U	R = 0 to T/2 ≤ 1/8	α = 30°	f = T/2 ≤ 1/8	r = 3T/4 ≤ 3/8	F, OH	d, g, m, n
GMAW FCAW	TC-U8a-GF	3/8 min. to U	1/8 min. to U	R = 0 to T/2 ≤ 1/8	α = 30°	f = T/2 ≤ 1/8	r = 3T/4 ≤ 3/8	All	a, d, g, m, n, o
SAW	TC-U8a-S	3/8 min. to U	—	R = 0	α = 45°	f = 1/4 max.	r = 3/8	F	d, g, m, n

[a]Limited by a minimum groove depth.

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



Tolerances	
As Detailed (see 3.24.2)	As Fit-Up (see 5.4)
R = +T/4 ≤ 1/16, –0	+1/16, –0
α = +10° –0°	+10°, –5°
f = +T/4 ≤ 1/16, –0	Not limited[a]
r = +T/2 ≤ 1/8, –0	±1/16

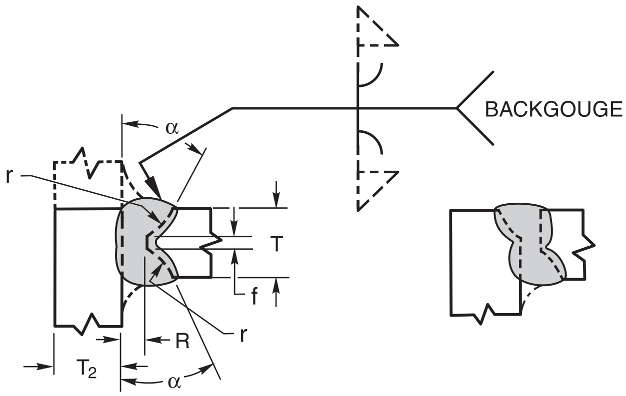
Welding Process	Joint Designation	Base Metal Thickness (U = Unlimited)	Groove Preparation				Permitted Welding Positions	Notes
		T	Root Opening	Groove Angle	Root Face	Groove Radius		
SMAW	B-U9	5/32 min. to U	R = 0 to T/2 ≤ 1/8	α = 45°	f = T/2 ≤ 1/8	r = 3T/4 ≤ 3/8	All	c, d, i, k, o
GTAW	B-L9	5/32 min. to 2						
GMAW FCAW	B-U9-GF	3/8 min. to U —	R = 0 to 1/8	α = 30°	f = 1/8 min.	r = 3/8 min.	All	a, c, d, i, k, o

[a]Limited by a minimum groove depth.

Figure 3.5 (Continued)—Prequalified CJP Groove Welded Joints—Nontubular (see 3.24.1)

See Notes on Page 70

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



Tolerances	
As Detailed (see 3.24.2)	As Fit-Up (see 5.4)
R = +T/4 ≤ 1/16, –0	+1/16, –0
α = +10°, –0°	+10°, –5°
f = +T/4 ≤ 1/16, –0	Not limited[a]
r = +T/2 ≤ 1/8, –0	±1/16

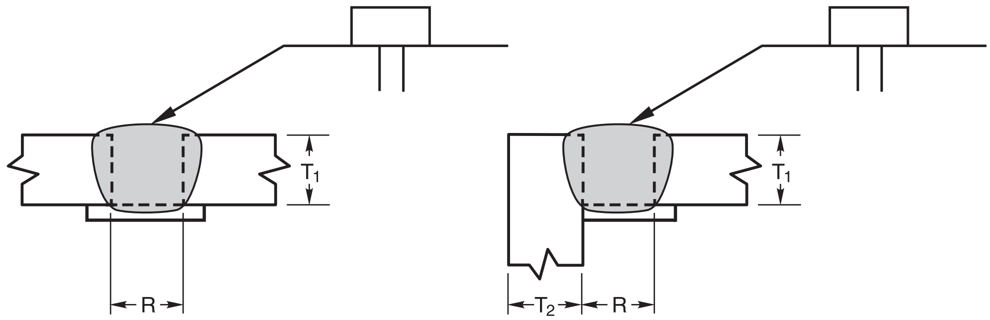
Welding Process	Joint Designation	Base Metal Thickness Max. (U = Unlimited)		Groove Preparation				Permitted Welding Positions	Notes
		T_1	T_2	Root Opening	Groove Angle	Root Face	Groove Radius		
SMAW	TC-U9a	5/32 min. to U	U	R = 0 to T/2 ≤ 1/8	α = 45°	f = T/2 ≤ 1/8	r = 3T/4 ≤ 3/8	All	d, g, i, m, n, o
GTAW	TC-L9a	5/32 min. to 2		R = 0 to T/2 ≤ 1/8	α = 30°	f = T/2 ≤ 1/8	r = 3T/4 ≤ 3/8	F, OH	d, g, i, m, n
GMAW FCAW	TC-U9a-GF	3/8 min. to U	U	R = 0 to 1/8	α = 30°	f = 1/8 min.	r = 3/8 min.	All	a, d, g, i, m, n, o

[a]Limited by a minimum groove depth.

Figure 3.5 (Continued)—Prequalified CJP Groove Welded Joints—Nontubular (see 3.24.1)

See Notes on Page 70

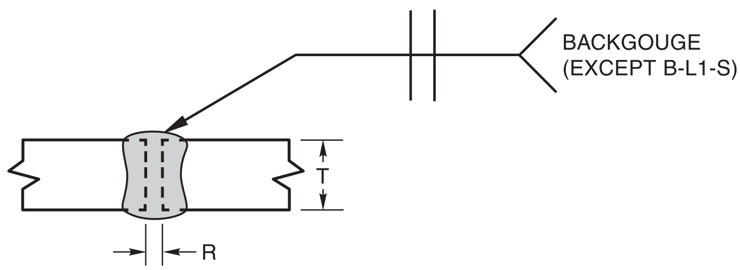
Square-groove weld (1)
Butt joint (B)
Corner joint (C)



ALL DIMENSIONS IN mm

Welding Process	Joint Designation	Base Metal Thickness (U = Unlimited)		Groove Preparation			Permitted Welding Positions	Notes
					Tolerances			
		T_1	T_2	Root Opening	As Detailed (see 3.24.2)	As Fit-Up (see 5.4)		
SMAW GMAW	B-L1a C-L1a	6 max.	—	$R = T_1$	+T/4 ≤ 2, –0	+T/4 ≤ 6, –T/4 ≤ 2	All	a, k, o
GTAW		6 max.	U	$R = T_1$	+T/4 ≤ 2, –0	+T/4 ≤ 6, –T/4 ≤ 2	All	k, o
FCAW	B-L1a-F	10 max.	—	$R = T_1$	+2, –0	+T/4 ≤ 6, –T/4 ≤ 2	All	k, o
SAW	B-L1-S	10 max.	—	$R = T_1$	+2, –0	+T/4 ≤ 6, –T/4 ≤ 2	F	k

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



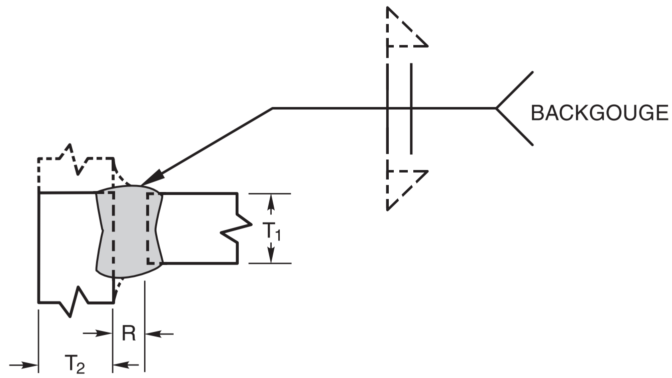
ALL DIMENSIONS IN mm

Welding Process	Joint Designation	Base Metal Thickness	Groove Preparation			Permitted Welding Positions	Notes
				Tolerances			
		T	Root Opening	As Detailed (see 3.24.2)	As Fit-Up (see 5.4)		
SMAW GTAW	B-L1b	6 max.	R = T/2	+T/4 ≤ 2, –0	+2, –T/2 ≤ 3	All	d, k, o
FCAW	B-L1b-F	10 max.	R = 0 to 3	+2, –0	+2, –T/2 ≤ 3	All	d, k, o
GMAW	B-L1b-G	10 max.	R = 0 to 3	+2, –0	+2, –T/2 ≤ 3	All	a, d, k
SAW	B-L1-S	10 max.	R = 0	±0	+2, –0	F	k
SAW	B-L1a-S	16 max.	R = 0	±0	+2, –0	F	d, k

Figure 3.5 (Continued)—Prequalified CJP Groove Welded Joints—Nontubular (see 3.24.1) (Dimensions in Millimeters)

See Notes on Page 70

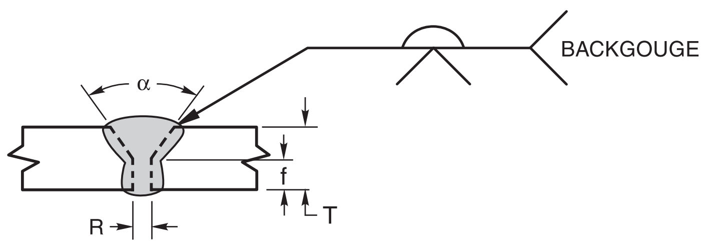
Square-groove weld (1)
T-joint (T)
Corner joint (C)



ALL DIMENSIONS IN mm

Welding Process	Joint Designation	Base Metal Thickness (U = Unlimited)		Groove Preparation			Permitted Welding Positions	Notes
					Tolerances			
		T_1	T_2	Root Opening	As Detailed (see 3.24.2)	As Fit-Up (see 5.4)		
SMAW GTAW	TC-L1b	6 max.	U	$R = T_1/2$	+T/4 ≤ 2, –0	+2, –T/2 ≤ 3	All	d, g, o
GMAW FCAW	TC-L1-GF	10 max.	U	R = 0 to 3	+2, –0	+2, –T/2 ≤ 3	GMAW—F	a, d, g
							FCAW—All	a, d, g, o
SAW	TC-L1-S	10 max.	U	R = 0	±0	+2, –0	F	d, g

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



ALL DIMENSIONS IN mm

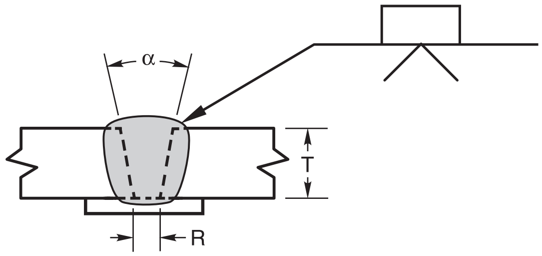
Welding Process	Joint Designation	Base Metal Thickness (U = Unlimited)	Groove Preparation			Permitted Welding Positions	Notes
				Tolerances			
		T	Root Opening Root Face Groove Angle	As Detailed (see 3.24.2)	As Fit-Up (see 5.4)		
SMAW GTAW	B-U2	U	R = 0 to T/2 ≤ 3 f = 0 to T/2 ≤ 3 α = 60°	+T/4 ≤ 2, –0 +T/4 ≤ 2, –0 + 10°, –0°	+2, –T/2 ≤ 3 Not limited[a] +10°, –5°	All	d, k, o
	B-L2	50 max.					
GMAW FCAW	B-U2-GF	U	R = 0 to T/2 ≤ 3 f = 0 to T/2 ≤ 3 α = 45°	+T/4 ≤ 2, –0 +T/4 ≤ 2, –0 + 10°, –0°	+2, –T/2 ≤ 3 Not limited[a] +10°, –5°	All	a, d, k, o
SAW	B-L2c-S	Over 12 to 25	R = 0 f = 6 max. α = 60°	R = ±0 f = +0, –2 α = +10°, –0°	+2, –0 ±2 +10°, –5°	F	d, k
		Over 25 to 40	R = 0 f = 12 max. α = 60°				
		Over 40 to 50	R = 0 f = 16 max. α = 60°				

[a]Limited by a minimum groove depth.

Figure 3.5 (Continued)—Prequalified CJP Groove Welded Joints—Nontubular (see 3.24.1) (Dimensions in Millimeters)

See Notes on Page 70

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

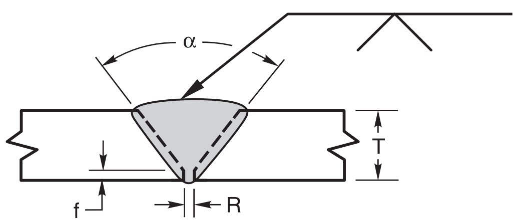


ALL DIMENSIONS IN mm

Tolerances	
As Detailed (see 3.24.2)	As Fit-Up (see 5.4)
R = +2, –0	+6, –2
α = +10°, –0°	+10°, –5°

Welding Process	Joint Designation	Base Metal Thickness (U = Unlimited) T	Groove Preparation: Root Opening	Groove Preparation: Groove Angle	Permitted Welding Positions	Notes
SMAW	B-U2a	U	R = 6	α = 45°	All	k, o
GTAW	B-L2a	25 max.	R = 10	α = 30°	All	k, o
			R = 12	α = 20°	All	k, o
GMAW FCAW	B-U2a-GF	U	R = 5	α = 30°	All	a, k, o
			R = 10	α = 30°	All	a, k, o
			R = 6	α = 45°	All	a, k, o
SAW	B-L2a-S	50 max.	R = 6	α = 30°	F	k
SAW	B-U2-S	U	R = 16	α = 20°	F	k

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



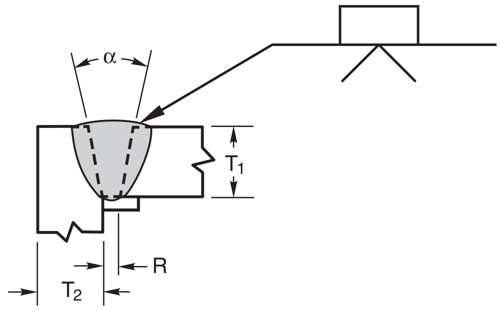
ALL DIMENSIONS IN mm

Welding Process	Joint Designation	Base Metal Thickness Max. T	Groove Preparation: Root Opening Root Face Groove Angle	Groove Preparation: Tolerances: As Detailed (see 3.24.2)	Groove Preparation: Tolerances: As Fit-Up (see 5.4)	Permitted Welding Positions	Notes
GTAW	B-L2b	2 min. to 25	R = 0 to T/2 ≤ 3 f = 0 to T/2 ≤ 2 α = 75°	+T/4 ≤ 2, –0 +T/4 ≤ 1, –0 0°, –10°	+2, –T/2 ≤ 1 +0, –T/2 ≤ 1 ±5%	All	e, o, p, q

Figure 3.5 (Continued)—Prequalified CJP Groove Welded Joints—Nontubular (see 3.24.1) (Dimensions in Millimeters)

See Notes on Page 70

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

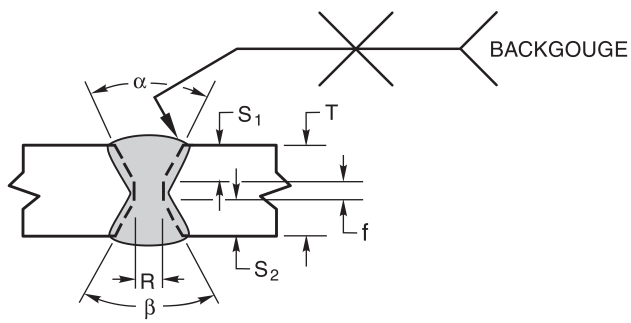


ALL DIMENSIONS IN mm

Tolerances	
As Detailed (see 3.24.2)	As Fit-Up (see 5.4)
R = +2, –0	+6, –2
α = +10°, –0°	+10°, –5°

Welding Process	Joint Designation	Base Metal Thickness (U = Unlimited) T_1	T_2	Groove Preparation Root Opening	Groove Angle	Permitted Welding Positions	Notes
SMAW	C-U2a	U	U	R = 6	α = 45°	All	l, o
GTAW	C-L2a	25 max.		R = 10	α = 30°	All	l, o
				R = 12	α = 20°	All	l, o
GMAW FCAW	C-U2a-GF	U	U	R = 5	α = 30°	All	a, o
				R = 10	α = 30°	All	a, l, o
				R = 6	α = 45°	All	a, l, o
SAW	C-L2a-S	50 max.	U	R = 6	α = 30°	F	l
SAW	C-U2-S	U	U	R = 16	α = 20°	F	l

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



ALL DIMENSIONS IN mm

For B-U3c-S only		
T Over	T to	S_1
50	60	35
60	80	45
80	90	55
90	100	60
100	120	70
120	140	80
140	160	90
For T > 160 or T ≤ 50 S_1 = 2/3 (T – 6)		

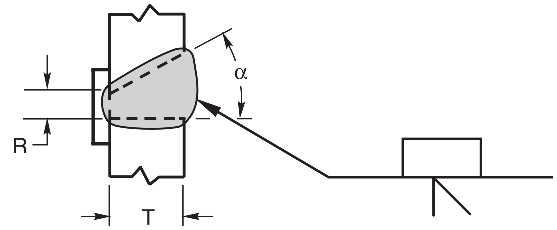
Welding Process	Joint Designation	Base Metal Thickness Max. (U = Unlimited) T	Groove Preparation Root Opening Root Face Groove Angle	Tolerances As Detailed (see 3.24.2)	Tolerances As Fit-Up (see 5.4)	Permitted Welding Positions	Notes
SMAW	B-U3b	U	R = 0 to T/2 ≤ 3 f = 0 to T/2 ≤ 3 α = β = 60°	+T/2 ≤ 2, –0 +T/2 ≤ 2, –0 +10°, –0°	+2, –T/2 ≤ 3 Not limited[a] +10°, –5°	All	d, i, k, o
GTAW	B-L3b	50				All	a, d, i, k, o
GMAW FCAW	B-U3-GF	U					
SAW	B-U3c-S	12 min. to U	R = 0 f = 6 min. α = β = 60°	+2, –0 +6, –0 +10°, –5°	+2, –0 +6, –0 +10°, –0°	F	d, i, k
			To find S_1 see table above: $S_2 = T - (S_1 + f)$				

[a] Limited by a minimum groove depth.

Figure 3.5 (Continued)—Prequalified CJP Groove Welded Joints—Nontubular (see 3.24.1) (Dimensions in Millimeters)

See Notes on Page 70

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

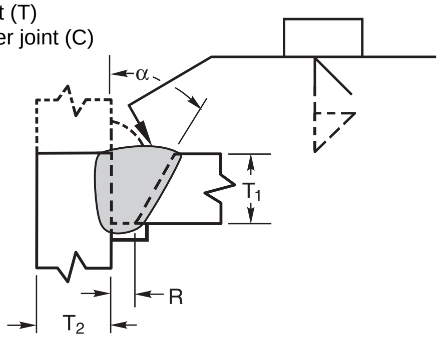


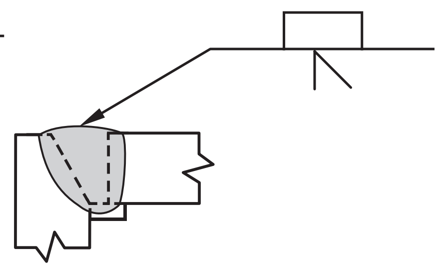
ALL DIMENSIONS IN mm

Tolerances	
As Detailed (see 3.24.2)	As Fit-Up (see 5.4)
R = +2, –0	+6, –2
α = +10°, –0°	+10°, –5°

Welding Process	Joint Designation	Base Metal Thickness (U = Unlimited)	Groove Preparation		Permitted Welding Positions	Notes
		T	Root Opening	Groove Angle		
SMAW	B-U4a	6 min. to U	R = 6	α = 45°	All	c, k, o
GTAW	B-L4a	6 min. to 25	R = 10	α = 30°	All	c, k, o
GMAW FCAW	B-U4a-GF	6 min. to U	R = 5	α = 30°	All	a, c, k, o
			R = 6	α = 45°	All	a, c, k, o
			R = 10	α = 30°	F	c, k
SAW	B-U4a-S	6 min. to U	R = 6	α = 45°	F	c, k
			R = 10	α = 30°		

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





ALL DIMENSIONS IN mm

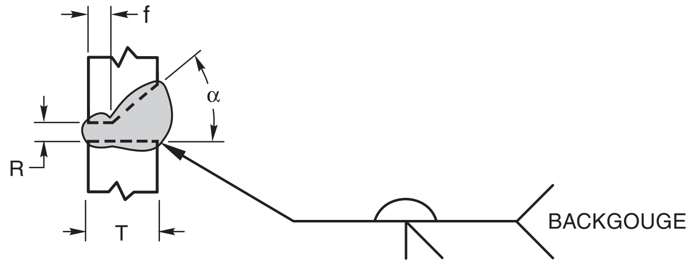
Tolerances	
As Detailed (see 3.24.2)	As Fit-Up (see 5.4)
R = +2, –0	+6, –2
a = +10°, –0°	+10°, –5°

Welding Process	Joint Designation	Base Metal Thickness (U = Unlimited)		Groove Preparation		Permitted Welding Positions	Notes
		T_1	T_2	Root Opening	Groove Angle		
SMAW	TC-U4a	6 min. to U	6 min. to U	R = 6	α = 45°	All	g, l, n, o
GTAW	TC-L4a	6 min. to 25		R = 10	α = 30°	All	g, l, n, o
GMAW FCAW	TC-U4a-GF	5 min. to U	5 min. to U	R = 5	α = 30°	All	a, g, l, n, o
				R = 6	α = 45°	F	a, g, l, n
				R = 10	α = 30°	All	a, g, l, n, o
SAW	TC-U4a-S	10 min. to U	10 min. to U	R = 10	α = 30°	F	g, l, n
				R = 6	α = 45°		

Figure 3.5 (Continued)—Prequalified CJP Groove Welded Joints—Nontubular (see 3.24.1) (Dimensions in Millimeters)

See Notes on Page 70

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

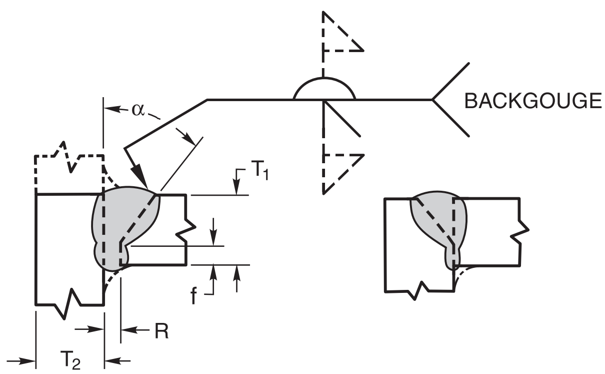


ALL DIMENSIONS IN mm

Welding Process	Joint Designation	Base Metal Thickness Max. (U = Unlimited)	Groove Preparation			Permitted Welding Positions	Notes
				Tolerances			
		T	Root Opening Root Face Groove Angle	As Detailed (see 3.24.2)	As Fit-Up (see 5.4)		
SMAW	B-U4b	2 min. to U	R = 0 to T/2 ≤ 3 f = 0 to T/2 ≤ 3 α = 45°	+T/4 ≤ 2, –0 +T/4 ≤ 2, –0 +10°, –0°	+2, –T/2 ≤ 3 Not limited[a] 10°, –5°	All	c, d, k, o
GTAW	B-L4b	2 min. to 1					
GMAW FCAW	B-U4b-GF	3 min. to U —	R = 0 to T/2 ≤ 3 f = 0 to T/2 ≤ 3 α = 45°	+T/4 ≤ 2, –0 +T/4 ≤ 2, –0 +10°, –0°	+2, –T/2 ≤ 3 Not limited[a] 10°, –5°	All	a, c, d, k, o
SAW	B-U4b-S	10 min. to U —	R = 0 f = 6 max. α = 60°	±0 +0, –3 +10°, –0°	+6, –0 ±2 10°, –5°	F	c, d

[a]Limited by a minimum groove depth.

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



ALL DIMENSIONS IN mm

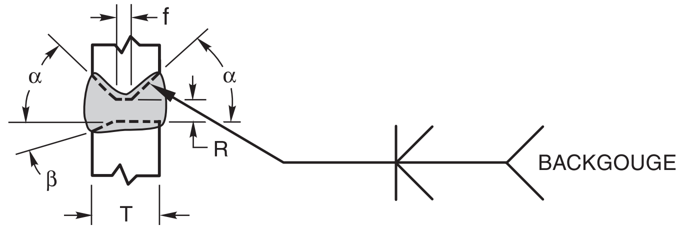
Welding Process	Joint Designation	Base Metal Thickness Max. (U = Unlimited)		Groove Preparation			Permitted Welding Positions	Notes
					Tolerances			
		T_1	T_2	Root Opening Root Face Groove Angle	As Detailed (see 3.24.2)	As Fit-Up (see 5.4)		
SMAW	TC-U4b	2 min. to U	2 min. to U	R = 0 to T/2 ≤ 3 f = 0 to T/2 ≤ 3 α = 45°	+T/4 ≤ 2, –0 +T/4 ≤ 2, –0 +10°, –0°	+2, –T/2 ≤ 3 Not limited[a] +10°, –5°	All	d, g, m, n, o
GTAW	TC-L4b	2 min. to 25	2 min. to 25					
GMAW FCAW	TC-U4b-GF	3 min. to U	3 min. to U	R = 0 to T/2 ≤ 3 f = 0 to T/2 ≤ 3 α = 45°	+T/4 ≤ 2, –0 +T/4 ≤ 2, –0 +10°, –0°	+2, –T/2 ≤ 3 Not limited[a] +10°, –5°	All	a, d, g, m, n, o
SAW	TC-U4b-S	10 min. to U	10 min. to U	R = 0 f = 6 max. α = 60°	±0 +0, –3 +10°, –0°	+6, –0 ±2 +10°, –5°	F	d, g, m, n

[a]Limited by a minimum groove depth.

Figure 3.5 (Continued)—Prequalified CJP Groove Welded Joints—Nontubular (see 3.24.1) (Dimensions in Millimeters)

See Notes on Page 70

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

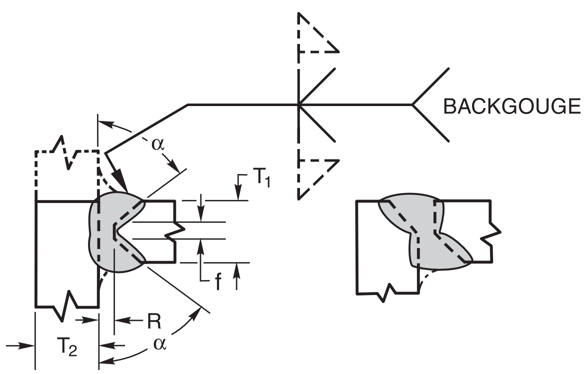


ALL DIMENSIONS IN mm

Welding Process	Joint Designation	Base Metal Thickness Max. (U = Unlimited) T	Groove Preparation: Root Opening Root Face Groove Angle	Tolerances: As Detailed (see 3.24.2)	Tolerances: As Fit-Up (see 5.4)	Permitted Welding Positions	Notes
SMAW GMAW	B-U5a	3 min. to U	R = 0 to T/2 ≤ 3 f = 0 to T/2 ≤ 3 α = 45° β = 0° to 15°	+T/4 ≤ 2, –0 +T/4 ≤ 2, –0 α + β = +10°, –0°	+2, –T/2 ≤ 3 Not limited[a] α + β = +10°, –5°	All	a, c, d, i, k, o
GTAW	B-L5a	3 min. to 50					
FCAW	B-U5-F	5 min. to U	R = 0 to T/2 ≤ 3 f = 0 to T/2 ≤ 3 α = 45° β = 0° to 15°	+T/4 ≤ 2, –0 +T/4 ≤ 2, –0 α + β = +10°, –0°	+2, –T/2 ≤ 3 Not limited α + β = +10°, –5°	All	c, d, i, k, o

[a] Limited by a minimum groove depth.

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



ALL DIMENSIONS IN mm

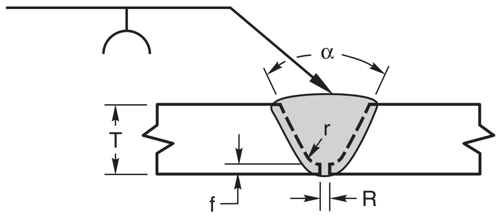
Welding Process	Joint Designation	Base Metal Thickness Max. (U = Unlimited) T_1	T_2	Groove Preparation: Root Opening Root Face Groove Angle	Tolerances: As Detailed (see 3.24.2)	Tolerances: As Fit-Up (see 5.4)	Permitted Welding Positions	Notes
SMAW GMAW	TC-U5b	3 min. to U	3 min. to U	R = 0 to T/2 ≤ 3 f = 0 to T/2 ≤ 3 α = 45°	+T/4 ≤ 2, –0 +T/4 ≤ 2, –0 +10°, –0°	+2, –T/2 ≤ 3 Not limited[a] +10°, –5°	All	a, d, g, i, m, n, o
GTAW	TC-L5b	3 min. to 50	3 min. to 50					
FCAW	TC-U5-F	3 min. to U	3 min. to U	R = 0 to T/2 ≤ 3 f = 0 to T/2 ≤ 3 α = 45°	+T/4 ≤ 2, –0 +T/4 ≤ 2, –0 +10°, –0°	+2, –T/2 ≤ 3 Not limited[a] +10°, –5°	All	d, g, i, m, n, o
SAW	TC-U5-S	10 min. to U	10 min. to U	R = 0 f = 6 max. α = 60°	±0 +0, –3 +10°, –0°	+6, –0 ±2 +10°, –5°	F	d, g, i, m, n

[a] Limited by a minimum groove depth.

Figure 3.5 (Continued)—Prequalified CJP Groove Welded Joints—Nontubular (see 3.24.1) (Dimensions in Millimeters)

See Notes on Page 70

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

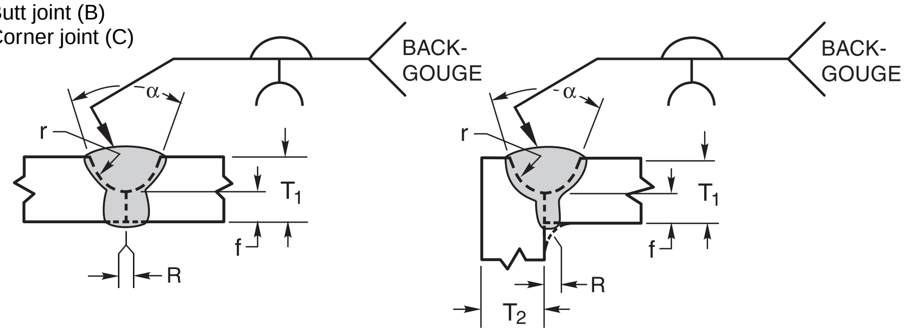


ALL DIMENSIONS IN mm

Tolerances	
As Detailed (see 3.24.2)	As Fit-Up (see 5.4)
R = ±T/4 ≤ 2	+2, –T/2 ≤ 1
α = ±5°	±5°
f = ±T/4 ≤ 2	+0, –T/2 ≤ 1
r = +T/2 ≤ 3, –0	+2, –1

Welding Process	Joint Designation	Base Metal Thickness Max.	Groove Preparation				Permitted Welding Positions	Notes
		T	Root Opening	Groove Angle	Root Face	Groove Radius		
GTAW	B-L6	2 min. to 25	R = 0 to T/2 ≤ 3	α = 45°	f = T/2 ≤ 3	r = T/2 ≤ 6	All	e, o, p, q

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



ALL DIMENSIONS IN mm

Tolerances	
As Detailed (see 3.24.2)	As Fit-Up (see 5.4)
R = +T/4 ≤ 2, –0	+2, –T/2 ≤ 3
α = +10°, –0°	+10°, –5°
f = ±T/4 ≤ 2	Not limited[a]
r = +T/2 ≤ 3, –0	+3, –0

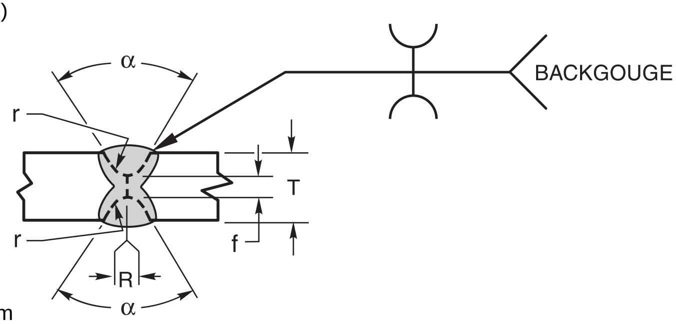
Welding Process	Joint Designation	Base Metal Thickness (U = Unlimited)		Groove Preparation				Permitted Welding Positions	Notes
		T_1	T_2	Root Opening	Groove Angle	Root Face	Groove Radius		
SMAW GTAW	B-U6	2.5 min. to U	2.5 min. to U	R = 0 to T/2 ≤ 3	α = 45°	f = T/2 ≤ 3	r = T/2 ≤ 6	All	d, f, k, o
				R = 0 to T/2 ≤ 3	α = 20°	f = T/2 ≤ 3	r = T/2 ≤ 6	F, OH	d, f, k
	C-U6	2.5 min. to U	2.5 min. to U	R = 0 to T/2 ≤ 3	α = 45°	f = T/2 ≤ 3	r = T/2 ≤ 6	All	d, f, g, m, o
				R = 0 to T/2 ≤ 3	α = 20°	f = T/2 ≤ 3	r = T/2 ≤ 6	F, OH	d, f, g, m
GMAW FCAW	B-U6-GF	3 min. to U	3 min. to U	R = 0 to T/2 ≤ 3	α = 20°	f = T/2 ≤ 3	r = T/2 ≤ 6	All	a, d, k, o
	C-U6-GF	3 min. to U	3 min. to U	R = 0 to T/2 ≤ 3	α = 20°	f = T/2 ≤ 3	r = T/2 ≤ 6	All	a, d, g, m, o
SAW	BC-U6-S	12 min. to U	12 min. to U	R = 0	α = 20°	f = 6 min.	r = 6 min.	F	d, g, m

[a]Limited by a minimum groove depth.

Figure 3.5 (Continued)—Prequalified CJP Groove Welded Joints—Nontubular (see 3.24.1) (Dimensions in Millimeters)

See Notes on Page 70

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



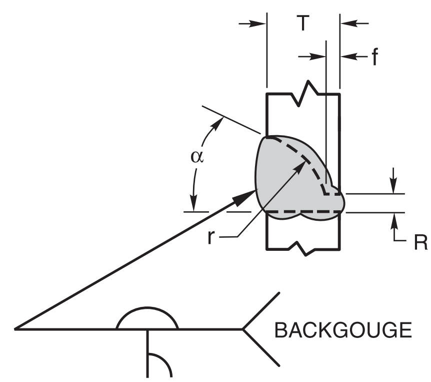
ALL DIMENSIONS IN mm

Tolerances	
As Detailed (see 3.24.2)	As Fit-Up (see 5.4)
For B-U7 and B-U7-GF	
R = +T/4 ≤ 2, –0	+2, –3
α = +10°, –0°	+10°, –5°
f = +T/4 ≤ 2, –0	Not limited[a]
R = +T/2 ≤ 6, –0	±2
For B-U7-S	
R = +0	+2, –0
f = +0, –6	±2

Welding Process	Joint Designation	Base Metal Thickness (U = Unlimited) T	Groove Preparation Root Opening	Groove Angle	Root Face	Groove Radius	Permitted Welding Positions	Notes
SMAW GTAW	B-U7	4 min. to U	R = 0 to T/2 ≤ 3	α = 45°	f = T/2 ≤ 3	r = T/2 ≤ 6	All	d, f, i, k, o
			R = 0 to T/2 ≤ 3	α = 20°	f = T/2 ≤ 3	r = T/2 ≤ 6	F, OH	d, f, i, k
GMAW FCAW	B-U7-GF	10 min. to U	R = 0 to T/2 ≤ 3	α = 20°	f = 3	r = 6 min.	All	a, d, k, i, o
SAW	BC-U7-S	12 min. to U	R = 0	α = 20°	f = 6 max.	r = 6 min.	F	d, i, k

[a]Limited by a minimum groove depth.

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



ALL DIMENSIONS IN mm

Tolerances	
As Detailed (see 3.24.2)	As Fit-Up (see 5.4)
R = +T/4 ≤ 2, –0	+2, –0
α = +10°, –0°	+10°, –5°
f = +T/4 ≤ 2, –0	Not limited[a]
r = +T/2 ≤ 3, –0	±2

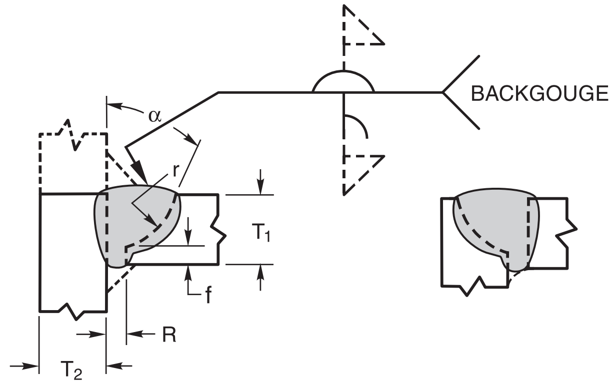
Welding Process	Joint Designation	Base Metal Thickness Max. (U = Unlimited) T	Groove Preparation Root Opening	Groove Angle	Root Face	Groove Radius	Permitted Welding Positions	Notes
SMAW	B-U8	2.5 min. to U	R = 0 to T/2 ≤ 3	α = 45°	f = T/2 ≤ 3	r = 3T/4 ≤ 10	All	c, d, k, o
GTAW	B-L8	2.5 min. to 25						
GMAW FCAW	B-U8-GF	3 min. to U	R = 0 to T/2 ≤ 3	α = 30°	f = T/2 ≤ 3	r = 3T/4 ≤ 10	All	a, c, d, k, o
SAW	B-U8-S	10 min. to U	R = 0	α = 45°	f = 6 max.	r = 10	F	c, d, k

[a]Limited by a minimum groove depth.

Figure 3.5 (Continued)—Prequalified CJP Groove Welded Joints—Nontubular (see 3.24.1) (Dimensions in Millimeters)

See Notes on Page 70

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



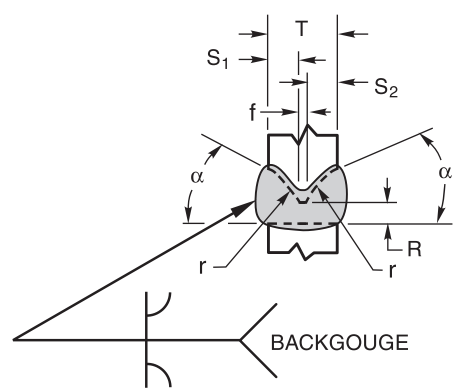
ALL DIMENSIONS IN mm

Tolerances	
As Detailed (see 3.24.2)	As Fit-Up (see 5.4)
R = +T/4 ≤ 2	+2, –0
α = +10°, –0°	+10°, –5°
f = +2, –0	Not limited[a]
r = +6, –0	±2

Welding Process	Joint Designation	Base Metal Thickness (U = Unlimited)		Groove Preparation				Permitted Welding Positions	Notes
		T_1	T_2	Root Opening	Groove Angle	Root Face	Groove Radius		
SMAW	TC-U8a	2.5 min. to U	2.5 min. to U	R = 0 to T/2 ≤ 3	α = 45°	f = T/2 ≤ 3	r = 3T/4 ≤ 10	All	d, g, m, n, o
GTAW	TC-L8a	2.5 min. to U	2.5 min. to U	R = 0 to T/2 ≤ 3	α = 30°	f = T/2 ≤ 3	r = 3T/4 ≤ 10	F, OH	d, g, m, n
GMAW FCAW	TC-U8a-GF	10 min. to U	3 min. to U	R = 0 to T/2 ≤ 3	α = 30°	f = T/2 ≤ 3	r = 3T/4 ≤ 10	All	a, d, g, m, n, o
SAW	TC-U8a-S	10 min. to U	—	R = 0	α = 45°	f = 6 max.	r = 10	F	d, g, m, n

[a]Limited by a minimum groove depth.

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



ALL DIMENSIONS IN mm

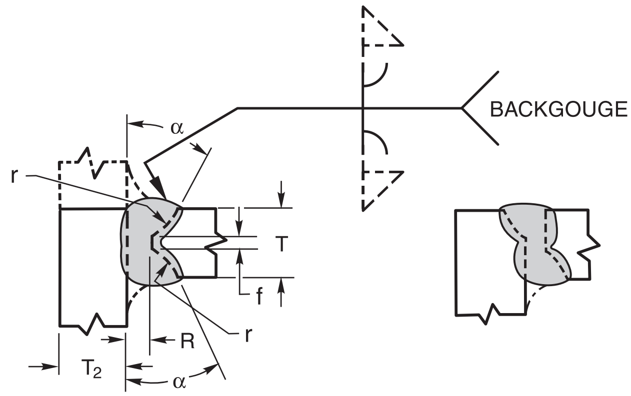
Tolerances	
As Detailed (see 3.24.2)	As Fit-Up (see 5.4)
R = +T/4 ≤ 2, –0	+2, –0
α = +10°, –0°	+10°, –5°
f = +T/4 ≤ 2, –0	Not limited[a]
r = +T/2 ≤ 3, –0	±2

Welding Process	Joint Designation	Base Metal Thickness Max. (U = Unlimited)	Groove Preparation				Permitted Welding Positions	Notes
		T	Root Opening	Groove Angle	Root Face	Groove Radius		
SMAW	B-U9	4 min. to U	R = 0 to T/2 ≤ 3	α = 45°	f = T/2 ≤ 3	r = 3T/4 ≤ 10	All	c, d, i, k, o
GTAW	B-L9	4 min. to 50						
GMAW FCAW	B-U9-GF	10 min. to U	R = 0 to 3	α = 30°	f = 3 min.	r = 10 min.	All	a, c, d, i, k, o

[a]Limited by a minimum groove depth.

Figure 3.5 (Continued)—Prequalified CJP Groove Welded Joints—Nontubular (see 3.24.1) (Dimensions in Millimeters)

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



ALL DIMENSIONS IN mm

Tolerances	
As Detailed (see 3.24.2)	As Fit-Up (see 5.4)
R = +T/4 ≤ 2, –0	+2, –0
α = +10°, –0°	+10°, –5°
f = +T/4 ≤ 2, –0	Not limited[a]
r = +T/2 ≤ 3, –0	±2

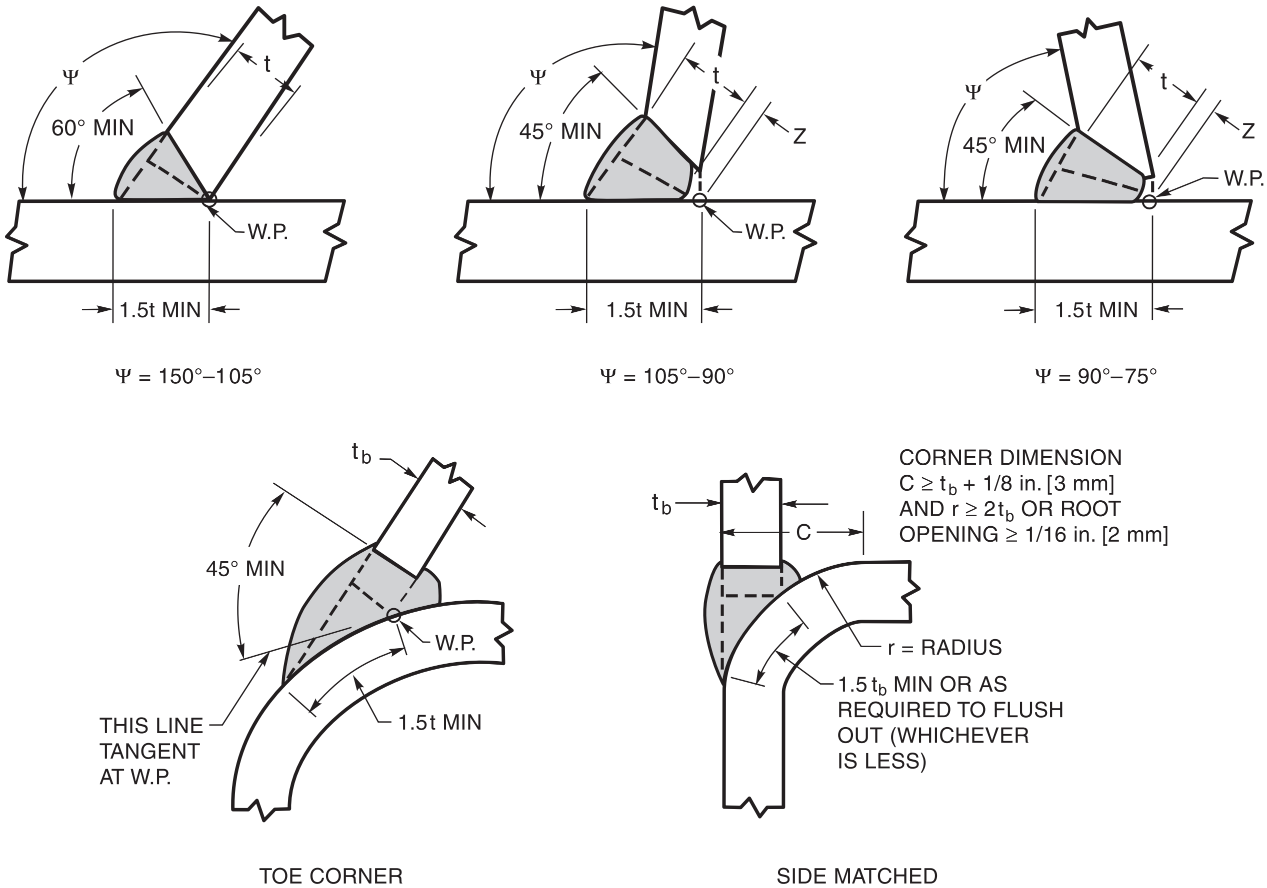
Welding Process	Joint Designation	Base Metal Thickness (U = Unlimited)		Groove Preparation				Permitted Welding Positions	Notes
		T_1	T_2	Root Opening	Groove Angle	Root Face	Groove Radius		
SMAW	TC-U9a	4 min. to U	U	R = 0 to T/2 ≤ 3	α = 45°	f = T/2 ≤ 3	r = 3T/4 ≤ 10	All	d, g, i, m, n, o
GTAW	TC-L9a	4 min. to 2		R = 0 to T/2 ≤ 3	α = 30°	f = T/2 ≤ 3	r = 3T/4 ≤ 10	F, OH	d, g, i, m, n
GMAW FCAW	TC-U9a-GF	10 min. to U	U	R = 0 to 3	α = 30°	f = 3 min.	r = 10 min.	All	a, d, g, i, m, n, o

[a] Limited by a minimum groove depth.

Figure 3.5 (Continued)—Prequalified CJP Groove Welded Joints—Nontubular (see 3.24.1) (Dimensions in Millimeters)

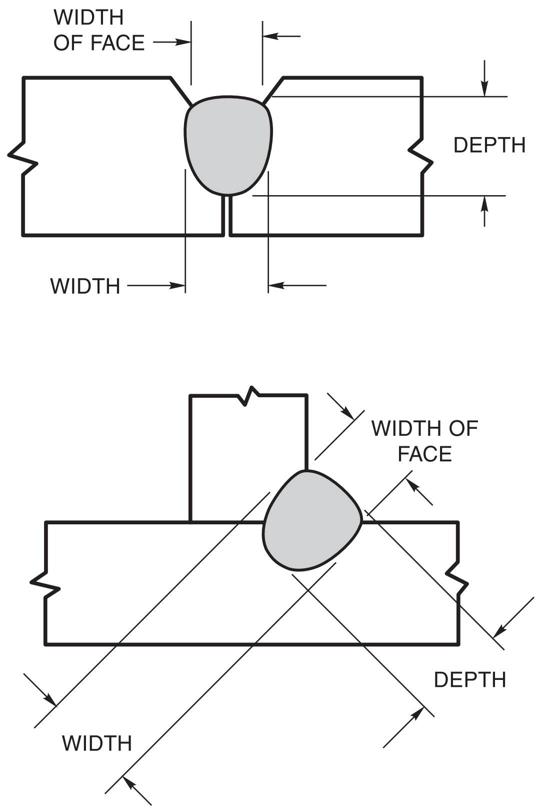
Notes for Figures 3.4 and 3.5

[a] Not prequalified for gas metal arc welding using short circuiting transfer for T > 3/16 in. [5 mm] (see 3.29 and Table 3.5 Note d).
[b] Joint is welded from one side only.
[c] Cyclic load applications limit these joints to the horizontal position.
[d] Backgouge root to sound metal before welding second side.
[e] Root welded from one side. Backgouging not required provided adequate gas purging is used.
[f] For GTAW, S is limited to 1 in. [25 mm] max.
[g] Fillet welds may be used to reinforce corner and T-joints.
[h] Butt and T-joints are not prequalified for cyclically loaded structures.
[i] Double-groove welds may have grooves of unequal depth, but the depth of the shallower groove shall be not less than one-fourth of the thickness of the thinner part joined.
[j] Double-groove welds may have grooves of unequal depth.
[k] The orientation of two members in the joints may vary from 135° to 180° provided that the basic joint configuration (groove angle, root face, root opening) remain the same and that the design weld size is maintained.
[l] The member orientation may be changed provided that the groove dimensions are maintained as specified.
[m] The orientation of two members in the joints may vary from 45° to 135° for corner joints and from 45° to 90° for T-joints, provided that the basic joint configuration (groove angle, root face, root opening) remain the same and that the design weld size is maintained.
[n] For corner joints, the outside groove preparation may be in either or both members, provided the basic groove configuration is not changed and adequate edge distance is maintained to support the welding operations without excessive edge melting.
[o] All position with suitable amperage or heat sink.
[p] For tube welding, the diameter of the tube shall be 1/2 in. [12 mm] min.
[q] Consumable inserts may be used.



Notes: Effective weld size = t_b
W.P. = Working Point

Figure 3.6—Prequalified Joint Details for PJP Groove Welds—Tubular (see 3.28.2)



Note: The weld bead width or depth shall not be greater than the weld face.

Figure 3.7—Weld Bead Width/Depth Limitations [see 3.29(11)]

4. Qualification

Part A
WPS Qualification Requirements

4.1 General

4.1.1 Qualification of WPSs. This clause establishes the requirements for the qualification of WPSs for each welding process listed in Table 4.1 and the documenting of actual welding variables listed on the Procedure Qualification Record (PQR). The destructive and nondestructive testing requirements for qualification of the WPS are designed to determine mechanical properties and soundness of welded joints.

4.1.2 Responsibility for WPS Qualification. Except for the WPSs exempted (prequalified) in Clause 3, WPSs which are to be employed in executing contract work under this code shall be qualified prior to use to the satisfaction of the engineer, by tests as prescribed in this clause. Each manufacturer or contractor shall conduct the tests required by this code to qualify WPSs (see exception in 4.1.3). It is permissible, however, to subcontract any or all of the work on the preparation of test materials for welding and subsequent work on the preparation of test specimens from the completed weldments for the performance of nondestructive and mechanical tests, provided the manufacturer or contractor accepts full responsibility for the work.

4.1.3 Previous Qualification Records. At the Engineer's discretion, evidence of previous qualification of the WPSs to be employed may be accepted. The acceptability of qualification to other standards is the Engineer's responsibility to be exercised based on the specific structures and service conditions. The provisions of AWS B2.1:2005, *Standard for Welding Procedure and Performance Qualification*, may be used for the qualification of WPSs and personnel. However, in instances when the provisions of AWS B2.1:2005 and AWS D1.6/D1.6M:2007 are in conflict, AWS D1.6/D1.6M:2007 shall take precedence.

4.1.4 WPS Variables. A written, qualified WPS establishes the allowable ranges for essential variables. The WPS is intended to be used to qualify welders and welding operators and provide direction for the welder and welding operator in the performance of production weldments.

4.1.5 Procedure Qualification Record (PQR). A PQR is a record which contains the actual variables used to weld a test specimen. This record also documents the destructive and nondestructive test results and the certifying organization.

4.1.6 Position of Welds. All welds that will be encountered in actual construction shall be classified as flat, horizontal, vertical, or overhead in accordance with the definition of welding positions (see Figures 4.1 and 4.2, as applicable).

4.1.7 Complete Joint Penetration Weld Qualification Limitations. Qualification of WPSs for CJP groove welds in any position listed in 4.1.9 qualifies for all positions. CJP groove welds qualified on pipe shall also qualify for plate and vice versa. Qualification of a CJP groove weld qualifies for all PJP groove welds, plug and slot, and fillet welds. Macroetch tests are still required to verify the design weld size and penetration for PJP and fillet welds (see 4.3.2 and 4.4). When backing is used, it shall be of a type compatible with the base metal and the weld metal.

4.1.8 Partial Penetration Groove Weld Qualification Limitations. Qualification of WPSs for PJP groove welds in any position listed in 4.1.9 qualifies for all positions. PJP groove WPSs qualified on pipe shall also qualify for plate and vice versa. Qualification of a PJP groove weld qualifies for all PJP groove welds, plug and slot welds, and fillet welds.

4.1.9 Test Positions. See Figure 4.3 for test positions for groove and fillet welds in plate, pipe, or tubing.

4.1.10 Mechanical Testing of Welds. Testing may be performed per AWS B4.0-98 (B4.0M:2000), *Standard Methods for Mechanical Testing of Welds*. However, in instances when the provisions of AWS B4.0-98 (B4.0M:2000) and AWS D1.6/D1.6M:2007 are in conflict, AWS D1.6/D1.6M:2007 shall take precedence.

4.2 Essential Variables for WPS Qualification

4.2.1 Changes to Essential Variables. Any change to the variables set forth in Table 4.1 shall be considered essential changes and shall require the qualification of a new WPS. When a combination of welding processes is used, the variables applicable to each process shall apply.

4.3 WPS Qualification Requirements

4.3.1 CJP Groove Welds. The type and number of test specimens that must be tested to qualify a WPS are shown in Table 4.2 together with the range of thickness that is qualified for use in construction. The range is based on the thickness of the test plate, pipe, or tubing used in making the qualification. The locations of test specimens are shown in Figure 4.4.

4.3.2 PJP Groove Welds

4.3.2.1 The type and number of test specimens that must be used to qualify a WPS are shown in Table 4.2, as applicable. A sample weld shall be made using a type of groove design to be used in construction, except the depth of the groove need not exceed 1 in. [25 mm]. For the macroetch test required below, any type of steel listed in 1.2 may be used to qualify the weld size on any steel or combination of steels for that type.

4.3.2.2 In addition to the type and number of tests required by Table 4.2, as applicable, PJP groove welds shall receive three macroetch cross-section specimens, which demonstrate that the designated weld size (obtained from the requirements of the WPS, or design specification as applicable) are met.

4.3.2.3 If a WPS is not covered by 4.3.2.2, or if the welding conditions do not meet a prequalified status, or if they have not been used and tested for a CJP weld in a butt joint, then a sample joint must be prepared to make a macroetch test specimen to determine the weld size of the joint. After welding, the excess material is machined off on the root side of the joint to the thickness of the weld size. Tension and bend test specimens shall be prepared and tests performed, as required for CJP groove welds (see 4.5.1).

4.3.2.4 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. As an option extra length can be added to the first production weld to provide at least two macroetch specimens.

4.4 Fillet Welds

4.4.1 The type and number of specimens that must be tested to qualify a WPS for fillet welds are shown in Table 4.2(B) and Figure 4.5.

4.4.1.1 A fillet welded T-joint, as shown in Figure 4.5 for plate or pipe, as applicable, shall be made for each WPS to be used in construction. The weldment shall be cut perpendicular to the direction of welding at locations shown in Figure 4.5, as applicable. Specimens representing one face of each cut shall constitute a macroetch test specimen and shall be tested in accordance with 4.5 and meet the requirements of 4.6.9. As an option, extra length can be added to the first production weld to provide at least two macroetch specimens.

4.5 Tests Required for Groove and Fillet Welds

4.5.1 Groove Welds (CJP and PJP). (See Table 4.2.)

(1) Visual inspection

(2) Reduced-section tension test

(3) Transverse guided bend test

(4) Longitudinal root and face guided bend test (optional, see 4.6.5).

4.5.2 Fillet Welds and PJP Groove Welds

(1) Visual inspection

(2) Macroetch test.

4.6 Types, Purposes, and Acceptance Criteria of Tests for WPS Qualification

4.6.1 Visual Examination. To determine that the final weld surfaces meet specified quality conditions. (All WPS qualification test specimens, except areas designated "discard," shall be visually examined).

4.6.2 Acceptance Criteria (Visual Examination)

(1) The weld shall be free of cracks.

(2) All craters shall be filled to the full cross section of the weld.

(3) Undercut shall not exceed 1/32 in. [1 mm]. Weld reinforcement shall not exceed 1/8 in. [3 mm].

(4) For CJP without steel backing, the root of the weld shall be inspected, and there shall be no evidence of cracks, incomplete fusion, or inadequate joint penetration. A concave root surface is permitted provided the total weld thickness is equal to or greater than that of the base metal.

(5) The maximum melt-through shall not exceed 1/8 in. [3 mm].

4.6.3 Transverse Guided-Bend Tests (Root and Face-Bend or Side Bend). To determine the degree of soundness and ductility of CJP and PJP weld joints. (CJP and PJP WPS qualification tests shall be guided-bend tested).

4.6.3.1 Each specimen shall be bent in a jig that meets the requirements shown in Figures 4.6 through 4.9, as applicable or is substantially in accordance with those figures, provided the maximum bend radius is not exceeded. The specimens shall be prepared for testing in accordance with Figures 4.16 through 4.18 and Figures 4.20 and 4.21.

4.6.4 Longitudinal Bend Tests (Face and Root Guided Bend). When material combinations differ markedly in mechanical properties (i.e., bending), as shown between two base materials or between the weld metal and the base metal, longitudinal bend tests may be used in lieu of the transverse face and root-bend tests. The test specimens shall be cut, removed and prepared for testing in accordance with Figures 4.4(B) and 4.19.

4.6.5 Acceptance Criteria (Root-, Face-, Side-, and Longitudinal-Bends)

4.6.5.1 The convex surface of the bend test specimens shall be visually examined for surface discontinuities. For acceptance, the surface shall contain no discontinuities exceeding the following dimensions:

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

(2) 3/8 in. [10 mm]—the sum of the greatest dimensions of all discontinuities exceeding 1/32 in. [1 mm], but less than or equal to 1/8 in. [3 mm].

(3) 1/4 in. [6 mm]—the maximum corner crack, except when the corner crack resulted from visible slag inclusion or other fusion type discontinuities, then the 1/8 in. [3 mm] maximum shall apply. Specimens with corner cracks exceeding 1/4 in. [6 mm] with no evidence of slag inclusion or other fusion type discontinuities shall be disregarded, and a replacement test specimen from the original weldment shall be tested.

4.6.6 Section Tension Test. To determine the ultimate strength of groove weld joints.

4.6.6.1 Before testing, the least width and corresponding thickness of the reduced section shall be measured. The specimen shall be ruptured under tensile load, and the maximum load shall be determined. The tensile strength shall be obtained by dividing the maximum load by the cross-sectional area (see Figures 4.10 through 4.13).

4.6.7 Acceptance Criteria (Tension Test)

4.6.7.1 The tensile strength shall be no less than the minimum of the specified tensile range of the base metal used, except as noted in 4.6.7.2. In a case in which two base metals of different minimum tensile strengths are used, the specified minimum tensile strength shall be the weaker of the two, except as noted in 4.6.7.2.

4.6.7.2 When weld metal of lesser strength than the base metal is permitted, the range of the tensile strength shall be no less than the minimum of the specified tensile range of the filler metal.

4.6.8 Macroetch Test. The weld test specimen shall be prepared with a finish suitable for macroetch examination to determine the extent of fusion and unacceptable discontinuities, and to demonstrate that the designated weld size is obtained.

4.6.9 Acceptance Criteria (Macroetch Test)

4.6.9.1 The visually inspected macroetch test shall conform to the following:

(1) PJP groove welds shall have the designed weld size.

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

(3) Minimum leg size shall meet the specified fillet weld size.

(4) The PJP groove welds and fillet welds shall have the following:

(a) No cracks.

(b) Through fusion between adjacent layers of weld metals and between weld metal and base metal.

(c) Weld profiles conforming to intended detail, but with none of the variations prohibited in Clause 5.

(d) No undercut exceeding 1/32 in. [1 mm].

4.6.10 Retest. If any specimen fails to meet the test requirements, two retests for the same type of specimen may be performed with specimens cut from the same WPS qualification material. The results of both test specimens shall meet the test requirements. For material over 1-1/2 in. [40 mm] thick, failure of a specimen shall require testing of all specimens of the same type from two additional locations in the test material.

4.6.11 Overlay Requirements

4.6.11.1 The essential variables for all welding processes are described in Table 4.1S.

4.6.11.2 See Figure 4.21 for overlay test weldment.

4.6.11.3 See Table 4.7 for qualification thickness limitations.

4.6.11.4 The overlay WPS qualification test shall be subjected to the following tests:

(1) Guided bend test

(2) Penetrant examination

(3) Chemical analysis.

4.6.11.5 Acceptance Criteria

(1) *Guided bend test*—no open discontinuity exceeding 1/8 in. [3 mm] measured in any direction on the convex surface shall be permitted in the overlay, and no open discontinuities exceeding 1/8 in. [3 mm] shall be permitted at the weld interface after bending.

(2) *Penetrant examination*—the entire surface of the test weldment shall be penetrant examined. No linear indication with major dimensions greater than 1/16 in. [2 mm] in a line separated by at least 1/16 in. [2 mm] shall be permitted. No more than three rounded indications with dimensions greater than 1/16 in. [2 mm] in a line separated by at least 1/16 in. [2 mm].

(3) *Chemical analysis*—the results of the required chemical analysis shall be within the range of analysis specified in the WPS (see Figure 4.22).

Part B
Performance Qualification Requirements for Welders and Welding Operators

4.7 General

4.7.1 Performance Qualification. Welders and welding operators using the welding processes in Table 4.1 shall have been qualified by the applicable tests as prescribed in this clause. The qualification tests described are specially devised tests to determine the welder or welding operator's ability to produce sound welds with a specific welding process.

4.7.2 Responsibility for Performance Qualification. The manufacturer or contractor shall conduct the test required by this code to qualify welders and welding operators. It is permissible, however, to subcontract any or all of the work on the preparation of test materials for welding and subsequent work on the preparation of test specimens from the completed weldments, performance of nondestructive and mechanical tests, provided the manufacturer or contractor accepts full responsibility for the work. The purpose of this requirement is to ensure that the manufacturer or contractor has determined that their welders and welding operators using their WPSs are capable of developing the minimum requirements specified for an acceptable weldment.

4.7.3 Previous Qualification Records. At the Engineer's discretion, properly documented evidence of previous qualification of welders and welding operators to be employed may be accepted, provided the requirements of 4.7.9 are met. Welders and welding operators qualified by standard test to AWS B2.1:2005, *Standard for Welding Procedure and Performance Qualification*, may, in this manner, be accepted for use in this code.

4.7.4 Qualification by WPS Qualification. The welder or welding operator who performs the welding on the WPS qualification test coupons is also qualified within the limits of the performance qualification variables defined in Tables 4.3 and 4.4.

4.7.5 Base Metal. The base metal used shall comply with 1.2. Qualification established with any one of these base metals shall be considered as qualification to weld any one of the base metals permitted by this code. For all types of welded joints, the length of the weld and dimensions of the base metal shall provide sufficient material for the test specimens required by this code. With the approval of the Engineer, performance qualification test coupons may be with any of the steels listed in AWS D1.1, Groups I or II. Qualification established with any one of these base metals shall be considered as qualification to weld any of the base metals permitted by this code.

4.7.6 Joint Details. Performance qualification test on plate, pipe or tubing shall be in accordance with the joint details prescribed by the WPS.

4.7.7 Records. Records of the test results shall be kept by the manufacturer or contractor and shall be made available to those authorized to examine them.

4.7.8 Retest For Performance Qualification. In case a welder or welding operator fails to meet the requirements of one or more test welds, a retest may be allowed under the following conditions:

4.7.8.1 Immediate Retest. An immediate retest may be made consisting of two welds of each type and position that the welder or welding operator failed. All retest specimens shall meet all the specified requirements.

4.7.8.2 Retest After Further Training or Practice. A retest may be made, provided there is evidence that the welder or welding operator has had further training or practice. A complete retest of the types and positions failed shall be made.

4.7.9 Period of Effectiveness. The welder or welding operator's qualification as specified by this code shall be considered as remaining in effect indefinitely unless:

(1) the welder or welding operator has not welded with a process during a period exceeding six months, his qualifications for that process shall terminate, or;

(2) there is a specific reason to question a welder's ability.

4.7.9.1 In the case of 4.7.9(1), the requalification test shall be in any position on pipe, tube or plate, and any thickness or diameter.

4.7.9.2 In the case of 4.7.9(2), the requirements of 4.7.8.2 shall apply.

4.7.10 Test Specimens For Welder and Welding Operator Qualification

4.7.10.1 The welder or welding operator qualification test shall conform to the thickness, diameter, and position limitations of Tables 4.3 and 4.4. For removal of test specimens, see Figures 4.14, 4.15, and 4.23.

4.7.11 Test Positions For Groove (G) and Fillet (F) Welds. See Table 4.4 for production welding positions qualified by test positions.

4.7.12 Tack Welding. It should be noted that this code does not recognize tack welders as such; tack welding to this code shall be performed only by welders or welding operators qualified to the requirements of ANSI/AWS D1.6.

4.8 Limitation of Variables for Welder Performance Qualification

4.8.1 Process. A welder shall be qualified for each process used. GMAW-S (short circuit transfer) shall require a separate qualification from GMAW (globular or spray transfer).

4.8.2 Electrodes. A welder qualified for welding with an electrode identified by F-number in Table 4.5 shall be considered qualified to weld with another electrode in the same F-number designation using the same process.

4.8.3 Electrode and Shielding Medium. A welder qualified with an approved electrode and shielding medium combination shall be considered qualified to weld with the same electrode F-number as classified in Table 4.5, and shielding medium combination for the process used in the qualification test.

4.8.4 Position. A change in the position of welding to one for which the welder is not qualified shall require requalification (see Table 4.4).

4.8.5 Diameter Limits. A change from one diameter grouping as shown in Table 4.4 to another shall require requalification.

4.8.6 Weld Progression. When the direction of welding progression is vertical, a change in the direction of welding shall require requalification.

4.8.7 Backing. The omission of backing or a backing gas in CJP welds welded from one side shall require requalification.

4.8.8 Weld Deposit. A change in the weld deposit thickness for the process qualified, as prescribed in Table 4.3, shall require requalification.

4.8.9 The addition or deletion of a consumable insert in a CJP, single side, open root weld joint shall require requalification.

4.9 Limitation of Variables for Welding Operator Performance Qualification

4.9.1 Electrode and Shielding Medium. A welding operator qualified with an approved electrode and shielding medium combination shall be considered qualified to weld with the same electrode F-number as classified in Table 4.5 and shielding medium combination for the process used in the qualification test.

4.9.2 Extent of Qualification Using Multiple Electrodes. A welding operator qualified to weld with multiple electrodes shall be qualified to weld with a single electrode, but not vice versa.

4.9.3 Extent of Qualification for Semiautomatic Welding. Welders qualified for semiautomatic arc welding shall be considered qualified for single electrode machine welding in the same process(es) subject to the limitations of 4.8. The welding operators should receive training and demonstrate their ability to make satisfactory welds.

4.9.4 Position. A change in the position of welding to one for which the welding operator is not already qualified shall require requalification.

4.10 Types, Purposes, and Acceptance Criteria of Tests and Examinations for Welders and Welding Operators

4.10.1 Visual Examination. To determine that the final weld surfaces meet specified quality conditions. All performance qualification test coupons (except areas designated "discard") shall be visually examined.

4.10.1.1 Acceptance Criteria (Visual Examination)

(1) The weld shall be free of cracks.

(2) Weld reinforcement shall not exceed 1/8 in. [3 mm].

(3) When accessible, the root of the weld shall be inspected, and there shall be no evidence of cracks, incomplete fusion, or inadequate joint penetration. A concave root surface is permitted, provided the total weld thickness is equal to or greater than that of the base metal.

(4) Undercut shall not exceed 1/32 in. [1 mm].

4.10.2 Guided-Bend Test. To determine the degree of soundness and ductility of groove-weld joints. (Groove weld performance qualification test shall be guided-bend tested.)

4.10.2.1 Type and Number of Guided-Bend Tests. The type and number of test specimens that must be tested to qualify a welder or welding operator by guided-bend testing are shown in Table 4.3, together with the range of thickness that is qualified by the thickness of the test plates, pipe or tubing used in making the qualification.

4.10.2.2 Substitution of RT for Guided-Bend Tests. Radiographic testing of the test weld may be used at the contractor's option in lieu of mechanical testing with the exception for joints welded by GMAW-S (which must be bend tested).

4.10.2.3 Guided-Bend Test Specimens. For mechanical testing, guided-bend test specimens shall be prepared by cutting the test specimen as shown in Figure 4.4, whichever is applicable, to form specimens approximately rectangular in cross section. The specimens shall be prepared for testing in accordance with Figures 4.16 through 4.20.

4.10.2.4 Acceptance Criteria for Guided-Bend Tests. The convex surface of the bend test specimens shall be visually examined for surface discontinuities. For acceptance, the surface shall contain no discontinuities exceeding the following dimensions:

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

(2) 3/8 in. [10 mm]—the sum of the greatest dimensions of all discontinuities exceeding 1/32 in. [1 mm], but less than or equal to 1/8 in. [3 mm].

(3) 1/4 in. [6 mm]—the maximum corner crack, except when the corner crack resulted from visible slag inclusion or other fusion type discontinuities, then the 1/8 in. [3 mm] maximum shall apply. Specimens with corner cracks exceeding 1/4 in. [6 mm] with no evidence of slag inclusion or other fusion type discontinuities shall be disregarded, and a replacement test specimen from the original weldment shall be tested. Failure of this specimen shall require requalification.

4.10.3 Radiography Testing. To obtain a volumetric evaluation of the test specimen.

4.10.3.1 If radiography is used in lieu of the prescribed bend test, the weld reinforcement need not be ground or otherwise smoothed for inspection unless its surface irregularities or junctures with the base metal would cause objectionable weld discontinuities to be obscured in the radiograph (see 4.10.5). If the backing is removed for radiographic testing, the root shall be ground flush with the base metal.

4.10.3.2 The radiographic procedure and technique shall be in accordance with the requirements of Clause 6. One (1) in. [25 mm] at each end of the length of the test plate shall be excluded from evaluation.

4.10.3.3 Acceptance Criteria. For acceptable qualification, the weld, as revealed by the radiographs, shall conform to the requirements of 6.28.2.

4.10.4 Macroetch Test. To determine complete fusion and unacceptable discontinuities. (Fillet welds shall be macroetch tested for performance qualification.)

4.10.4.1 The test specimens shall be prepared with a finish suitable for macroetch examination. A suitable solution shall be used to give a clear definition of the weld (see Annex G).

4.10.4.2 Acceptance Criteria (Macroetch Test). For acceptable qualification, the test specimens shall conform to the following requirements:

(1) Visual examination of the weld shall show

(a) Complete fusion.

(b) Fillet welds shall have complete fusion to the bottom of the joint but not necessarily beyond.

(c) No cracks.

(2) The actual weld size shall be equal to or greater than the specified weld size.

(3) The weld shall not have any concavity or convexity greater than 1/16 in. [2 mm].

4.10.5 Fillet Weld Break Test. The entire length of the fillet weld shall be examined visually and then a 6 in. [150 mm] long specimen (see Figure 4.5) or a quarter-section of the pipe fillet weld assembly shall be loaded in such a way that the root of the weld is in tension. At least one welding start and stop shall be located within the test specimen. The load shall be increased or repeated until the specimen fractures or bends flat upon itself.

4.10.5.1 Acceptance Criteria for Fillet Weld Break Test. To pass the visual examination prior to the break test, the weld shall present a reasonably uniform appearance and shall be free of overlap, cracks, and undercut in excess of the requirements of 6.28.1. There shall be no porosity visible on the weld surface.

The broken specimen shall pass if:

(1) The specimen bends flat upon itself, or

(2) The fillet weld, if fractured, has a fracture surface showing complete fusion to the root of the joint with no inclusion or porosity larger than 3/32 in. [2.5 mm] in greatest dimension, and

(3) The sum of the greatest dimensions of all inclusions and porosity shall not exceed 3/8 in. [10 mm] in the 6 in. [150 mm] long specimen.

4.11 Overlay Requirements

4.11.1 The limitation of variables of 4.8 and 4.9 shall apply for welders and welding operators, respectively, except welders or welding operators shall be qualified for unlimited maximum deposited thickness.

4.11.2 See Figure 4.21 for overlay test weldment.

4.11.3 See Table 4.7 for qualification thickness limitations.

4.11.4 The overlay performance qualification test shall be subjected to the following tests:

(1) Visual examination

(2) Guided bend test

(3) Penetrant examination.

4.11.5 Acceptance Criteria

(1) *Visual examination.* There shall be no cracks, trapped slag, visible porosity, or incomplete fusion. The appearance of the weld shall satisfy the qualifier that the welder is skilled in using the process and procedure specified for the test.

(2) Guided-bend tests [see 4.6.11.4(1)].

(3) Penetrant examination [see 4.6.11.4(2)].

Table 4.1
WPS Qualification Variables (see 4.2.1)

	SMAW	GTAW	GMAW	FCAW	SAW	PAW
1.0 Base Metals						
1.1 A change in the base metal group shown in Table 3.2 or in base metal type if unlisted (Table 3.2)	X	X	X	X	X	X
1.2 A change in base metal thickness qualified per Table 4.2	X	X	X	X	X	X
2.0 Filler Metal						
2.1 A change from one F-Number to any other F-Number or to any filler metal not listed in Table 4.5	X	X	X	X	X	X
2.2 A change from one A-Number to any other A-Number or to a chemistry which cannot be classified as an A-Number listed in Table 4.6	X	X	X	X	X	X
2.3 A change in the flux trade name					X	
2.4 A change from one flux trade name-electrode combination to any other flux trade name-electrode combination					X	
2.5 A change in diameter of electrode(s) when using an alloy flux					X	X
2.6 A change in the number of electrodes used		X	X	X	X	X
2.7 The addition or deletion of supplemental powdered or granular filler metal					X	X
2.8 A change from solid or metal cored to flux cored or vice versa.		X	X	X	X	
2.9 The addition or deletion of filler metal		X				X
2.10 A change to tubular flux cored or powdered metal or vice versa					X	X
3.0 Electrical						
3.1 A change in the type of welding current (AC or DC), or polarity.	X	X	X	X	X	X
3.2 A change in the mode of metal transfer from globular, spray, and pulsed spray transfer to short circuit transfer, or vice versa			X			
4.0 Positions						
4.1 In vertical welding, a change in the progression specified for any pass from upward to downward or vice versa	X	X	X	X		X
5.0 Groove Welds						
5.1 The addition or deletion of nonmetallic retainers or nonfusing metal retainers	X	X	X	X	X	X
6.0 Postweld Heat Treatment/Preheat						
6.1 The addition or deletion of postweld heat treatment	X	X	X	X	X	X
6.2 Test coupons receiving a postweld heat treatment in which the upper transformation temperature is exceeded, the maximum qualified thickness for production welds is 1.1 times the thickness of the test coupon	X	X	X	X	X	X
6.3 A decrease of more than 100°F [55°C] in the preheat temperature qualified. The minimum temperature for welding shall be specified in the WPS	X	X	X	X	X	X
7.0 Shielding Gas						
7.1 A change from a single shielding gas to any other single shielding gas or to a mixture of shielding gases, or a change in specified percentage composition of shielding gas mixture, or omission of shielding gas		X	X	X		X
7.2 The addition or deletion of a shielding gas				X		

Table 4.1S
(Supplement to Table 4.1)
Overlay Essential Variables for all Processes (see 4.6.11.1)

	SMAW	GTAW	GMAW	FCAW	SAW	PAW
1.0 Base Metals						
1.1 A change in the base metal group shown in Table 3.2 or in base metal type if unlisted (Table 3.2)	X	X	X	X	X	X
1.2 A change in base metal thickness qualified per Table 4.2	X	X	X	X	X	X
2.0 Filler Metal						
2.1 A change from one F-Number to any other F-Number or to any filler metal not listed in Table 4.5	X	X	X	X	X	X
2.2 A change from one A-Number to any other A-Number or to a chemistry which cannot be classified as an A-Number listed in Table 4.6	X	X	X	X	X	X
2.3 A change in the flux trade name					X	
2.4 A change from one flux trade name-electrode combination to any other flux trade name-electrode combination					X	
2.5 A change in diameter of electrode(s) when using an alloy flux					X	
2.6 A change in the number of electrodes used		X	X	X	X	X
2.7 The addition or deletion of supplemental powdered or granular filler metal					X	X
2.8 A change from solid or metal cored to flux cored or vice versa		X	X	X	X	
2.9 A change to tubular flux cored or powdered metal or vice versa					X	X
2.10 A change from multiple layer to single layer, or reduction in the number of layers	X	X	X	X	X	X
3.0 Electrical						
3.1 A change in the type of welding current (AC or DC), or polarity.	X	X	X	X	X	X
3.2 A change in the mode of metal transfer from globular, spray, and pulsed spray transfer, to short circuit transfer, or vice versa.			X			
3.3 An increase of more than 10% in the welding current beyond the range specified	X	X	X	X	X	X
4.0 Positions						
4.1 In vertical welding, a change in the progression specified for any pass from upward to downward or vice versa	X	X	X	X		X
5.0 Postweld Heat Treatment/Preheat						
5.1 The addition or deletion of postweld heat treatment	X	X	X	X	X	X
5.2 Test coupons receiving a postweld heat treatment in which the upper transformation temperature is exceeded, the maximum qualified thickness for production welds is 1.1 times the thickness of the test coupon	X	X	X	X	X	X
5.3 A decrease of more than 100°F [55°C] in the preheat temperature qualified. The minimum temperature for welding shall be specified in the WPS	X	X	X	X	X	X
6.0 Shielding Gas						
6.1 A change from a single shielding gas to any other single shielding gas or to a mixture of shielding gases, or a change in specified percentage composition of shielding gas mixture, or omission of shielding gas		X	X	X		X
6.2 The addition or deletion of a shielding gas				X		

Table 4.2
PQR Type, Number of Test Specimens, and Range of Thickness Qualified (see 4.3.2.1)

(A) Groove Welds

Thickness T of Test Plate or Pipe Wall, in. (mm)	Range of Thickness Qualified, in. [mm] Min	Max	Type and Number of Tests Required: Macroetch for Weld Size (E)[a]	Tension	Side Bend	Face Bend	Root Bend
1/16 to 3/8 [2 to 10], inclusive	1/16 [2]	2T	3	2		2	2
Over 3/8 to 3/4 [over 10 to 20]	3/16 [5]	2T	3	2	4[b]	2[b]	2[b]
3/4 and over [20 and over]	3/16 [5]	Unlimited	3	2	4		

[a] Partial joint penetration groove welds only.
[b] Four (4) side bend or two face and two root bends.

(B) Fillet Welds (see 4.4)

Test Specimen[d]	Fillet Weld Size	Number of Welds per WPS	Macroetch Test Specimens Required (4.6.8, 4.6.9)	Sizes Qualified: Plate/Pipe Thickness[c]	Sizes Qualified: Fillet Weld Size
Plate T-test (Figure 4.5)	Single pass, max size to be used in construction	1 in each position to be used	3 faces	Unlimited	Max. tested single pass and smaller
	Multiple pass, min size to be used in construction	1 in each position to be used	3 faces	Unlimited	Min. tested multiple pass and smaller
Pipe T-test[e] (Figure 4.5)	Single pass, max size to be used in construction	1 in each position to be used (see Table 4.1)	3 faces (except for 4F and 5F, 4 faces req'd)	Unlimited	Max. test single pass and smaller
	Multiple pass, min size to be used in construction	1 in each position to be used (see Table 4.1)	3 faces (except for 4F and 5F, 4 faces req'd)	Unlimited	Min. tested multiple pass and larger

[c] The minimum thickness qualified is 1/8 in. [3 mm].
[d] All welded test pipes and plates shall be visually inspected per 4.6.2.
[e] See Table 4.3 for small pipe diameter fillet-weld test.

Table 4.3
Performance Qualification—Thickness Limits and Test Specimens (see 4.7.4)

Type of Joint[d]	Thickness (t) of Test Coupon, in. [mm]	Thickness (t) of Qualified Deposited Weld		Type and Number of Tests Required (Guided Bend Tests)[a, c]		
		Minimum,[b] in. [mm]	Maximum, in.	Side Bend	Face Bend	Root Bend
Groove	Up to 3/8 [10], inclusive	1/16 [2]	2t	—	1	1
Groove	Over 3/8 [10] but less than 3/4 [20]	1/8 [3]	2t	—	1	1
Groove	3/4 [20] and over	1/8 [3]	Max. to be welded	2	—	—

[a] To qualify for positions 5G and 6G, two root-bend and two face-bend specimens, or four side-bend specimens, as applicable.
[b] Welder qualifications limited to minimum WPS limits.
[c] See Figures 4.14, 4.15, and 4.23 for specimen locations.
[d] Groove weld tests qualify fillet welds within the limitation of Tables 4.3 and 4.4.

Note: Two or more pipe test coupons of different thicknesses and different diameters may be used to determine the weld metal thickness qualified and that thickness may be applied to production welds to the smallest pipe diameter for which the welder is qualified.

Small Pipe Diameter Fillet-Weld Test

Outside Diameter of Test Coupon, in. (mm)	Maximum Outside Diameter Qualified, in. (mm)	Thickness Qualified[f]
Less than 1 (25)	Size welded	All
1 (25) to less than 2-7/8 (73)[e]	1 (25) and over	All
2-7/8 (73) and over	2-7/8 (73) and over	All

[e] 2-7/8 (73) O.D. is equivalent to NPS 2-1/2 (65).
[f] Welder qualifications limited to minimum WPS limits.

Table 4.4
Performance Qualification—Position and Diameter Limitations (see 4.7.4)

Weld	Position[a]	Plate and Pipe Over 24 in. [600 mm] O.D.	Pipe ≤ 24 in. [600 mm] O.D.	Plate and Pipe Fillet
Plate—Groove	1G	F	F[b]	F
	2G	F, H	F, H[b]	F, H
	3G	F, V	F[b]	F, H, V
	4G	F, O	F[b]	F, H, O
	3G and 4G	F, V, O	F[b]	All
	2G, 3G, and 4G	All	F, H[b]	All
Plate—Fillet	1F	—	—	F[b]
	2F	—	—	F, H[b]
	3F	—	—	F, H, V[b]
	4F	—	—	F, H, O[b]
	3F and 4F	—	—	All[b]
Pipe—Groove	1G	F	F[c]	F, H
	2G	F, H	F, H[c]	F, H
	5G	F, V, O	F, V, O[c]	All
	6G	All	All[c]	All
	2G and 5G	All	All[c]	All
Pipe—Fillet	1F	—	—	F
	2F	—	—	F, H
	2FR	—	—	F, H
	4F	—	—	F, H, O
	5F	—	—	All

[a] Positions of welding
F = Flat
H = Horizontal
V = Vertical
O = Overhead
[b] Pipe 2-7/8 in. [73 mm] NPS and over.
[c] Note c:

Test Weldment Pipe Diameter, in. [mm]	Outside Diameter Qualified, in. [mm]	
	Groove	Fillet
Less than 1 [25] O.D.	Size welded and over	All
1 [25] through 2-7/8 [73] O.D.	1 [25] and over	All
Over 2-7/8 [73]	2-7/8 [73] and over	All

Table 4.5
F-Numbers—Grouping of Electrodes and Welding Rods for Qualification (see 4.9.1)

Stainless Steels (Ferritic, Martensitic, Austenitic, and Duplex)	
F-Number	AWS Specification Number
4	A5.1, A5.5
4	A5.4 other than austenitic and duplex
5	A5.4 austenitic and duplex
6	A5.9, A5.18, A5.28
6	A5.22
43	A5.11, A5.14

Table 4.6
A-Numbers—Classification of Stainless Steel Weld Metal Analysis for WPS Qualification[a] (see Table 4.1)

A-Number	Types of Weld Deposit	C%	Cr%	Mo%	Ni%	Mn%	Si%
1, 3, 4, 5, or 6	Chromium–Martensitic	0.15	11.00–15.00	0.70	—	2.00	1.00
7	Chromium–Ferritic	0.15	11.00–30.00	1.00	—	1.00	3.00
8	Chromium–Nickel	0.15	14.50–30.00	4.00	7.50–15.00	2.50	1.00
9	Chromium–Nickel	0.30	25.00–30.00	4.00	15.00–37.00	2.50	1.00

[a] In lieu of an A-Number designation, the nominal chemical composition of the weld deposit shall be indicated on the WPS and on the PQR.

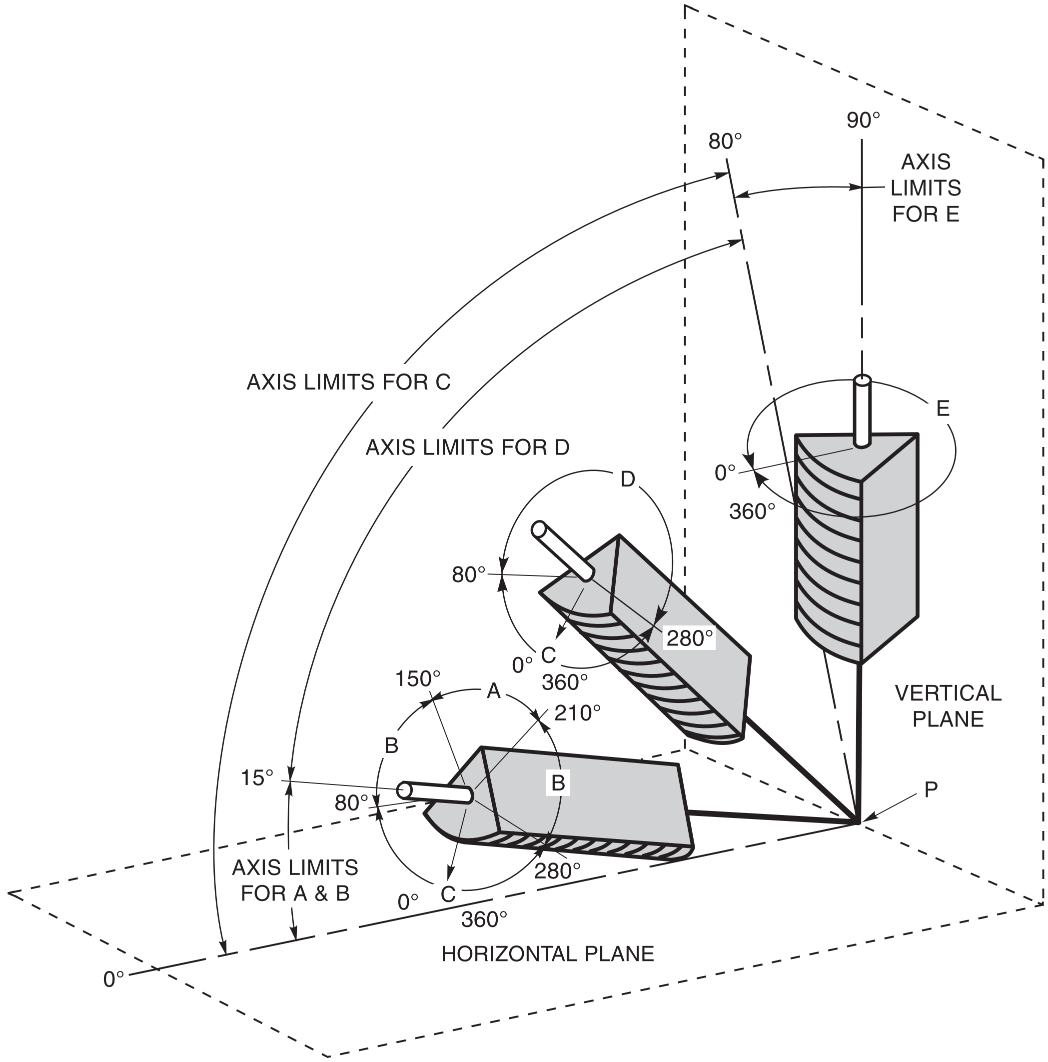
Table 4.7
Thickness Limitations for Overlay WPS and Welding Operator Performance Qualification (see 4.6.11.3)

A. Overlay WPS

Test Weldment Base Metal Thickness (T), in. [mm]	Thickness of Qualified Base Metal, in. [mm]	
	Min.	Max.
1/16 [2] ≤ T < 1 [25]	T	Unlimited
1 [25] and over	1 [25]	Unlimited

B. Welding Operator Performance for Overlay

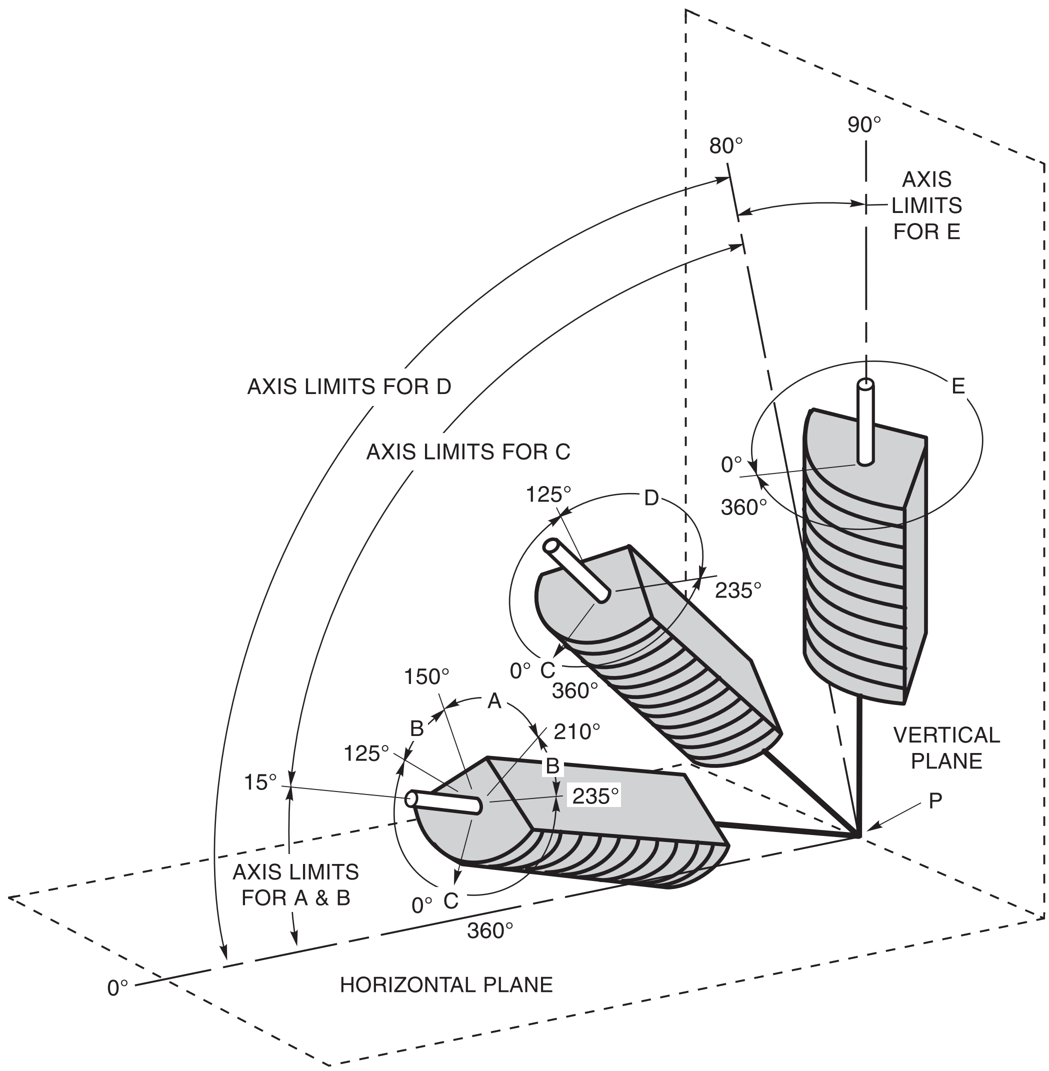
Test Weldment Base Metal Thickness (T), in. (mm)	Qualifies for			
	Base Metal Thickness, in. (mm)		Weld Metal Thickness	
	Min.	Max.	Min.	Max.
1/16 [2] ≤ T < 1 [25]	T	Unlimited	Same as WPS Minimum Qualified	Unlimited
1 [25] and over	1 [25]	Unlimited		



Tabulation of Positions of Groove Welds			
Position	Diagram Reference	Inclination of Axis	Rotation of Face
Flat	A	0° to 15°	150° to 210°
Horizontal	B	0° to 15°	80° to 150° 210° to 280°
Overhead	C	0° to 80°	0° to 80° 280° to 360°
Vertical	D E	15° to 80° 80° to 90°	80° to 280° 0° to 360°

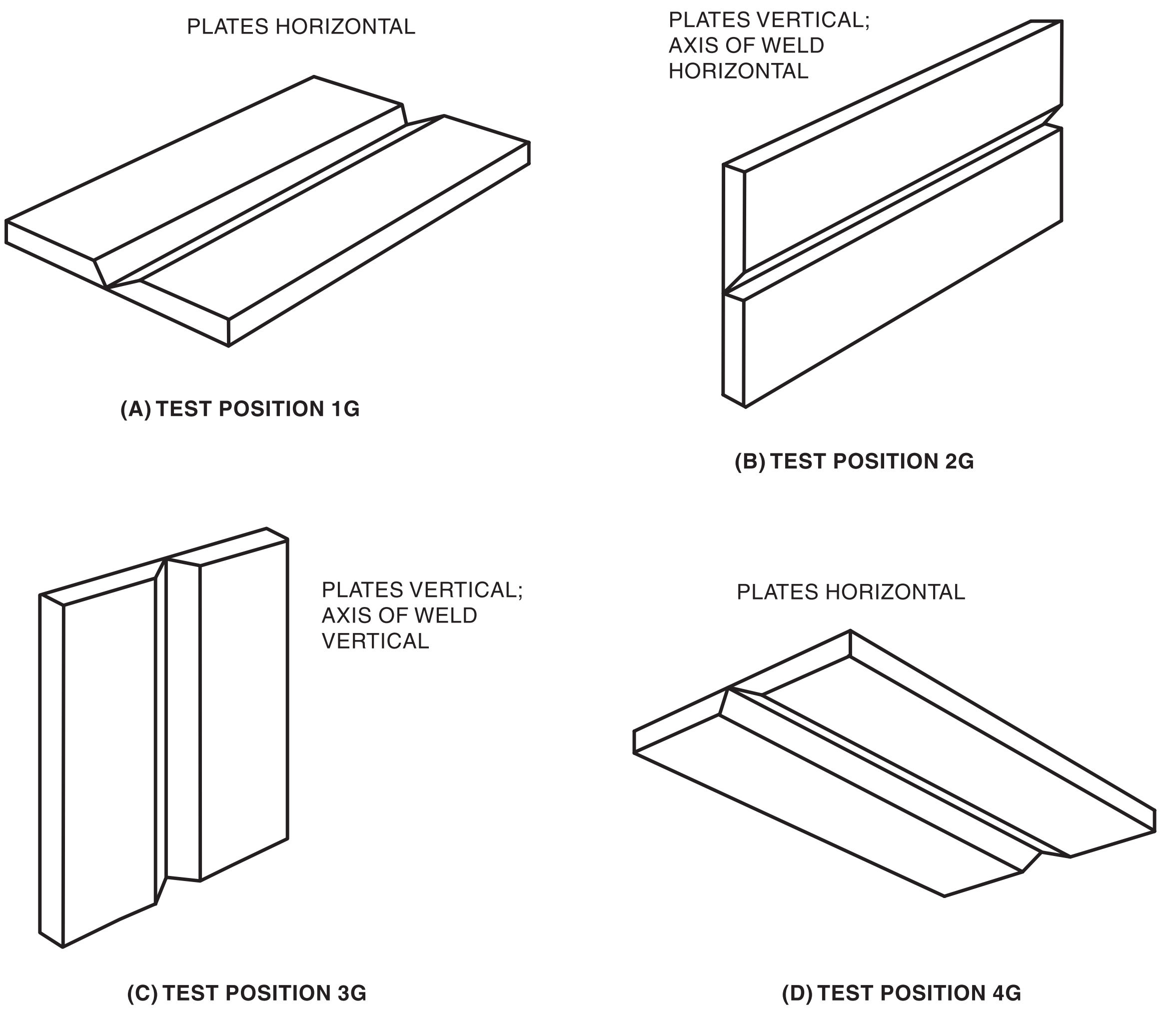
Notes:
1. The horizontal reference plane is always taken to lie below the weld under consideration.
2. The inclination of axis is measured from the horizontal reference plane toward the vertical reference plane.
3. The angle of rotation of the face is determined by a line perpendicular to the theoretical face of the weld which passes through the axis of the weld. The reference position (0°) of rotation of the face invariably points in the direction opposite to that in which the axis angle increases. When looking at point P, the angle of rotation of the face of the weld is measured in a clockwise direction from the reference position (0°).

Figure 4.1—Positions of Groove Welds (see 4.1.6)



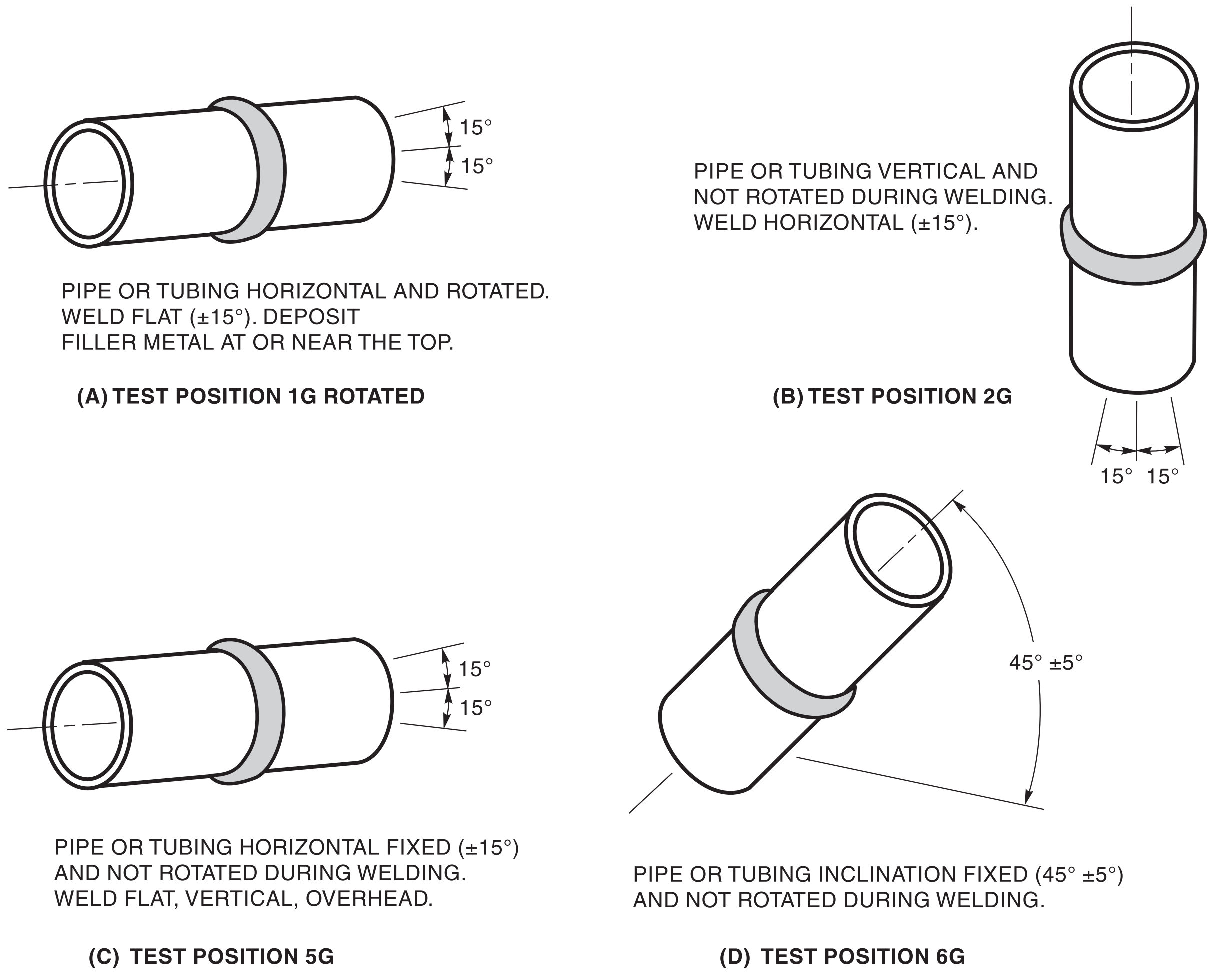
Tabulation of Positions of Fillet Welds			
Position	Diagram Reference	Inclination of Axis	Rotation of Face
Flat	A	0° to 15°	150° to 210°
Horizontal	B	0° to 15°	125° to 150° 210° to 235°
Overhead	C	0° to 80°	0° to 125° 235° to 360°
Vertical	D E	15° to 80° 80° to 90°	125° to 235° 0° to 360°

Figure 4.2—Positions of Fillet Welds (see 4.1.6)



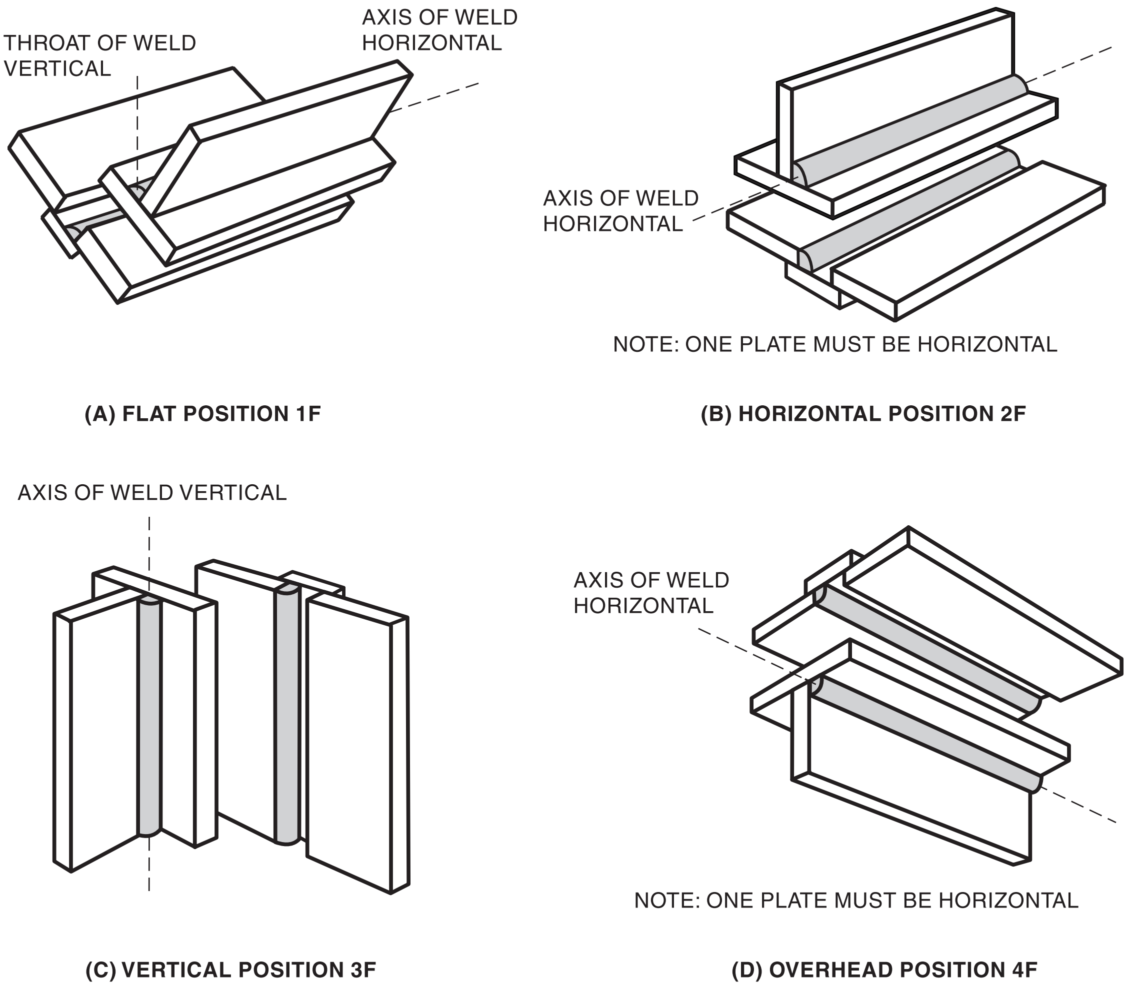
(A) Groove Welds in Plate—Test Positions

Figure 4.3—Test Positions of Welds (see 4.1.9)



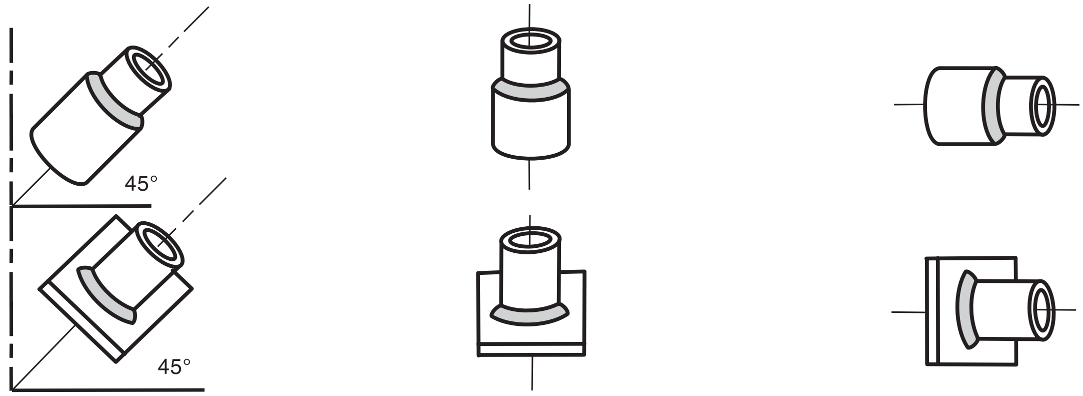
(B) Groove Welds in Pipe or Tubing—Test Positions

Figure 4.3 (Continued)—Test Positions of Welds (see 4.1.9)



(C)—Fillet Welds in Plate—Test Positions

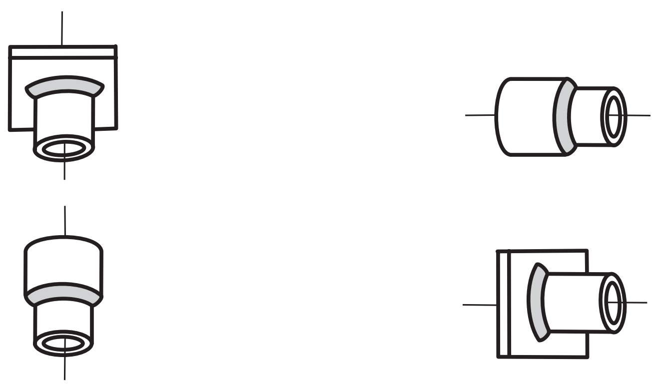
Figure 4.3 (Continued)—Test Positions of Welds (see 4.1.9)



(A) TEST POSITION 1F FOR FLAT POSITION (ROTATED)

(B) TEST POSITION 2F FOR HORIZONTAL POSITION (FIXED)

(C) TEST POSITION 2F FOR HORIZONTAL POSITION (ROTATED)

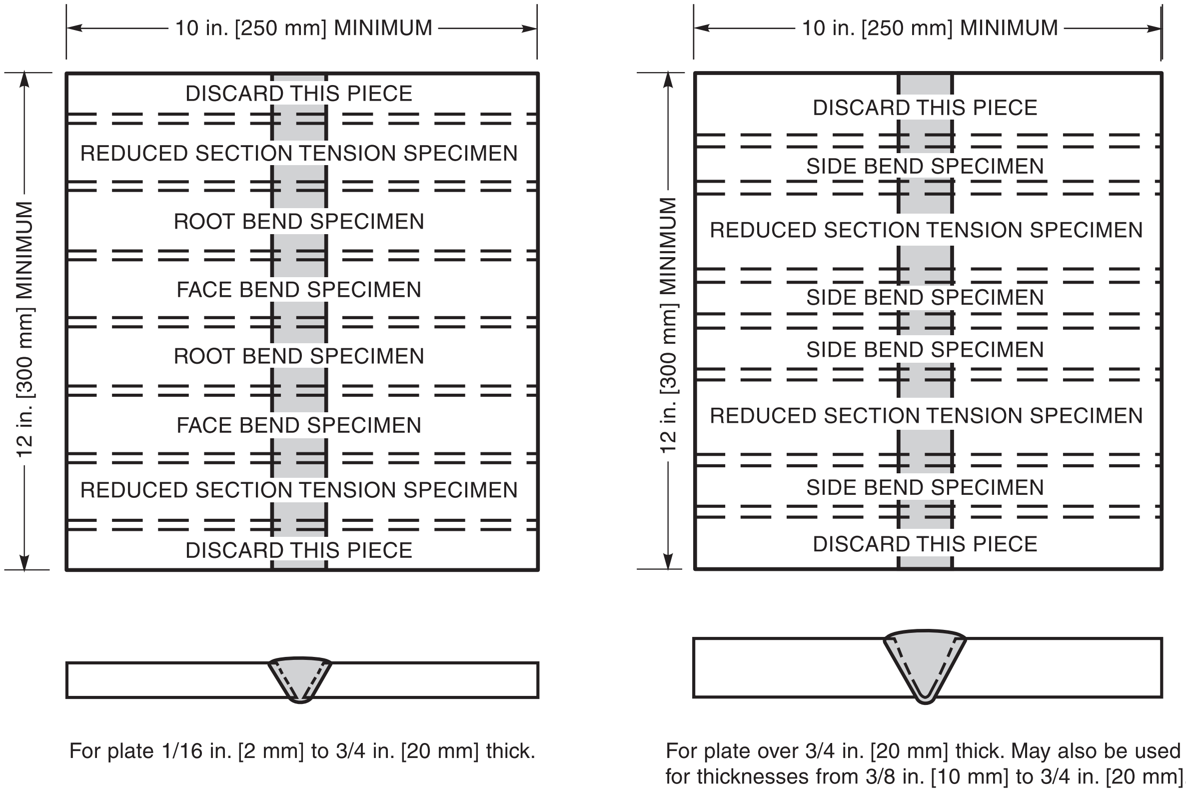


(D) TEST POSITION 4F FOR OVERHEAD POSITION (FIXED)

(E) TEST POSITION 5F FOR MULTIPLE POSITION (FIXED)

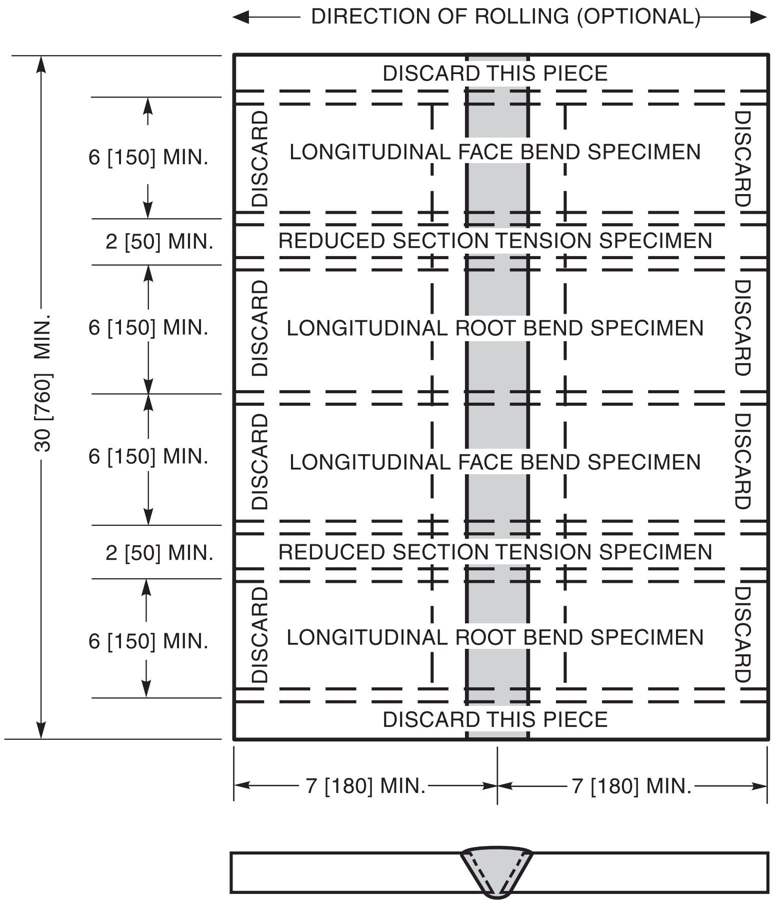
(D)—Fillet Welds in Pipe or Tubing—Test Positions

Figure 4.3 (Continued)—Test Positions of Welds (see 4.1.9)



(A) PQR Transverse Specimens—Plate

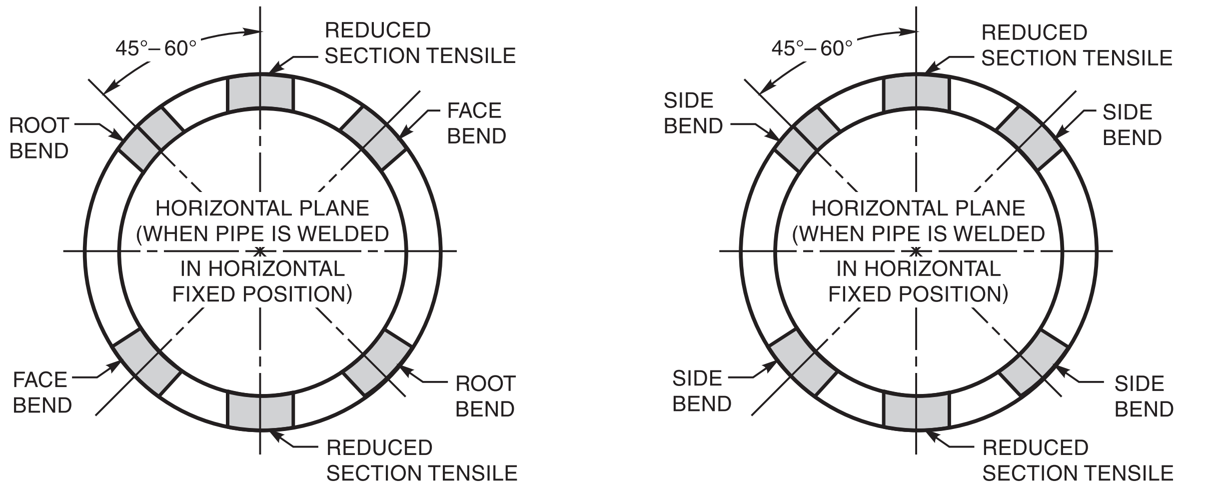
Figure 4.4—Location of Test Specimens on PQR Plate or Pipe (see 4.3.1)



All dimensions in inches [millimeters].

(B) PQR Longitudinal Plate Specimens—Plate
Order of removal of test specimens from welded test plate for longitudinal bend tests.

Figure 4.4 (Continued)—Location of Test Specimens on PQR Plate or Pipe (see 4.3.1)

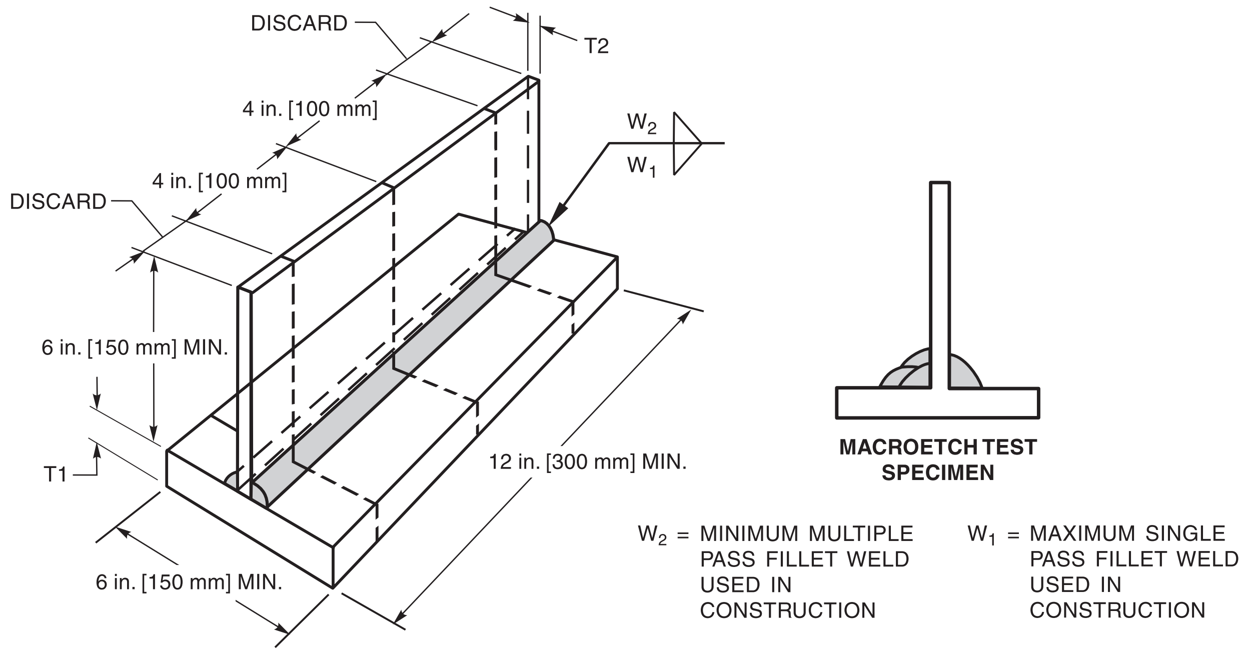


For pipe 1/16 in. [2 mm] to 3/4 in. [20 mm] wall thickness.

For pipe over 3/4 in. [20 mm] wall thickness. May also be used for thicknesses from 3/8 in. [10 mm] to 3/4 in. [20 mm].

(C) PQR Pipe Specimens

Figure 4.4 (Continued)—Location of Test Specimens on PQR Plate or Pipe (see 4.3.1)



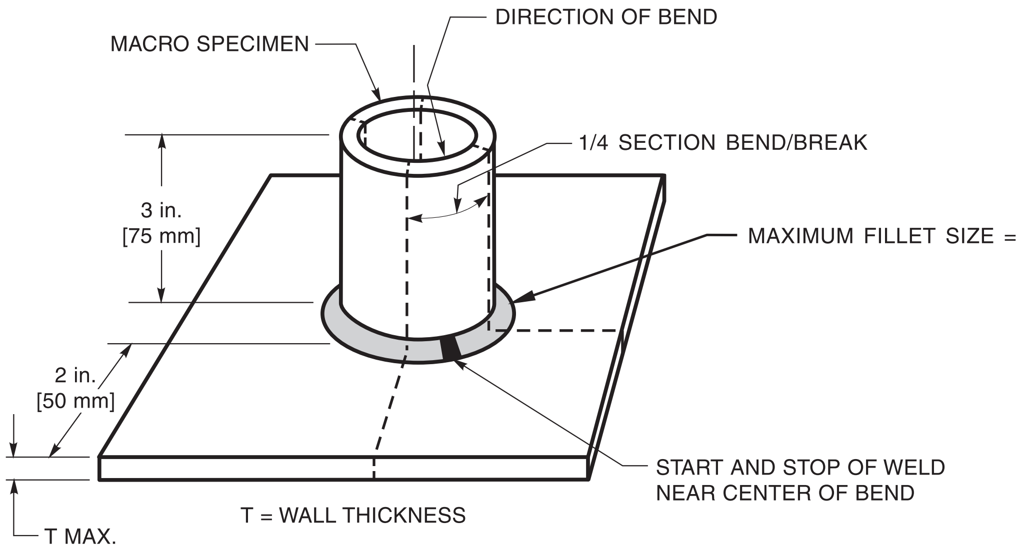
DETAIL A—PLATE TO PLATE ASSEMBLY

INCHES		
Weld Size	T1 min.[a]	T2 min.[a]
3/16	1/2	3/16
1/4	3/4	1/4
5/16	1	5/16
3/8	1	3/8
1/2	1	1/2
5/8	1	5/8
3/4	1	3/4
> 3/4	1	1

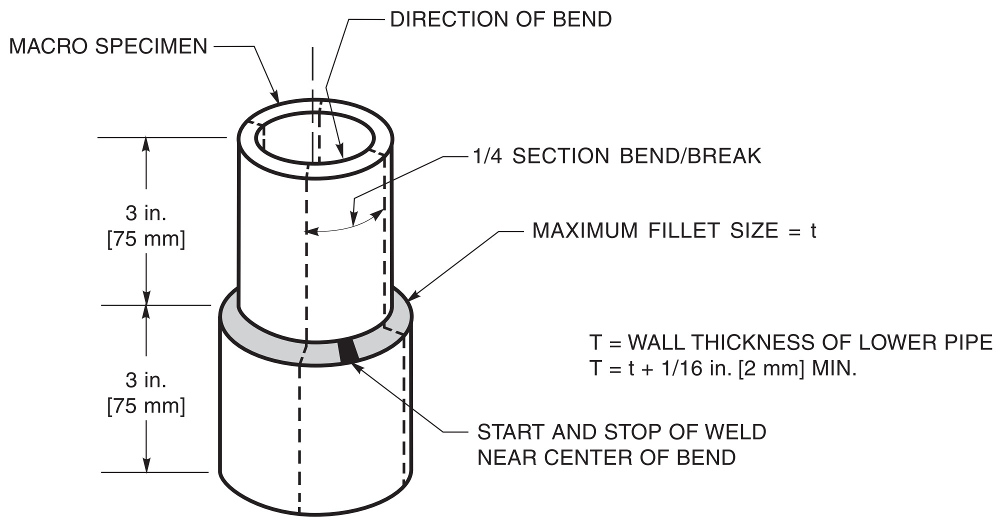
MILLIMETERS		
Weld Size	T1 min.[a]	T2 min.[a]
5	12	5
6	20	6
8	25	8
10	25	10
12	25	12
16	25	16
20	25	20
> 20	25	25

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

Figure 4.5—PQR Fillet Weld Specimens (see 4.4.1)



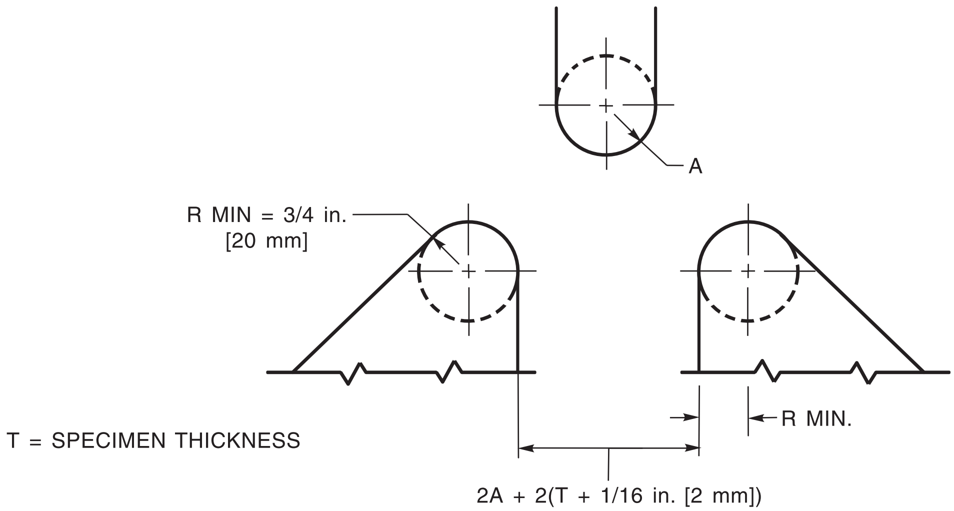
DETAIL B—PIPE TO PLATE ASSEMBLY



DETAIL C—PIPE TO PIPE ASSEMBLY

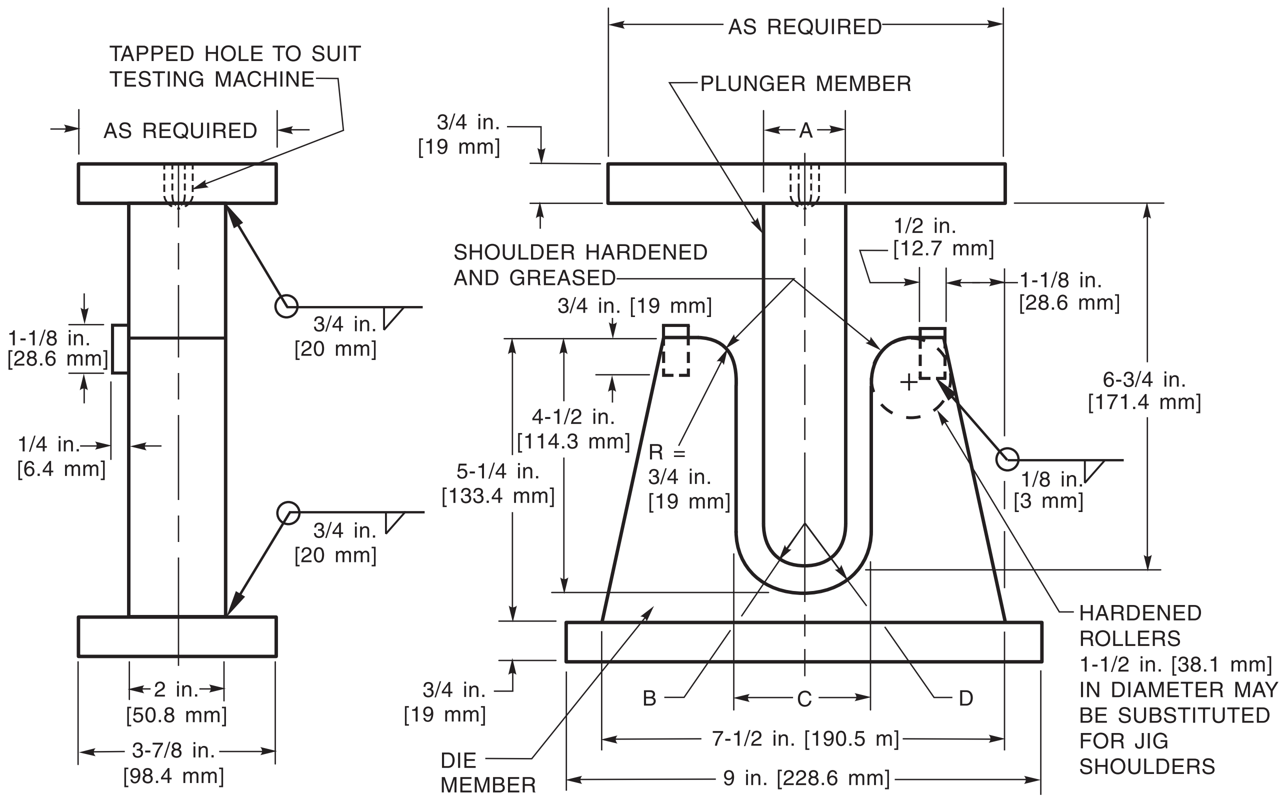
Notes:
1. Either pipe-to-plate or pipe-to-pipe may be used as shown.
2. All dimensions in inches [millimeters].

Figure 4.5 (Continued)—PQR Fillet Weld Specimens



Notes:
1. Either hardened and greased shoulders or hardened rollers free to rotate shall be used.
2. The shoulders or rollers shall have a minimum bearing length of 2 in. [50 mm] for placement of the specimens.
3. The shoulders or rollers shall be high enough above the bottom of the testing jig so that the specimen will clear the shoulder or rollers when the plunger is in the low position.
4. The plunger shall be fitted with an appropriate base and provision for attachment to the testing machine and shall be designed to minimize deflection or misalignment.
5. The shoulder or roller supports may be made adjustable in the horizontal direction so that specimens of various thickness may be tested in the same jig.
6. The shoulder or roller supports shall be fitted to a base designed to maintain the shoulders or rollers centered and aligned with respect to the plunger, and minimize deflection or misalignment.
7. The plunger radius, A, shall be determined from the nomogram in Figure 4.9.

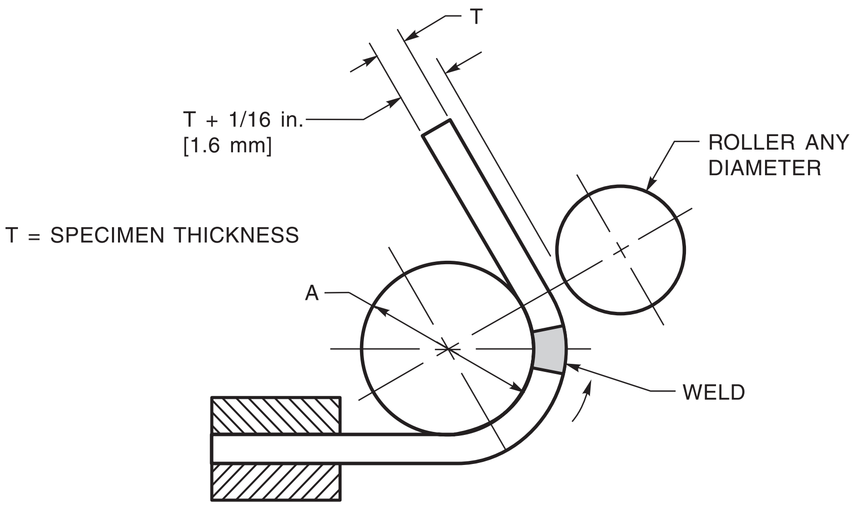
Figure 4.6—Bottom Ejecting Guided-Bend Test Jig



Jig Dimensions for 20% Elongation					
Specimen Thickness, T		Plunger Radius, B		Die Radius, D	
in.	mm	in.	mm	in.	mm
3/8	9.5	3/4	19.0	1-3/16	30.2
T		2T		B + T + 1/16	B + T + 1.6

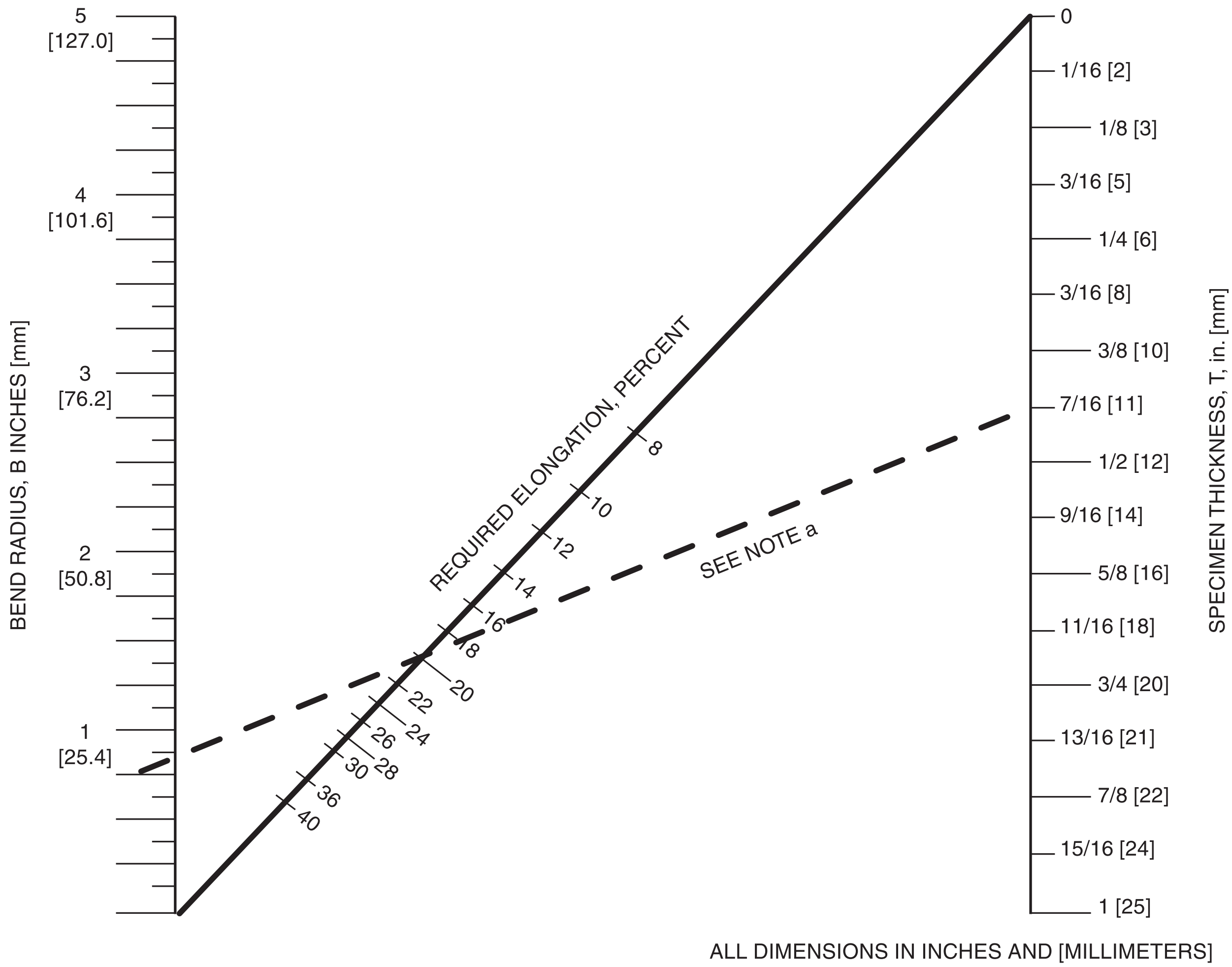
Note: For elongation other than 20%, the specimen thickness, T_1, and the plunger radius, B, shall be adjusted in accordance with the nomogram of Figure 4.9.

Figure 4.7—Bottom Guided-Bend Test Jig (see 4.6.3.1)



Notes:
1. Radius A shall be as specified, or as determined from the nomogram in Figure 4.9. Dimensions not shown are the option of the designer, except that the minimum width of the components shall be 2 in. [50 mm].
2. It is essential to have adequate rigidity so that the jig will not deflect during testing. The specimen shall be firmly clamped on one end so that it does not slide during the bending operation.
3. Test specimens shall be removed from the jig when the outer roll has traversed 180° from the starting point.

Figure 4.8—Alternative Wrap-Around Guided-Bend Test Jig (see 4.6.3.1)

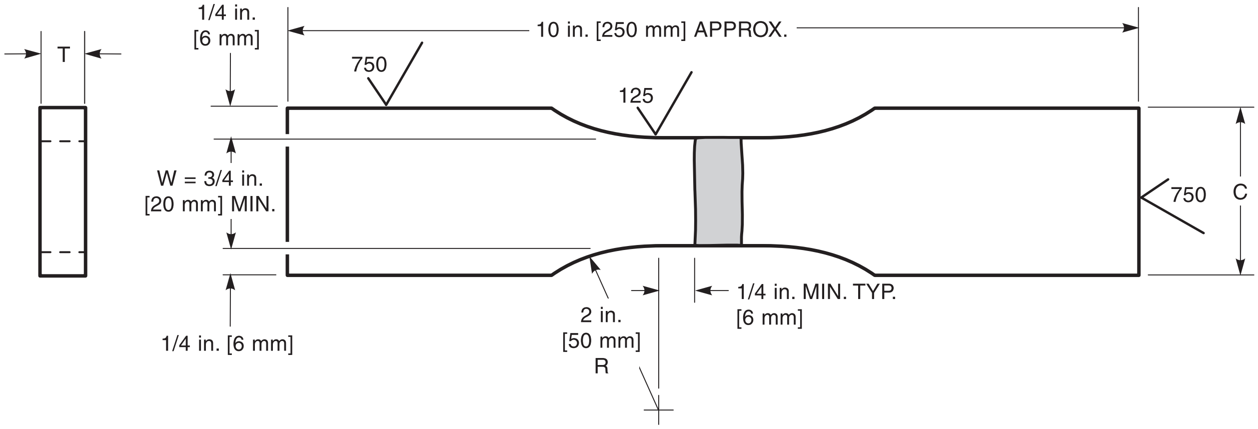


[a] Example: A standard jig requires a minimum elongation of 20%. If the specimen is 7/16 in. [11 mm] thick, a line is drawn between these two points and extended to determine the appropriate bend radius, which would be 7/8 in. [22 mm].

Notes:

1. It is generally recommended that the specimens for the bend tests be approximately 3/8 in. [10 mm]. However, the specimen thickness may be any value within the range given above as dictated by the material thickness, available equipment, or the applicable specification.
2. Required accuracy of measurement is as follows:
   (1) Specimen thickness: ±1/64 in. [0.4 mm].
   (2) Elongation: ±1%.
   (3) Bend radius: ±1/16 in. [1.6 mm].
3. When applying the nomogram data, jigs that will provide 20% elongation may be used for any metal having an elongation over 20%.

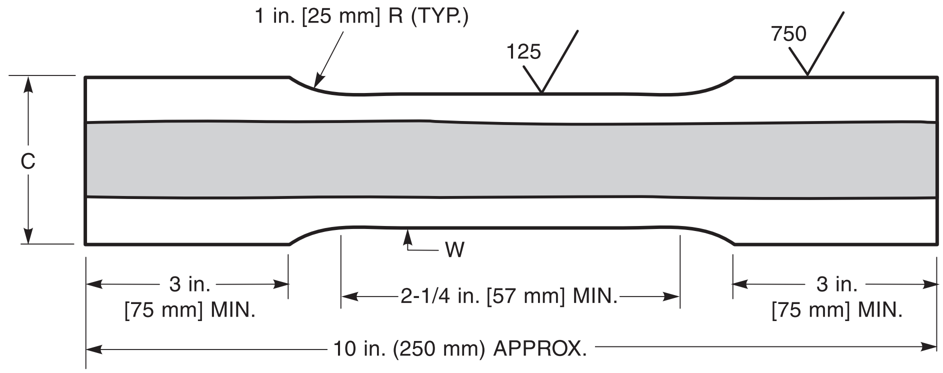
Figure 4.9—Nomogram for Selecting Minimum Bend Radius (see 4.6.3.1)



T = SPECIMEN THICKNESS OR THICKNESS OF TEST WELDMENT (t) PER NOTE 3.

Notes:
1. Thin sheet metal being tested tends to tear and break near the shoulder. In such cases, dimension C shall be no greater than 1-1/3 times W.
2. Weld reinforcement and backing strip, if any, shall be removed flush with the surface of the specimen.
3. When the thickness, T, of the test weldment is such that it would not provide a specimen within the capacity limitations of the available test equipment, the specimen shall be parted through its thickness into as many specimens as required.
4. The length of the reduced sections shall be equal to the width of the widest portion of the weld plus 1/4 in. [6 mm] on each side.

Figure 4.10—Transverse Rectangular Tension Test Specimen (see 4.6.6.1)

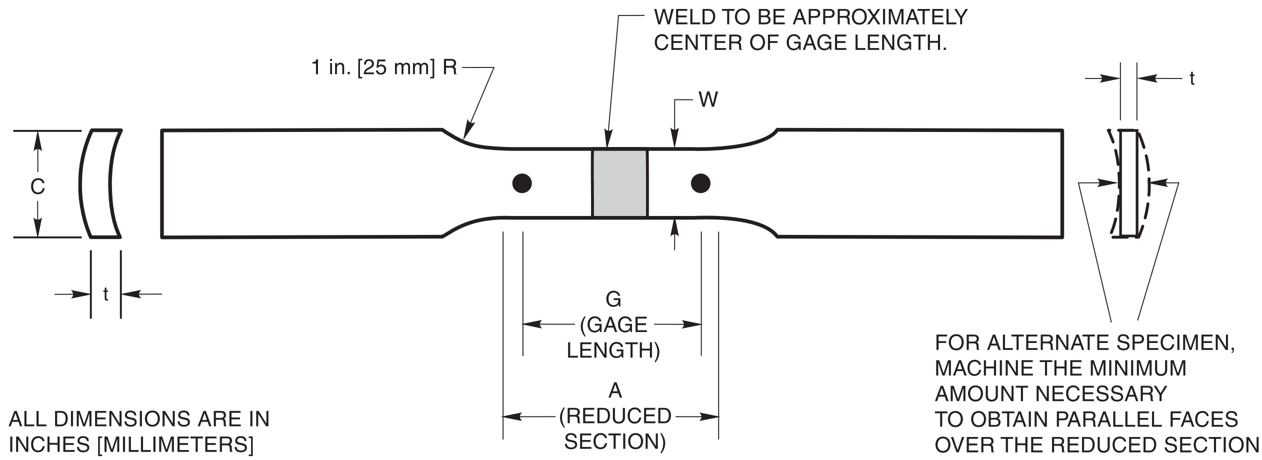


t = THICKNESS OF THE PLATE SECTION AS PER APPLICATION SPECIFICATION.
T = THICKNESS OF TENSILE SPECIMEN AS PER APPLICATION SPECIFICATION.

Dimensions				
	Specimen 1		Specimen 2	
	in.	mm	in.	mm
W = width	1 ± 0.05	25 ± 1	1.50 ± 0.125	40 ± 3
B = width of weld	0.50 approx.	12 approx.	0.75 approx.	20 approx.
C = nominal width of section	1.5	40	2.0	50

Notes:
1. The weld reinforcement and backing, if any, shall be removed.
2. The width, B, of the weld may be varied to approximately W/2 by selecting an appropriate specimen thickness, T, and its location within the weld.
3. The width, W, may be varied within reason to accommodate the approximately of B = W/2 if it is not possible to meet the requirements of Note 2.
4. The grip section of the specimen shall be symmetrical, with the centerline of the reduced section within 1/8 in. [3 mm].

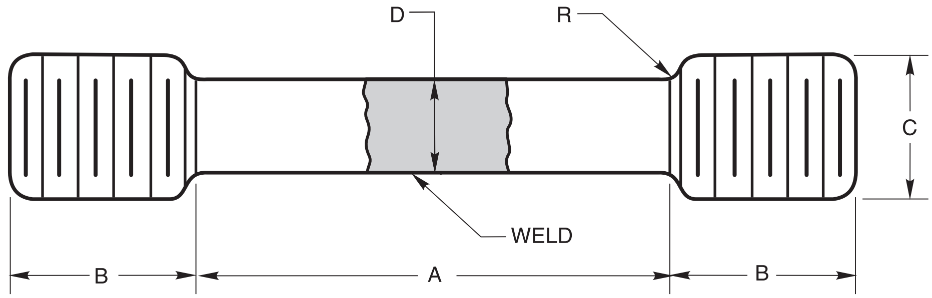
Figure 4.11—Tension Specimens (Longitudinal) (see 4.6.6.1)



Specimen No.	W, in. [mm]	C, in. [mm]	G, in. [mm]		A (min.), in. [mm]
1	1/2 ± 1/64 [12 ± 0.4]	1-1/16 [27] approx.	2± [50±]		2-1/4 [57]
2	3/4 ± 1/32 [20 ± 1]	1 [25] approx.	2± [50±] 4± [100±]		2-1/4 [57] 4-1/2 [115]
3	1 ± 1/16 [25 ± 2]	1-1/2 [40] approx.	2± [50±] 4± [100±]	1/64 [0.5]	2-1/4 [57] 4-1/2 [115]
4	1-1/2 ± 1/8 [40 ± 3]	2 [50] approx.	2± [50±] 4± [100±] 8± [200±]		2-1/4 [57] 4-1/2 [115] 9 [230]

Notes:
1. The weld reinforcement and backing, if any, shall be removed flush with the specimen.
2. Alternate specimen shall not be used for nominal wall thickness less than 3/8 in. [10 mm].
3. Only grip sections of the specimen may be flattened.
4. In the case of full wall thickness specimens, cross-sectional areas may be calculated by multiplying W and t (t = T).
5. T is the thickness of the test specimen as provided for in the applicable specification.
6. The reduced section shall be parallel within 0.010 in. [0.25 mm] and may have a gradual taper in width from the ends toward the center with the ends not more than 0.010 in. [0.25 mm] wider than the center.
7. The grip section of the specimen shall be symmetrical, with the centerline of the reduced section within 1/8 in. [3 mm].

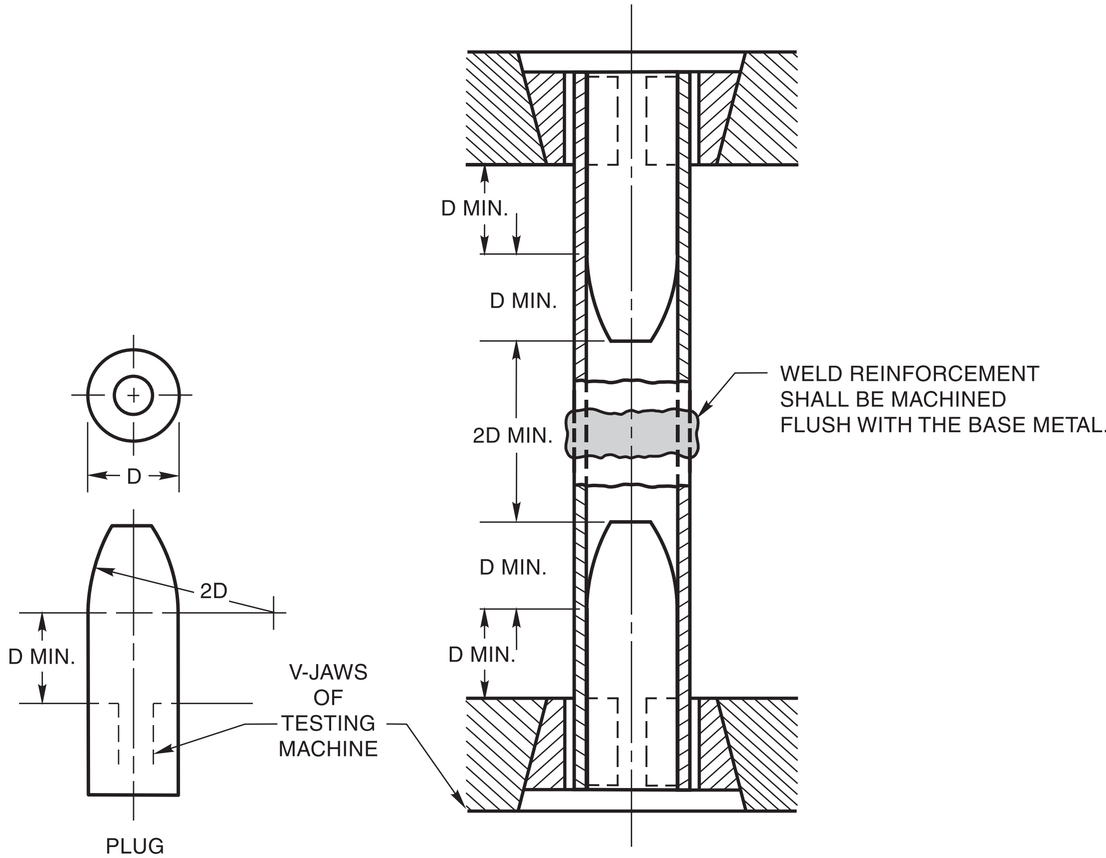
Figure 4.12—Tension Specimen for Pipe Size Greater Than 2 in. [50 mm] Nominal Diameter (see 4.6.6.1)



	Standard Dimension (in.)			
	(a) 0.505 Specimen	(b) 0.353 Specimen	(c) 0.252 Specimen	(d) 0.188 Specimen
A—Length, reduced section	See Note 4	See Note 4	See Note 4	See Note 4
D—Diameter	0.500 ± 0.010	0.350 ± 0.007	0.250 ± 0.005	0.188 ± 0.003
R—Radius of fillet	3/8, min.	1/4, min.	3/16, min.	1/8, min.
B—Length of end section	1-3/8, approx.	1-1/8, approx.	7/8, approx.	1/2, approx.
C—Diameter of end section	3/4	1/2	3/8	1/4
	Standard Dimension (mm)			
	(a) 12.83 Specimen	(b) 8.97 Specimen	(c) 6.4 Specimen	(d) 4.78 Specimen
A—Length, reduced section	See Note 4	See Note 4	See Note 4	See Note 4
D—Diameter	12.7 ± 0.25	8.9 ± 0.18	6.4 ± 0.13	4.78 ± 0.08
R—Radius of fillet	9.5, min.	6.4, min.	4.8, min.	3.2, min.
B—Length of end section	35, approx.	28.6, approx.	22.2, approx.	12.7, approx.
C—Diameter of end section	19.0	12.7	9.5	6.4

Notes:
1. Use maximum diameter specimen (a), (b), (c), or (d) that can be cut from the section.
2. Weld should be in center of reduced section.
3. Where only a single specimen is required, the center of the specimen should be midway between the surfaces.
4. Reduced Section "A" should not be less than width of weld plus two times "D."
5. The ends may be of any shape to fit the holders of the testing machine in such a way that the load is applied axially.

Figure 4.13(A)—Tension Specimens—Reduced Section—Turned Specimens (see 4.6.6.1)



NOTE: FOR 2 in. [50 mm] NOMINAL DIAMETER OR SMALLER.

**Figure 4.13(B)—Tension Specimens—Full Section—
Small Diameter Pipe (see 4.6.6.1)**

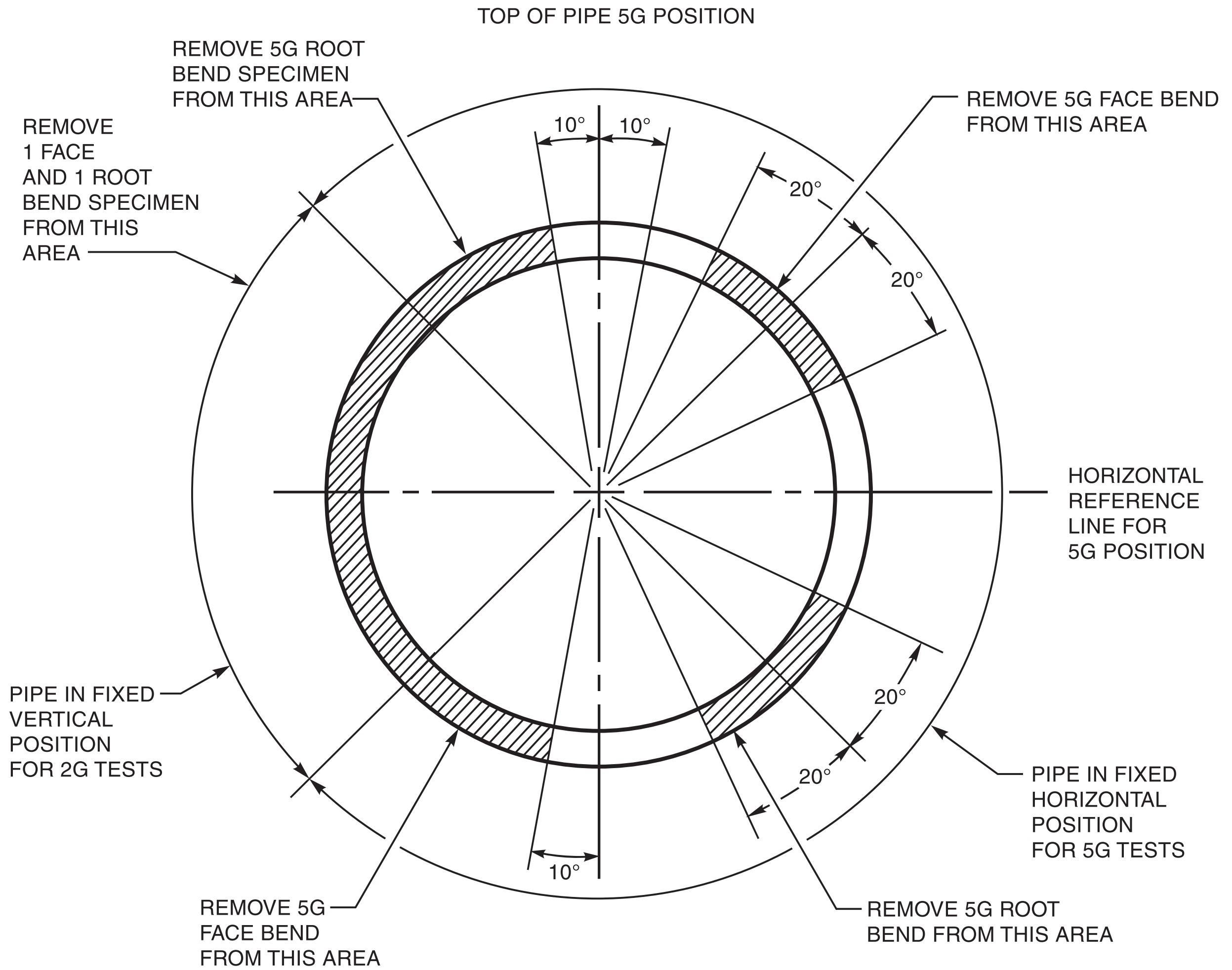
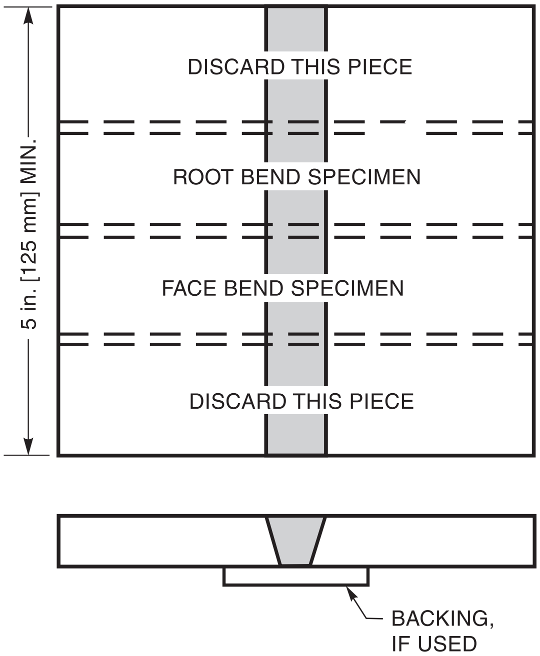
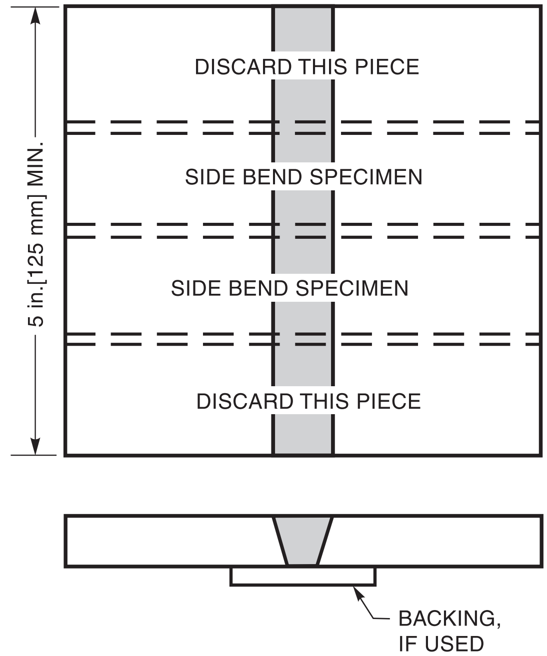


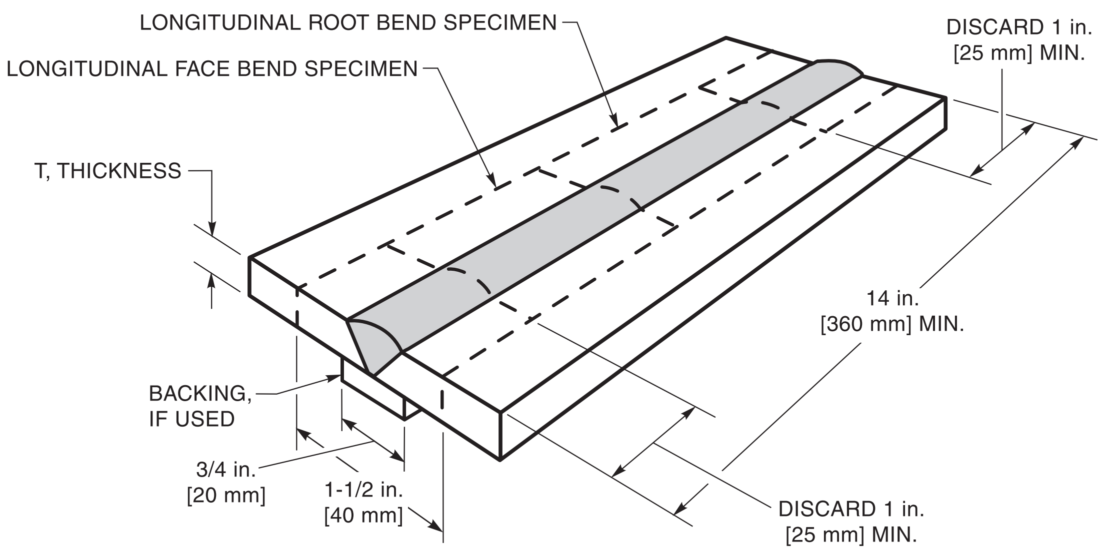
Figure 4.14—6 in. [150 mm] or 8 in. [200 mm] Pipe Assembly for Performance Qualification—2G and 5G Position [see 4.7.10.1]



**(A) PLATES — 1/16 TO 3/4 in. [2 mm TO 20 mm]
PERFORMANCE QUALIFICATION**

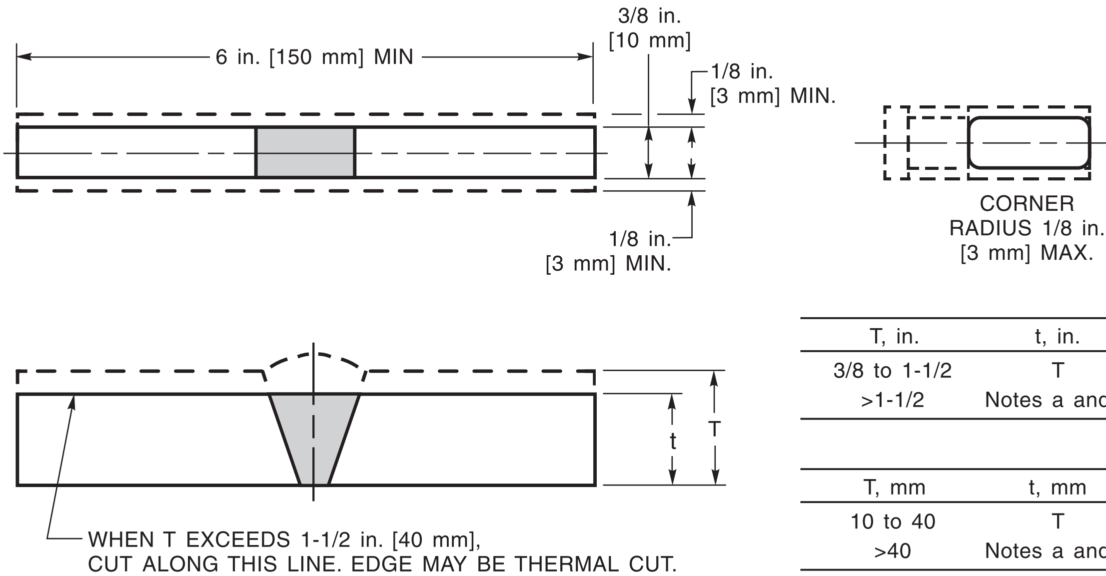


**(B) PLATES — OVER 3/4 in. [20 mm] AND
ALTERNATE 3/8 TO 3/4 in. [10 mm TO 20 mm]
PERFORMANCE QUALIFICATION**



(C) PLATES — LONGITUDINAL PERFORMANCE QUALIFICATION

Figure 4.15—Plates—Longitudinal Performance Qualification [see 4.7.10.1]



T, in.	t, in.
3/8 to 1-1/2	T
>1-1/2	Notes a and b

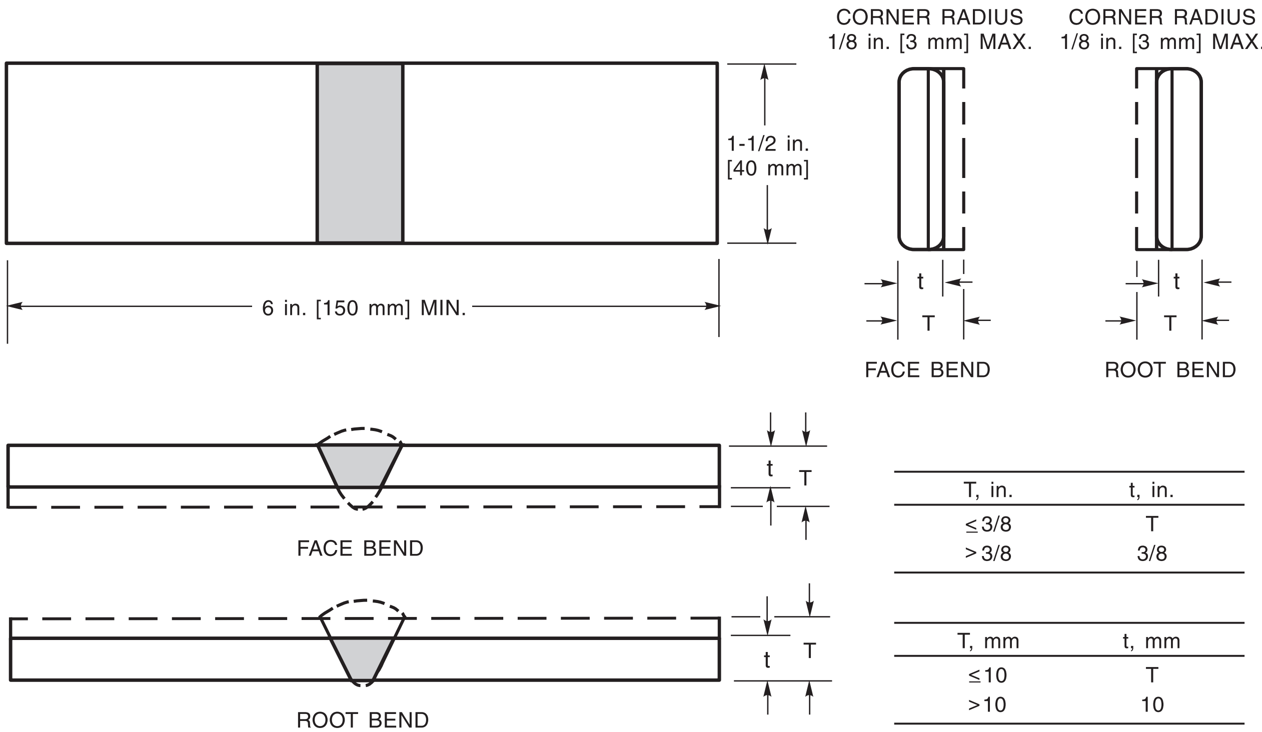
T, mm	t, mm
10 to 40	T
>40	Notes a and b

[a] If the thickness, T, of a single-groove weld joint exceeds 1-1/2 in. [40 mm], the specimen may be cut into approximately equal strips between 3/4 in. [20 mm] and 1-1/2 in. [40 mm] wide. Each strip shall be tested by bending to the same radius as determined by the nomogram in Figure 4.9.

[b] If the plate thickness, T, of a double-groove weld joint exceeds 1-1/2 in. [40 mm], the specimen may be cut into multiple strips so that the root of the weld is centered in one of the strips. These strips shall be bent to the same radius as determined by the nomogram in Figure 4.9.

Notes:
1. The specimen may be thermally cut but, in this case, at least 1/8 in. [3 mm] of material shall be mechanically removed from the thermally cut surface.
2. The weld reinforcement and backing, if any, shall be mechanically removed flush with the specimen surface.
3. The diameter of the test plunger shall be equal to or exceed the weld width. If this requirement cannot be met, a greater thickness, T, shall be chosen in accordance with the nomogram in Figure 4.9.
4. All longitudinal surfaces shall be no rougher than 125 microinches [3 μm] RMS. It is not recommended that the lay of the surface roughness be oriented parallel to the longitudinal axis of the specimen.

Figure 4.16—Transverse Side-Bend Specimens—Plate (see 4.10.2.3)

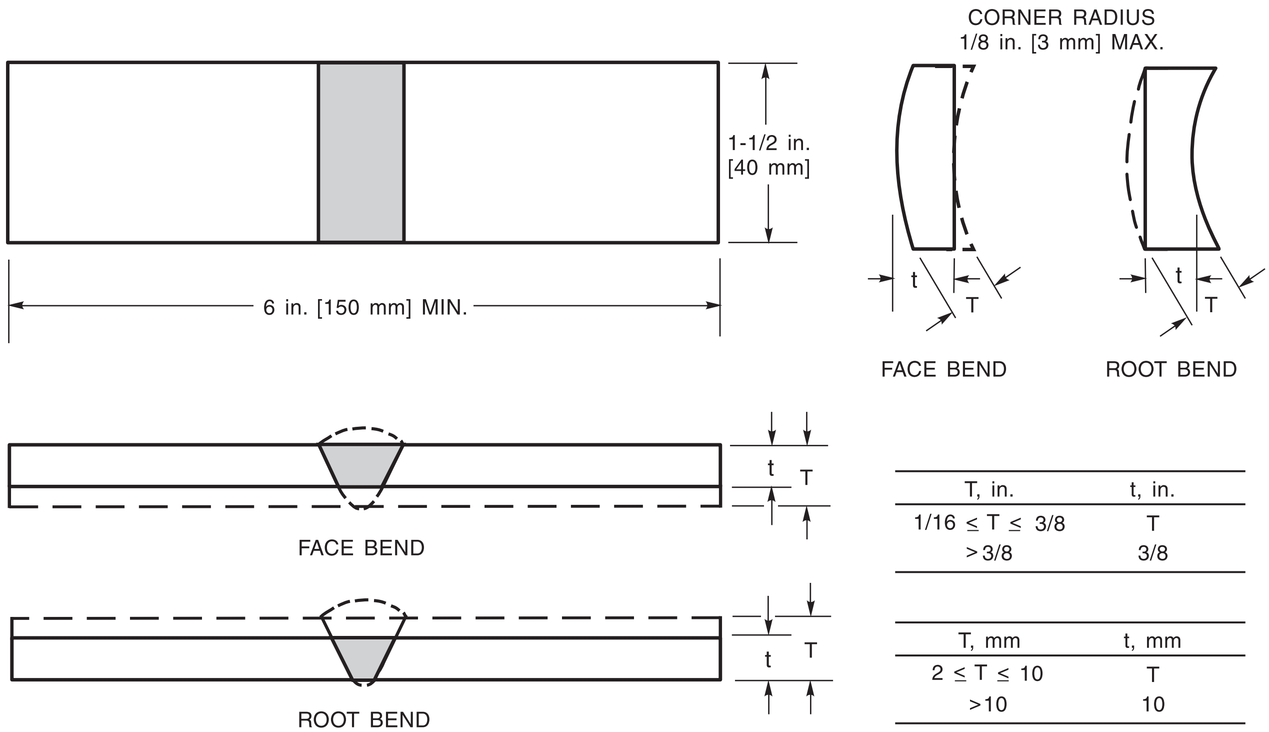


T, in.	t, in.
≤ 3/8	T
> 3/8	3/8

T, mm	t, mm
≤10	T
>10	10

Notes:
1. The specimen may be thermally cut but, in this case, at least 1/8 in. [3 mm] of material shall be mechanically removed from the thermally cut surface.
2. For clad metals having an elongation requirement of at least 25%, the specimen thickness, t, may be reduced when using a bend-radius testing jig. The specimen thickness shall comply with the nomogram in Figure 4.9.
3. If the weld joins base metals with different thicknesses, the specimen should be reduced to a constant thickness based on the thinner base metal.
4. The weld reinforcement and backing, if any, shall be mechanically removed flush with the specimen surfaces.
5. The diameter of the test plunger shall be equal to or exceed the weld width. If this requirement cannot be met, a greater thickness, T, shall be chosen in accordance with the nomogram in Figure 4.9.
6. All longitudinal surfaces shall be no rougher than 125 microinches [3 μm] RMS. It is not recommended that the lay of the surface roughness be oriented parallel to the longitudinal axis of the specimen.

Figure 4.17—Transverse Face-Bend and Root-Bend Specimens—Plate (see 4.10.2.3)

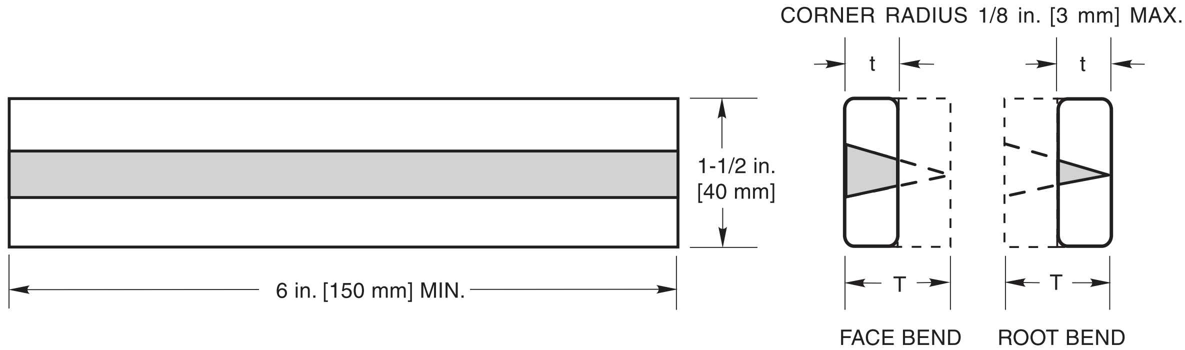


T, in.	t, in.
1/16 ≤ T ≤ 3/8	T
> 3/8	3/8

T, mm	t, mm
2 ≤ T ≤ 10	T
>10	10

Notes:
1. The specimen may be thermally cut but, in this case, at least 1/8 in. [3 mm] of material shall be mechanically removed from the thermally cut surface.
2. If the weld joins base metals with different thicknesses, the specimen should be reduced to a constant thickness based on the thinner base metal. If the back of the joint is recessed, this surface of the specimen may be removed to a depth not exceeding the recess.
3. The specimen width shall be 4t, except that it shall not exceed ID/3 where ID is the inside diameter of the pipe.
4. The weld reinforcement and backing, if any, shall be mechanically removed flush with the specimen surfaces.
5. The diameter of the test plunger shall be equal to or exceed the weld width. If this requirement cannot be met, a greater thickness, T, shall be chosen in accordance with the nomogram in Figure 4.9.
6. All longitudinal surfaces shall be no rougher than 125 microinches [3 µm] RMS. It is not recommended that the lay of the surface roughness be oriented parallel to the longitudinal axis of the specimen.

Figure 4.18—Transverse Face-Bend and Root-Bend Specimens—Pipe (see 4.10.2.3)

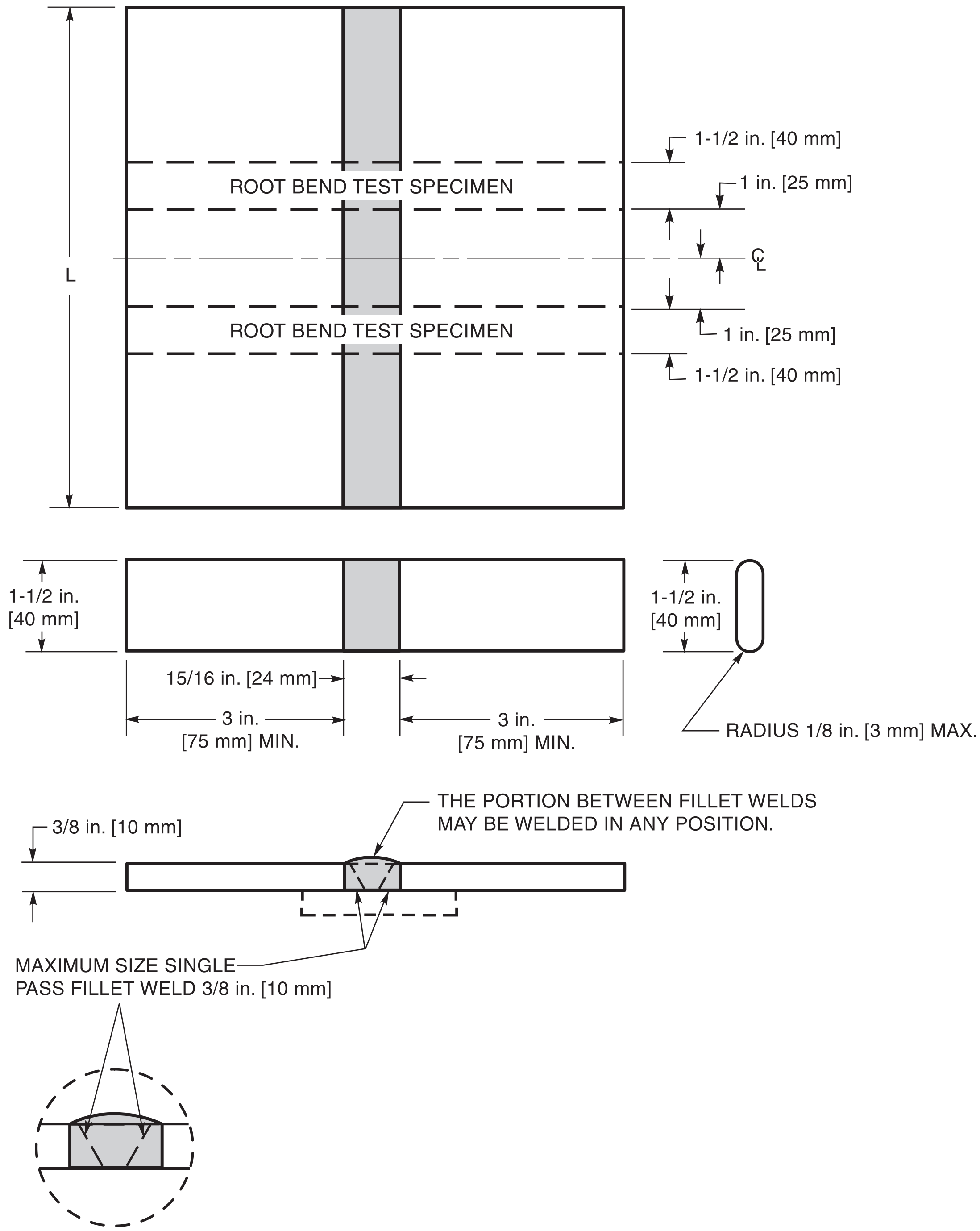


T, in.	t, in.
≤ 3/8	T
> 3/8	3/8

T, mm	t, mm
≤ 10	T
> 10	10

Notes:
1. The specimen may be thermally cut but, in this case, at least 1/8 in. [3 mm] of material shall be mechanically removed from the thermally cut surface.
2. If the weld joins base metals with different thicknesses, the specimen should be reduced to a constant thickness based on the thinner base metal.
3. The weld reinforcement and backing, if any, shall be mechanically removed flush with the specimen surfaces.
4. All longitudinal surfaces shall be no rougher than 125 microinches [3 µm] RMS. It is not recommended that the lay of the surface roughness be oriented parallel to the longitudinal axis of the specimen.

Figure 4.19—Longitudinal Face-Bend and Root-Bend Specimens—Plate (see 4.10.2.3)



Notes:
1. The backing bar shall be 3/8 in. by 2 in. [10 mm by 50 mm] minimum unless the test weld is to be inspected radiographically, in which case the backing bar shall be 3/8 in. by 3 in. [10 mm by 75 mm] minimum. The backing bar shall be in intimate contact with the base plate.
2. The test plate length, L, shall be sufficient for the required number of specimens. Specimens shall be removed mechanically from the test plate.
3. The weld reinforcement and backing bar shall be removed mechanically, flush with the base plate.
4. All longitudinal surfaces shall be no rougher than 125 microinches [3 µm] RMS. It is not recommended that the lay of the surface roughness be oriented parallel to the longitudinal axis of the specimen.

Figure 4.20—Fillet Weld Root-Bend Test Specimens (see 4.10.2.3)

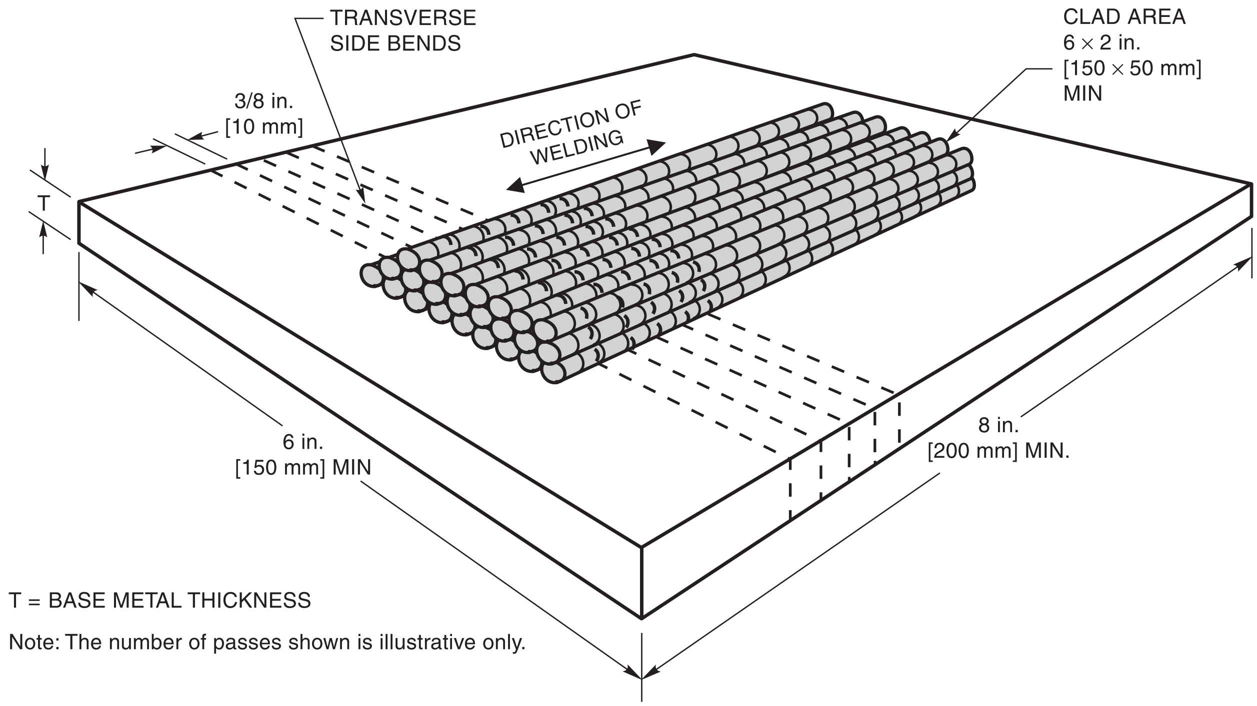
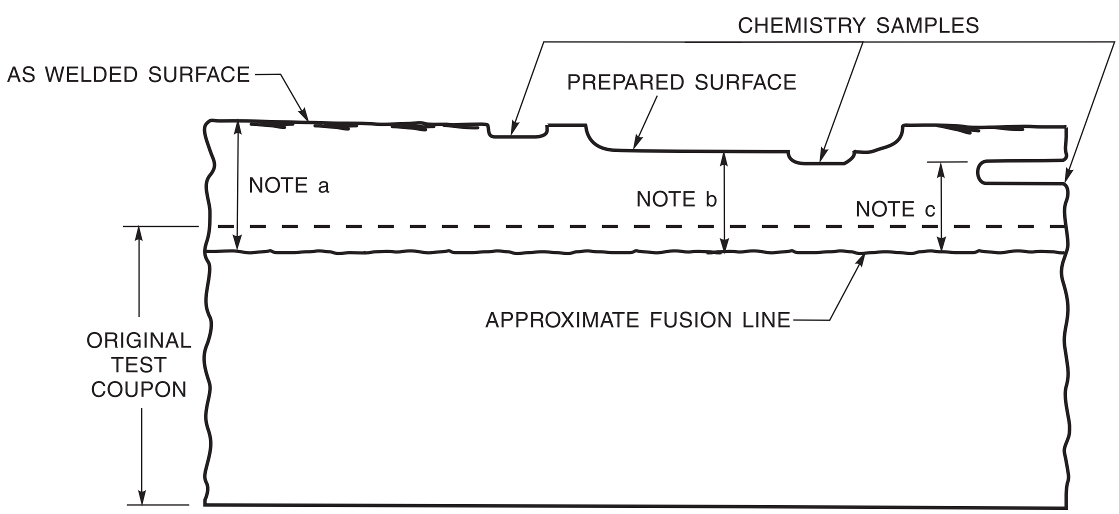


Figure 4.21—Overlay WPS and Performance Qualification (see 4.11.2)



[a] When a chemical analysis is conducted on the as-welded surface, the distance from the approximate fusion line to the final as-welded surface shall become the minimum qualified overlay thickness. The chemical analysis may be performed directly on the as-welded surface or on chips of material taken from the as-welded surface.

[b] When a chemical analysis is conducted after material has been removed from the as-welded surface, the distance from the approximate fusion line to the prepared surface shall become the minimum qualified overlay thickness. The chemical analysis may be made directly on the prepared surface or from chips removed from the prepared surface.

[c] When a chemical analysis test is conducted on material removed by a horizontal drill sample, the distance from the approximate fusion line to the uppermost side of the drilled cavity shall become the minimum qualified overlay thickness. The chemical analysis shall be performed on chips of material removed from the drilled cavity.

Figure 4.22—Chemical Analysis Test [see 4.6.11.5(3)]

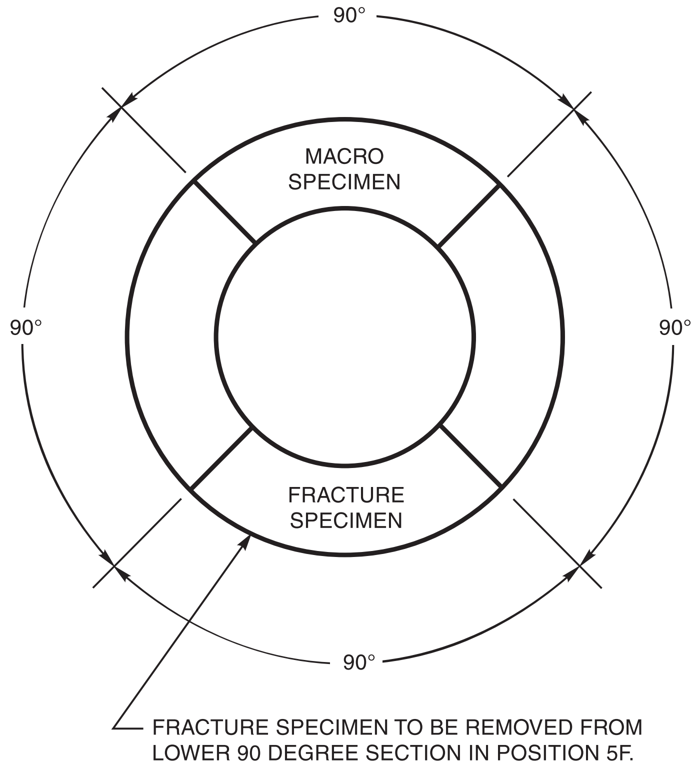


Figure 4.23—Performance Qualification Specimen Locations [see 4.7.10.1)]

5. Fabrication

5.0 General

This clause applies general requirements for the fabrication, assembly, construction or erection of stainless steel products within the scope of this code. The fabricator, contractor or erector (hereafter referred to jointly as the contractor) is cautioned that this code is not a design handbook; it does not eliminate the need for competent engineering judgement of the designer.

5.1 Responsibilities

The contractor, and individuals employed by the contractor, working in accordance with this code are responsible for the quality of work and items they produce. They shall evaluate the quality of their work prior to release for subsequent stages of processing or fabrication/erection inspections. Fabrication/erection inspections shall be in accordance with Clause 6 of this code and as prescribed in contract or engineering specifications.

5.1.1 Processes and WPSs. Welding shall be performed using either qualified or prequalified WPSs, and shall meet the requirements of Clause 3 or Clause 4 of this code, as applicable.

5.1.2 Environmental Conditions. Welding shall not be performed on surfaces that are wet, or in wind velocities that would adversely effect the shielding properties of the welding processes used.

5.1.2.1 Preheat temperatures shall be sufficient to remove moisture from the joints to be welded, as a minimum. Specific preheat and interpass temperatures are largely dependent on the material types and thickness to be welded. Both preheat and interpass temperatures shall be in accordance with the approved WPS or as otherwise specified or approved by the Engineer.

5.1.3 Base Materials. The materials used shall be consistent with good manufacturing and inspection practices. Also see Clause 1 of this code.

5.1.3.1 Base material discontinuities or defects that exceed material specifications are unacceptable unless repairs are approved by the Engineer. If repairs are approved they shall meet the requirements of 5.2.2, 5.2.3, or 5.13 as applicable.

5.1.4 Filler Materials and Fluxes. Certification, storage and handling of filler materials and fluxes shall be controlled as specified in Clause 3, Part D. Filler materials removed from the original packaging in which the filler materials were received shall be protected and storage shall be in accordance with the manufacturer's recommendations.

5.2 Preparation of Base Metal

Corrosion resistance properties of materials and the service conditions that fabrications will be exposed to should be considered prior to the actual fabrication. It may be necessary to remove surface oxides from the base metal prior to the welding. Surface oxides may be removed by mechanical methods, chemical cleaning, or other means approved by the Engineer. Contact with lead, zinc, or lead or zinc compounds shall be avoided due to the potential for hot cracking. Where pitting corrosion, crevice corrosion, intergranular corrosion or stress corrosion cracking are anticipated, special fabrication considerations should be specified in the contract documents.

5.2.1 Surface Preparation. Acceptable methods of material or joint preparation or repairs may include machining, thermal cutting, gouging, chipping or grinding. Surface conditions shall be within the limits of 5.2.2. Grinding disks, saw blades, files or other cutting tools that have been used on carbon steels shall not be reused on stainless steels. Grinding shall be done with an iron-free abrasive wheel.

5.2.1.1 Surfaces on which weld metal is to be deposited (including adjacent surfaces) shall be clean, free from organic contaminants and surface oxides. Surfaces shall be free from material discontinuities including fins, tears, laminations, and cracks that would affect the quality or strength of weldments (see 5.2.2.1).

5.2.1.2 Grooves produced by thermal cutting, gouging or grinding shall have surfaces equivalent to those specified in 5.2.1.1 above. Groove profile dimensions, as specified on the WPS shall be maintained unless alternate tolerances are approved by the Engineer. Suitable access to the root area shall be provided as applicable.

5.2.2 Cutting Requirements. Cutting equipment shall be adjusted in such a way as to make smooth cuts. Notches or gouges on cut surfaces (edges) not exceeding 1/16 in. [2 mm] for materials less than 5/8 in. [16 mm] or 10% of the material thickness (T) for materials 5/8 in. [16 mm] or greater need not be repaired unless specified by the Engineer or contract specifications. Notches or gouges exceeding the above limits shall be repaired as specified below.

5.2.2.1 Notches, gouges, or other material discontinuities may be repaired by grinding or machining provided the depth of the notch or gouge does not exceed the lesser of 1/8 in. [3 mm] or 20% of the material thickness. Repairs shall be blended smoothly into the surrounding surfaces to a slope not exceeding 1 in. in 4 in. [25 mm in 100 mm].

5.2.2.2 Notches or gouges exceeding 5.2.2.1 shall be repaired by excavation and welding in accordance with 5.13 unless otherwise directed by the Engineer. Repaired surfaces shall be cleaned to bright metal after completing the repair.

5.2.2.3 If discontinuities other than notches or gouges are observed during the cutting operation, the indications shall be explored and repaired as required. Excavation of defective areas shall be limited to a depth of T/3 without prior approval of the Engineer.

5.2.2.4 Defect excavation or repairs exceeding T/3 may be done only with prior approval and direction from the Engineer. Defect exploration or repairs anticipated to exceed a depth of T/3 shall be examined by methods specified by the Engineer to determine the extent of the defect before exceeding a depth of T/3. Welded repairs shall be accomplished in accordance with 5.13.

5.2.3 Mill Induced Discontinuities. Mill induced discontinuities observed on the plane surface of material (not cut edges) shall be evaluated, explored, or repaired as specified in applicable material or contract specifications.

5.2.3.1 Evaluation of mill induced discontinuities shall be performed by ultrasonic examination in accordance with Clause 6 of this code, or as directed by the Engineer or contract specification.

5.2.3.2 Unacceptable surface defects may be removed by grinding, gouging or machining, provided the remaining thickness of the section is within material specifications, and the depression, after defect removal, is blended uniformly into the surrounding surface. Appropriate NDT methods shall be specified by the Engineer to assure complete defect removal.

5.2.3.3 Welded repairs of base metals, when required or specified shall be accomplished in accordance with 5.13. As an alternative to repairs, the contractor may replace the materials in question.

5.2.4 Beam Copes and Weld Access Holes. All beam copes and weld access holes shall be free of notches or sharp reentrant corners. Beam cope radii and access holes shall provide a smooth transition past the points of tangency of adjacent surfaces.

5.2.4.1 All weld access holes required to facilitate welding operations shall, where practical, have a length from the edge of the weld preparation or edge of backing (as applicable), 1.5 times the thickness of the material in which the hole is made. The size and shape of access holes shall be adequate for deposition of sound weld metal and provide clearance for weld tabs (see Figure 5.1).

5.2.4.2 Reentrant corners or cut materials shall be formed to provide a gradual transition with a radius of 1 in. [25 mm] where practical. The reentrant corners may be formed by mechanical or thermal cutting, followed by grinding, if necessary, to meet the surface requirements of 5.2.2.

5.3 Assembly

5.3.1 The Engineer and contractor shall refer to design drawings, contract specifications and Clause 2 of this code as a basis for the detail drawings. All connections shall be fabricated in such a manner as to maintain compliance with this code and contract specifications.

5.3.2 Assembly and joining of parts to fabrications or built-up members, and welding of reinforcing parts to members shall be done using procedures and sequences that will minimize distortion and shrinkage. Insofar as practical, all welds shall be made in a sequence that will balance the applied heat of welding while the welding progresses (see Clause 2). Joints or groups of joints for which it is especially important that welding sequence and technique be carefully controlled to minimize shrinkage stresses and distortion shall be clearly identified on the applicable drawings.

5.3.3 It is the responsibility of the contractor to prepare WPSs and employ fabrication methods capable of producing welds meeting the quality requirements of this code. All welders shall be qualified per Clause 4. A welding sequence and distortion control program shall be prepared by the contractor and evaluated by the Engineer prior to the start of welding if shrinkage or distortion is expected to affect the end use of the fabrication.

5.3.4 In assemblies, joints expected to have significant shrinkage should be welded before joints expected to have less shrinkage. They should also be welded with as little restraint as possible.

5.3.5 Welding of martensitic materials where conditions of severe external shrinkage restraint are present shall be welded continuously to completion, or to a point that will ensure freedom from cracking before the joint is allowed to cool below the minimum specified preheat and interpass temperature.

5.3.6 Members to be welded shall be brought into correct alignment and held in position by bolts, clamps, wedges, guy lines, struts, and other suitable devices, or by tack welds until welding has been completed. The use of jigs and fixtures is recommended where practical. Allowances shall be made for warpage and shrinkage.

5.3.7 All welded shop splices in each component part of a cover-plated beam or built-up member shall be made before welding component parts to other component parts of the member. When making subassembly splices, whether in the shop or field, the welding sequence should be reasonably balanced between the web and flange welds as well as about the major and minor axes of the member.

5.3.8 Edges of built-up beam and girder webs shall be cut to the prescribed camber with suitable allowance for shrinkage due to cutting and welding.

5.3.9 Corrections to meet camber tolerances shall be in conformance with procedures approved by the Engineer.

5.4 Assembly Tolerances

5.4.1 Parts to be joined by fillet welds shall be brought into alignment. Fit-up separations 1/16 in. [2 mm] or greater are acceptable provided the fillet weld size is increased by an amount equal to the separation. Fit-up separations greater than 3/16 in. [5 mm] are unacceptable without prior approval by the Engineer and demonstration that the required effective throat has been attained.

5.4.1.1 The separations between the faying surfaces of lap joints, plug and slot welds, and butt joints landing on a backing shall not exceed 1/16 in. [2 mm].

5.4.1.2 Where dimensions in rolled shapes do not permit alignment within specified limits (after straightening), corrective actions shall be approved by the Engineer. The use of filler plates is prohibited except as specified on drawings or specifically approved by the Engineer. When approved, the use of filler plates shall be in accordance with 2.7.

5.4.2 Parts joined by groove welds shall be brought into alignment. The root openings between parts shall be in accordance with Figures 3.4, 3.5, or 3.6, or an approved WPS as applicable. Tolerances for bearing joints shall be in accordance with the applicable contract specifications.

5.4.3 Parts joined at butt joints shall be carefully aligned. Where parts are effectively restrained against bending due to eccentricity in alignment, offsets which do not exceed the lesser of 10% of the thickness of the thinner part joined, or 1/8 in. [3 mm] are permitted as a departure from the theoretical alignment. For correcting misalignment, parts shall not be drawn in to a slope greater than 1/2 in. [12 mm] in 12 in. [300 mm]. Measurement of offsets shall be based on the centerline of parts unless otherwise shown on the drawings. In the case of tubular products, measurement of offset shall be based on misalignment of internal surfaces.

5.4.4 Root openings greater than those permitted in Figures 3.4, 3.5, or 3.6 or the approved WPS, but not greater than twice the thickness of the thinner part or 1/2 in. [12 mm], whichever is less, may be corrected by welding to acceptable dimensions prior to joining the parts by welding.

5.4.5 Root openings greater than permitted by 5.4.4 may be corrected by welding only with approval of the Engineer.

5.4.6 Heat shall not be applied to form parts or improve alignment unless approved by the Engineer.

5.5 Distortion of Members

Members distorted by welding may be straightened by mechanical straightening methods specified and approved by the Engineer. This clause of the code does not prohibit, but makes no provisions for the use of heat straightening of stainless steels with the following exception: If heat straightening is used, it is the Engineer's responsibility to determine the effect that the heat has on corrosion resistance properties of the materials and external stresses of the fabrication. Heat straightening temperatures should not exceed 600°F [315°C] for ferritic, martensitic or duplex steels; 800°F [430°C] for austenitic stainless steel; and the aging temperature for precipitation hardening stainless steel.

5.6 Groove Weld Backing

5.6.1 When used, fused metal backing shall be the full length of the welded joint. Metal backing materials shall be of the same base metal type as was qualified and listed in the WPS. All backing shall be removed unless permitted to remain in place by detail drawings, specifications or the Engineer.

5.6.2 Groove welds made with metal backing shall have the weld metal fused thoroughly with the backing and shall be welded in a manner that meets the quality requirements of this code. Recommended nominal thicknesses of backing bars to prevent melt through are shown below in Table 5.1.

5.6.3 Nonmetallic or nonfused metallic backing, if used, shall be completely removed when the welding is completed, unless otherwise specified by the Engineer. The back side of the welds shall be properly prepared by grinding or other suitable means for visual or specified nondestructive testing (NDT). Weld profile requirements of 5.11 shall be applicable to the back side of such joints.

5.7 Tack Welds and Temporary Welds

5.7.1 Tack welds shall be subject to the same quality requirements as the final welds.

5.7.2 Tack welds to be incorporated into the final weld shall be made with weld filler materials meeting the requirements of the final weld and shall be cleaned thoroughly with stainless steel wire brushes or iron free abrasive wheels.

5.7.3 Tack welds not incorporated into final welds shall be removed unless otherwise permitted by the Engineer.

5.7.4 Temporary welds shall be subject to the same WPS requirements as final welds. Temporary welds shall be removed unless otherwise permitted by the Engineer.

5.7.5 Temporary weld removals shall be made flush with permanent materials and the surfaces examined by methods specified by the Engineer or contract documents. As a minimum, visual examination shall be performed to assure permanent materials have not been gouged, nicked or otherwise damaged.

5.8 Peening

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

5.8.2 When approved by the Engineer, peening may be used on intermediate weld layers to mechanically reduce and control the residual stresses and distortion created by welding. Care should be taken to prevent overlapping or cracking of the weld or base metal. Peening on the root, or cover passes of welds, is prohibited unless specifically approved by the Engineer.

5.8.3 To prevent sharp impressions, peening (when approved), shall be done by mechanically striking surfaces of intermediate weld beads or layers with a suitable tool having a minimum radius of a 1/8 in. [3 mm], unless otherwise approved.

5.8.4 The Engineer shall specify the required preheat (if any) and interpass temperatures prior to peening.

5.9 Weld Termination

5.9.1 Welds shall be terminated at the end of joints in a manner that will ensure sound welds and in a manner consistent with Clause 2 of this code. Weld tabs aligned in such a manner to provide an extension of the weld joint may be used.

5.9.2 Backing or weld tabs shall be of a base metal type which is compatible with the material being welded, unless the design or contract documents specifically dictate otherwise.

5.9.3 All weld tabs need not be removed unless required by detail drawings, contract specifications or by the Engineer.

5.10 Weld Cleaning

In all cases where brushes are used, the brush wires shall be made of stainless steel materials. Grinding, if required, shall be done with iron free abrasive wheels.

5.10.1 Before welding over previously deposited weld metal, all slag or other foreign materials shall be completely removed from the weld and adjacent base metal. This requirement shall apply not only to successive beads but also to the crater area when welding is resumed after any interruption.

5.10.2 Slag shall be completely removed from all finished welds. All welds and adjacent base metals shall be cleaned by brushing or other suitable means after welding is completed. Spatter remaining after cleaning that is considered harmful to the finished product shall be removed.

5.10.3 Arc strikes shall be removed by grinding or other suitable means. Cracks or blemishes caused by arc strikes shall be ground to a smooth contour and examined visually to assure complete removal. Other nondestructive testing (NDT) methods may also be specified by the Engineer or in contract documents.

5.11 Weld Profiles

5.11.1 The sizes, lengths, and locations of welds shall be as specified by design requirements and detail drawings. Unless otherwise specified by contract or design requirements, weld length tolerances shall be –0, +25% or 6 in. [150 mm], whichever is less, provided that the overlength welding does not cause interference with other members. All welds shall be free from cracks, overlaps, and other unacceptable profiles exhibited in Figure 5.2. Undercut shall not exceed the requirements of 6.28 and 6.29.

5.11.2 Fillet Welds. Fillet weld profiles may be slightly convex, flat, or slightly concave. Convexity of individual weld passes on multiple pass fillet welds need not be measured provided the completed weld is sufficiently free from coarse ripples, abrupt ridges and valleys, and the reentrant angle at the fillet weld toe is not less than 90°.

5.11.3 Figures 5.2(A) and (B) show typical examples of fillet weld profiles. Figure 5.2(C) shows typically unacceptable fillet weld profiles. Measurement of fillet weld sizes shall be determined by the leg size for convex welds, and the theoretical throat size for concave welds.

5.11.4 Fillet weld leg sizes may be equal or unequal as specified by design or detail drawings. Unequal leg fillet welds produced where weld symbol(s) indicate equal leg fillets are acceptable (provided the minimum specified size is met) unless specifically prohibited or cause interference with mating members.

5.11.5 Groove Welds. Groove welds shall be made with minimum weld reinforcement unless otherwise specified. Reinforcement shall not exceed 1/8 in. [3 mm] in height and shall have a gradual transition to the plane of the base metal surface. Individual passes on multiple pass welds shall be transitioned into previous passes in such a way as to avoid coarse ripples, and abrupt ridges and valleys. Figure 5.2(D) shows typical groove weld profiles. Figure 5.2(E) shows typically unacceptable weld profiles.

5.11.6 Finishing of groove welds in materials 1/8 in. [3 mm] thick and greater with a reduced finished contour of flush shall not be reduced by more than 1/32 in. [1 mm] or 10%, whichever is less. In materials less than 1/8 in. [3 mm] thick, no reduction exceeding 10% shall be permitted.

5.11.7 Weld finishes and architectural requirements shall be as specified in the contract or detail drawings.

5.12 Weld Metal Removal and Repair

5.12.1 Removal and Repair of Welds. The removal of rejectable weld metal or portions of the base metal may be done by machining, grinding, chipping, plasma, or air carbon arc gouging. The process(es) used for removal shall be controlled in such a manner that the adjacent weld metal or base metal is not nicked, gouged or without substantial removal of the base metal. Oxyfuel gas gouging is not permitted.

5.12.2 The affected surfaces of materials shall be cleaned thoroughly to bright metal by mechanical means before rewelding. Chemical cleaning to remove residual surface oxides is also permitted. If chemical cleaning is used, the chemical's characteristics should be evaluated by the Engineer for safety, corrosion and weldability effects.

5.12.3 Repaired or replaced welds shall be performed using qualified or prequalified WPSs. Repaired or replaced welds shall be re-examined by the same methods and quality acceptance criteria originally used unless otherwise specified by the Engineer.

5.12.4 During the welding operation, the contractor has the option of repairing an unacceptable weld, by removing the defective area or by replacing the entire weld. Welds found rejectable by NDE methods after welding is complete shall be repaired as described in 5.12.3.

5.13 Base Metal Repairs by Welding

5.13.1 Prior to the repair of base material defects the extent of defects shall be determined. Defective areas shall be prepared for welding by grinding, gouging, or other suitable means. Surface conditions shall meet 5.2.1, 5.2.1.1, or 5.2.1.2 requirements, as applicable prior to repair welding.

5.13.2 Base metal defects shall be completely removed to sound metal. Prior to making welded repairs, the defect removal areas shall be inspected as specified by the Engineer. Joint geometries, including applicable tolerances, shall be essentially in conformance with the WPS approved for use in the repair.

5.13.3 Areas to be repaired by welding shall be thoroughly cleaned as specified in 5.12.2.

5.13.4 The WPS used in making repairs shall meet the requirements of Clause 3 or Clause 4 of this code, as applicable.

5.13.5 After completing the welded repair, the repaired areas shall be examined for fusion and base material damage (such as undercut). If visual inspection of the repaired areas is acceptable, they shall be blended smooth, flush and uniformly into the surrounding surfaces. Blending may be done by grinding or machining. Chemical cleaning, if required, shall be specified by the Engineer.

5.13.6 Repaired areas shall be inspected by an appropriate NDT method or as specified by the Engineer. Acceptance criteria of welded repairs shall be per applicable material specifications, contract requirements and Clause 6 of this code.

5.14 Mislocated Holes

Mislocated holes that have been punched or drilled in base materials may be left open or filled with stainless steel bolts when approved by the Engineer. Where restoration by welding is necessary for structural or other reasons the welding shall be performed in accordance with the applicable subclauses of 5.13.

5.15 Inaccessibility of Unacceptable Welds

If work has progressed to a stage that has made an unacceptable weld inaccessible, or has created new conditions that make correction of the unacceptable weld dangerous or ineffectual, the weld repair shall be made by removing welds or members until the unacceptable weld is accessible for repair. In lieu of the above, unacceptable welds may be compensated for by performing additional work as approved by the Engineer.

5.16 Postweld Heat Treatment and Recommendations

In the selection of the proper stress-relieving or solution annealing treatment, consideration must be given to the specific material used, fabrication procedures involved, and to the design and intended function of the fabrication and assembly.

5.16.1 All welds and adjacent surfaces of base metals that are subject to Postweld Heat Treatment (PWHT) shall be thoroughly cleaned prior to PWHT.

5.16.2 Materials that have been subjected to PWHT shall be cleaned and visually examined after heat treatment, as a minimum, unless otherwise specified.

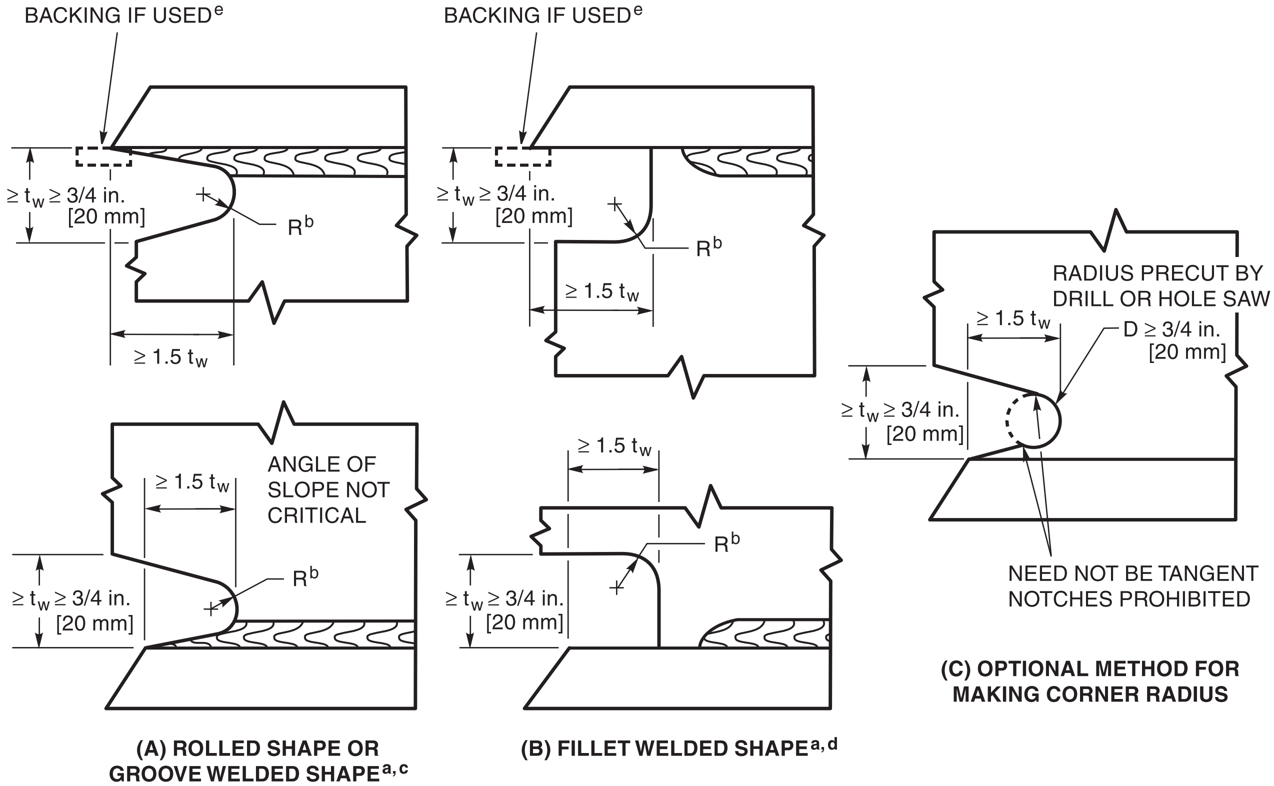
5.16.3 Postweld heat treatment of the 200 and 300 series is necessary only to dissolve precipitated carbides or stress relieve components used in conditions where stress corrosion cracking is of concern. Postweld heat treatment of nonprequalified welding of ferritic, martensitic, duplex and precipitation-hardenable stainless steel weldments is discussed in detail in Annex B. Refer to this Annex for more information.

5.16.4 PWHT shall be performed in accordance with the WPS, e.g., range of PWHT temperatures, holding times, and heating and cooling rates.

Table 5.1
Recommended Backing Thicknesses
(see 5.6.2)

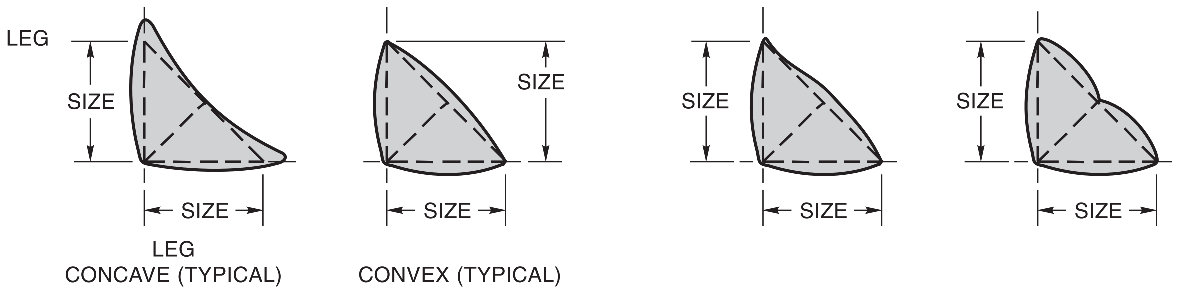
Process	Recommended Backing Thickness
GTAW	1/8 in. [3 mm]
PAW	1/8 in. [3 mm]
SMAW	3/16 in. [5 mm]
GMAW	3/16 in. [5 mm]
FCAW	1/4 in. [6 mm]
SAW	1/4 in. [6 mm]

Note: Use of commercially available stainless steel backing for pipe and tubing is acceptable.



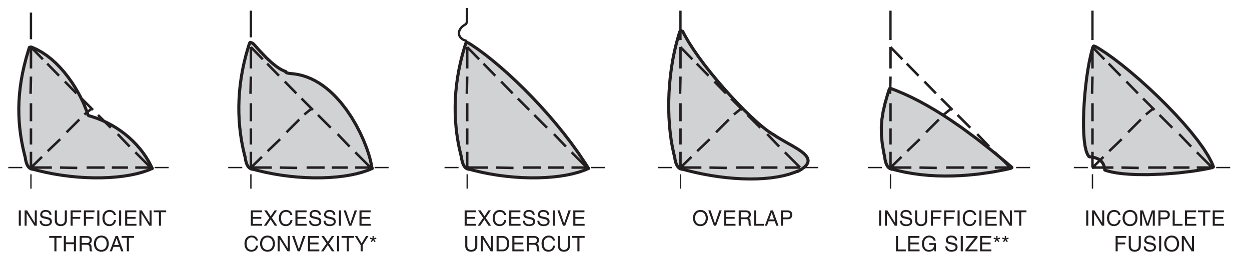
[a] For martensitic steels, grind and inspect thermally cut edges of access holes prior to making web and flange splice groove welds. Inspection methods shall be specified by the Engineer.
[b] Radius shall provide smooth, notch free transition.
[c] Access opening made *after* welding web to flange.
[d] Access opening made *before* welding web to flange. Weld not returned through opening.
[e] These are typical details for joints welded from one side against fused metal backing. Alternative joint details should also be considered.

Figure 5.1—Typical Weld Access Hole Geometries (see 5.2.4.1)



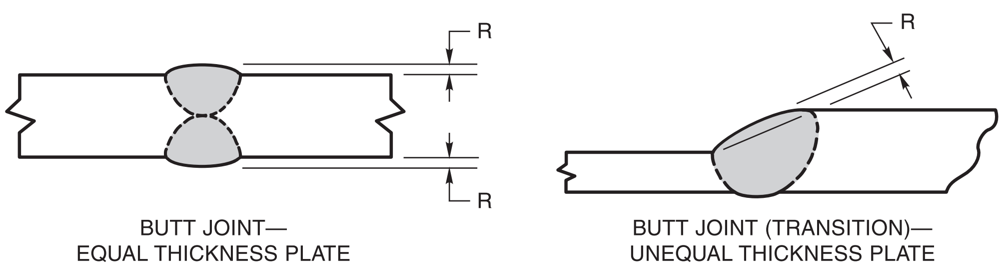
(A) DESIRABLE FILLET WELD PROFILES **(B) TYPICALLY ACCEPTABLE FILLET WELD PROFILES**

Note: Except at outside welds in corner joints, the reentrant angle between the weld face and the base metal at the weld toe or the weld faces of adjacent weld beads shall not be less than 90° (also see 5.11.2).



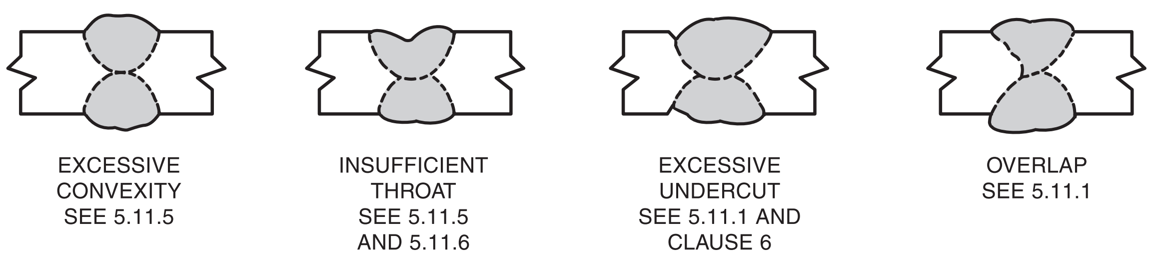
(C)) TYPICALLY UNACCEPTABLE FILLET WELD PROFILES

*SEE 5.11.2 AND NOTE ABOVE. **THIS MAY NOT BE A DEFICIENCY IF UNEQUAL LEG FILLETS ARE SPECIFIED,



(D) TYPICALLY ACCEPTABLE GROOVE WELD PROFILES

Note: Reinforcement (R) shall not exceed 1/8 in. [3 mm] (see 5.11.5).



(E) TYPICALLY UNACCEPTABLE GROOVE WELD PROFILES IN BUTT JOINTS

Figure 5.2—Typical Weld Profiles (see 5.11)

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6. Inspection

Part A
General Requirements

6.1 General

6.1.1 For the purpose of this code, quality control and quality assurance are separate inspection functions.

6.1.1.1 Fabrication/erection is the responsibility of the contractor. The contractor shall perform inspection and testing at least to the extent specified in this clause and additionally as necessary to assure conformance with the requirements of the contract documents.

6.1.1.2 Verification is the prerogative of the owner. The owner may perform inspection and testing necessary to verify that an acceptable product is being furnished in accordance with the provisions of the contract documents. Verification inspection and testing should be scheduled to minimize interference with production insofar as possible.

6.1.2 Inspector—Definition

6.1.2.1 The fabrication/erection Inspector is the person who acts for and in behalf of the contractor on inspection, testing, and quality matters within the scope of the contract documents.

6.1.2.2 The verification Inspector is the person who acts for and in behalf of the Engineer and owner on all matters within the scope of the contract documents and the limits of authority delegated by the owner.

6.1.2.3 When the term Inspector is used without further qualification, it is mandatory for fabrication/erection and optional for verification as defined in 6.1.2.1 and 6.1.2.2.

6.2 Inspection Personnel Qualification

6.2.1 All fabrication/erection Inspectors responsible for acceptance or rejection of materials and workmanship shall be qualified as follows:

(1) The Inspector shall be an AWS Certified Welding Inspector (CWI) qualified and certified in accordance with the provisions of AWS QC1, *Standard for AWS Certification of Welding Inspectors*, or

(2) The Inspector shall be qualified by the Canadian Welding Bureau (CWB) to the requirements of the Canadian Standard Association (CSA) standard W178.2, *Certification of Welding Inspectors*, or

(3) The Inspector shall be an engineer or technician who, by training and experience in metal fabrication, inspection and testing, is acceptable to the Engineer.

6.2.2 An Inspector, previously certified as a Welding Inspector under the provisions of AWS QC1 or CSA standard W178.2, Level II or III, may serve as an Inspector for this work, provided there is acceptable documentation that the Inspector has remained active as an Inspector of welded fabrication since last being certified, and there is no reason to question the Inspector's ability.

6.2.3 The Inspector may be supported by Assistant Inspectors who may perform specific inspection functions under the supervision of the Inspector. Assistant Inspectors shall be qualified by training and experience to perform the specific functions to which they are assigned. The work of Assistant Inspectors shall be regularly monitored, generally on a daily basis, by the Inspector.

6.2.4 Inspectors, Assistant Inspectors and personnel performing nondestructive testing (NDT) shall have passed an eye examination, with or without corrective lenses, to prove (1) near vision acuity of Snellen English, or equivalent Jaeger, at not less than 12 in. [300 mm], and (2) far vision acuity of 20/40 or better. Vision tests are required every three years, or less if necessary, to demonstrate adequacy.

6.2.5 The Inspector shall be furnished with complete detailed drawings showing the size, length, type, and location of all welds to be made. The Inspector shall be furnished with the portion of the contract documents which describes material and quality requirements for the products to be fabricated or erected, or both. In addition, Inspectors not familiar with stainless steel welding should review this code, the contract special provisions and their supervisor's special instructions, as applicable.

6.2.6 The Inspector shall be notified in advance of the start of fabrication/erection operations subject to inspection and verification.

6.2.7 NDT Personnel Qualification. Personnel performing nondestructive testing shall be qualified in accordance with the American Society for Nondestructive Testing's (ASNT) Recommended Practice No. SNT-TC-1A, or equivalent. Certification of Level I and Level II individuals shall be performed by a Level III individual who has been certified by (1) ASNT, or (2) has the education, training, experience, and has successfully passed the written examination prescribed in ASNT SNT-TC-1A. Only individuals qualified for NDT Level II or individuals qualified for NDT Level I and working under the direct supervision of an individual qualified for NDT Level II may perform nondestructive testing. Special training for qualification may be needed for personnel performing UT to meet the additional requirements of 6.14 of this code.

6.2.7.1 The Engineer shall have the authority to verify the qualifications of fabrication/erection Inspectors and NDT personnel to specified levels by retests or other means.

6.2.7.2 Personnel performing nondestructive tests under the provisions of 6.2.7 are not required to be qualified under the provisions of 6.2.1 but shall have adequate vision as required by 6.2.4 and meet the requirements of 6.2.7.

6.3 Inspection and Verification of Materials

The Inspector shall make certain that only materials conforming to the requirements of the contract documents are used. This includes review of the mill test reports, if required, and visual inspection.

6.4 Verification of Procedure Qualification Record (PQR), Welding Procedure Specification (WPS), and Performance Qualification

6.4.1 The Inspector shall make certain all WPSs are prequalified per Clause 3 or qualified in accordance with Clause 4 of this code. The Inspector shall make certain that each WPS is written and available to the welders and Inspectors for reference.

6.4.2 The Inspector shall permit welding to be performed only by welders and welding operators, who are qualified in accordance with the requirements of Clause 4, and shall verify their qualifications authorize them to use the WPSs specified for the work, or shall make certain that each welder or welding operator has previously demonstrated such qualification under supervision acceptable to the Engineer.

6.4.3 When the quality of work by a welder or welding operator appears to be below the requirements of this code, the Inspector may require that the welder or welding operator demonstrate an ability to produce sound welds by means of a simple test or by requiring complete requalification in accordance with Clause 4.

6.4.4 The Inspector shall require requalification of any welder or welding operator whose qualification is not current by the requirements of this code.

6.4.5 When qualifying welders and welding operators, the Inspector, at his or her discretion, may observe the performance qualification tests.

6.5 Inspection and Verification of Work and Records

6.5.1 The Inspector shall make certain that the minimum size, length, and location of all welds conform to the requirements of this code and to the detail drawings and that no unspecified welds have been added without approval.

6.5.2 The Inspector shall verify, at suitable intervals, that electrodes are used only in those positions and with the type of welding current and polarity for which they are qualified or prequalified.

6.5.3 The Inspector shall observe, at suitable intervals, the joint preparation, assembly practice, welding techniques, and performance of each welder and welding operator, to make certain applicable requirements of this code are met. The Inspector shall examine the work to make certain that it meets the requirements of Clause 5 and 6.28 or 6.29, as applicable. The size and contour of welds shall be measured using suitable gages. Acceptance criteria different from those specified in this code may be used when approved by the Engineer.

6.5.4 The Inspector shall identify with a distinguishing mark or adequate document control, as approved by the Engineer, all parts or joints that the Inspector has inspected and approved.

6.5.5 The Inspector shall keep a record of qualifications of all welders and welding operators, all WPS qualifications or other tests that are made, the control of welding materials and equipment, and such other information as may be required by the Engineer.

6.5.6 When nondestructive testing is required, the Inspector shall ascertain that procedures and techniques are in accordance with 6.8. The verification Inspector may view the making of nondestructive tests, examine and evaluate the test results, approve satisfactory welds or reject unsatisfactory welds, and inspect the preparation and rewelding of unacceptable welds.

6.5.7 The Inspector shall record the location of inspected areas and the results of all nondestructive tests, together with detailed descriptions of all repairs made. Inspectors shall identify with a distinguishing mark or other recording methods all parts or joints that they have inspected and accepted. Any recording method which is mutually agreeable may be used. Die stamping of cyclically loaded members is not permitted without the approval of the Engineer.

6.6 Obligations of the Contractor

6.6.1 The contractor shall allow access to the project fabrication facility by representatives of the Owner. The contractor shall cooperate with such personnel and provide ready access to fabrication/erection inspection records and fabrication or erection areas, as applicable.

6.6.2 The contractor shall be responsible for visual inspection and nondestructive testing specified in 6.8 and necessary correction of all deficiencies in materials and workmanship in accordance with the requirements of Clause 5 and as provided elsewhere in contract documents.

6.6.3 The contractor shall comply with all requests of the Inspector to correct deficiencies in materials and workmanship, as provided in the contract documents.

6.6.4 In the event that faulty welding or its removal for rewelding damages the base metal so that, in the judgment of the Engineer, its retention is not in accordance with the intent of the contract documents, the contractor shall remove and replace the damaged base metal or shall compensate for the deficiency in a manner approved by the Engineer.

6.6.5 If nondestructive testing other than visual inspection is not specified in the original contract agreement but is subsequently requested by the owner, the contractor shall perform any requested testing or shall permit any testing to be performed in accordance with 6.7. The owner shall be responsible for all associated costs including handling, surface preparation, nondestructive testing, and repair of discontinuities other than those listed in 6.28.1 or 6.29.1, whichever is applicable, at rates mutually agreeable between owner and contractor. However, if such testing should disclose an attempt to defraud or gross nonconformance to this code, repair work shall be done at the contractor's expense.

6.6.6 The contractor shall schedule nondestructive testing to facilitate attendance by the verification Inspector. The verification Inspector shall be advised by the contractor of operational and nondestructive testing schedules and scheduled changes.

6.7 Nondestructive Testing

Nondestructive testing is not a mandatory part of this code, unless specified in contract documents. When NDT is required, this code provides standard requirements, unless others are specified in contract documents. The nondestructive testing procedures as described in this code provide reasonable assurance of weld integrity; however, it appears that some users of the code incorrectly consider each method capable of detecting all injurious defects. Users of the code should become familiar with all the limitations of nondestructive testing methods to be used, particularly the inability to detect and characterize planar defects with specific flaw orientations. (The limitations and complementary use of each method are explained in the latest edition of AWS B1.10, *Guide for Nondestructive Inspection of Welds*.)

6.7.1 When nondestructive testing other than visual is to be required, it shall be so stated in the information furnished to the bidders. This information shall designate the categories of welds to be examined, the extent of examination of each category, and the method or methods of testing.

6.7.2 Welds inspected by nondestructive examination that do not meet the requirements of this code or alternate acceptance criteria per 1.7 shall be repaired in accordance with 5.12.

6.7.3 When radiographic testing is used, the procedure and technique shall be in accordance with Part B of this clause.

6.7.4 When examination is performed using radiation imaging systems, the procedures and techniques shall be in accordance with Part D of this clause.

6.7.5 When ultrasonic testing is used, the procedure and technique shall be in accordance with Part C of this clause.

6.7.6 For detecting discontinuities that are open to the surface, dye penetrant inspection may be used, provided it is suitable for stainless steel. The standard methods set forth in ASTM E 165 shall be used for dye penetrant inspection, and the standards of acceptance shall be in accordance with this code, whichever is applicable.

6.7.7 For detecting discontinuities that are open to or just below the surface, magnetic particle inspection using yoke type equipment may be used on ferritic or martensitic stainless steel, and some, but not all, precipitation hardening alloys. The standards set forth in ASTM E 709 shall be used for magnetic particle inspection, and the standards of acceptance shall be in accordance with this code, whichever is applicable.

6.8 Extent of Testing

Information furnished to the bidders shall clearly identify the extent of nondestructive testing (types, categories, or location) of welds to be tested. See Annex A for nonmandatory recommended inspection procedures, as applicable.

6.8.1 Weld joints requiring testing by contract specification shall be tested for their full length, unless partial or spot testing is specified.

6.8.2 When partial testing is specified, the location and lengths of welds or categories of weld to be tested shall be clearly designated in the contract documents.

6.8.3 When spot testing is specified, the number of spots in each designated category of welded joint to be tested in a stated length of weld or a designated segment of weld shall be included in the information furnished to the bidders. Each spot test shall cover at least 4 in. [100 mm] of the weld length. When spot testing reveals indications of rejectable discontinuities that require repair, the extent of those discontinuities shall be explored. Two additional spots in the same segment of weld joints shall be taken at locations away from the original spot. The location of the additional spots shall be agreed upon between the contractor and the verification Inspector.

When either of the two additional spots show defects that require repair, the entire segment of weld, as defined by the Engineer, represented by the original spot shall be completely tested. If the weld involves more than one segment, two additional spots in each segment shall be tested at locations agreed upon by the contractor and the verification Inspector, subject to the foregoing interpretation.

6.8.4 Prior to testing, nondestructive test personnel shall, be furnished or have access to relevant information, including weld joint geometries, material thicknesses, and welding processes and any weld repairs used in making the weldment.

Part B
Radiographic Testing of Groove Welds in Butt Joints

6.9 General

6.9.1 The procedures and standards set forth in Part B are to govern radiographic testing of welds when such inspection is required by the contract documents as provided in 6.7. The requirements listed herein are specifically for testing groove welds in butt joints in plate, shapes, and bars by X-ray or gamma-ray sources. The methodology shall conform to ASTM E 94, *Guide for Radiographic Testing*, and ASTM E 142, *Method for Controlling Quality of Radiographic Testing*, and ASTM E 747, *Practice for Design, Manufacture, and Material Grouping of Wire Image Quality Indicators (IQI) for Radiology*, and ASTM E 1032, *Method for Radiographic Examination of Weldments*.

6.9.2 Variations in testing procedures, equipment, and acceptance standards may be used upon agreement between the contractor and the owner. Such variations include, but are not limited to, the following: radiographic testing of fillet, T, and corner welds; changes in source-to-film distance; unusual application of film; unusual hole type image quality indicators (IQI) applications (including film side hole type IQI); and radiographic testing of thicknesses greater than 6 in. [150 mm] film types, densities, and variations in exposure, development, and viewing techniques.

6.10 Radiographic Procedures

6.10.1 Radiographs shall be made using a single source of either X- or gamma radiation. The radiographic sensitivity shall be judged based on hole type IQI image or wire image quality indicators (IQI). Radiographic technique and equipment shall provide sufficient sensitivity to clearly delineate the required IQIs and the essential holes or wires as described in 6.10.7, Tables 6.1 and 6.2, and Figures 6.5 and 6.6. Identifying letters and numbers shall show clearly in the radiograph.

6.10.2 Radiography shall be performed in accordance with the applicable safety requirements.

6.10.3 When the contract documents require the removal of weld reinforcement, the welds shall be prepared by grinding as described in 5.11.6. Other weld surfaces need not be ground or otherwise smoothed for purposed of radiographic testing objectionable weld discontinuities to be obscured in the radiograph.

6.10.3.1 Weld tabs shall be removed prior to radiographic inspection unless otherwise approved by the Engineer.

6.10.3.2 When required by provisions of the contract documents, steel backing shall be removed and the surface shall be finished flush by grinding prior to radiography. Grinding shall be as described in 5.11.6.

6.10.3.3 When weld reinforcement or backing, or both, is not removed, or wire IQI alternate placement is not used, steel shims when extended at least 1/8 in. [3 mm] beyond three sides of the required hole type IQI or wire IQI shall be placed under the hole type IQI or wire IQI so that the total thickness of steel between the IQI and the film is approximately equal to the average thickness of the weld measured through its reinforcement and backing.

6.10.4 Radiographic film shall be as described in ASTM E 94. Lead foil screens shall be used as described in ASTM E 94. Fluorescent screens shall not be permitted.

6.10.5 Radiographs shall be made with a single source of radiation centered as near as practicable with respect to length and width of that portion of the weld being examined.

6.10.5.1 Gamma ray sources, regardless of size, shall be capable of meeting the geometric unsharpness limitation of ASME *Boiler and Pressure Vessel Code*, Section V, Article 2.

6.10.5.2 The source-to-subject distance shall not be less than the total length of film being exposed in a single plane. This provision does not apply to panoramic exposures for tubulars made under the provisions of 6.9.2.

6.10.5.3 The source-to-subject distance shall not be less than seven times the thickness of weld plus reinforcement and backing, if any, nor such that the inspection radiation shall penetrate any portion of the weld represented in the radiograph at an angle greater than 26-1/2° from a line normal to the weld surface.

6.10.6 X-ray units, 600 kvp maximum, cobalt 60, and iridium 192 may be used as a source for all radiographic inspection provided they have adequate penetrating ability. Other radiographic sources shall be subject to the approval of the Engineer.

6.10.7 IQI Selection and Placement. IQIs shall be selected and placed on the weldment in the area of interest being radiographed as shown in Table 6.3.

6.10.8 Welded joints shall be radiographed and the film indexed by methods that will provide complete and continuous inspection of the joint within the limits specified to be examined. Joint limits shall show clearly in the radiographs. Short film, short screens, excessive undercut by scattered radiation, or any other process that obscures portions of the total weld length shall render the radiograph unacceptable.

6.10.8.1 Films shall have sufficient length and shall be placed to produce at least 1/2 in. [12 mm] of film, exposed to direct radiation from the source, beyond each free edge where the weld is terminated.

6.10.8.2 Welds longer than 14 in. [350 mm] may be radiographed by overlapping film cassettes and making a single exposure, or by using single film cassettes and making separate exposures. The provisions of 6.10.5 shall apply.

6.10.8.3 To check for backscatter radiation, a lead symbol "B" 1/2 in. [12.7 mm] high, 1/16 in. [1.6 mm] thick shall be attached to the back of each film cassette. If the "B" image appears on the radiograph, the radiograph shall be considered unacceptable.

6.10.9 Film widths shall be sufficient to depict all portions of the weld joint, including the heat-affected zones, and shall provide sufficient additional space for the required hole type IQIs or wire IQI and film identification without infringing upon the area of interest in the radiograph.

6.10.10 Quality of Radiographs. All radiographs shall be free from mechanical, chemical, or other blemishes to the extent that they cannot mask or be confused with the image of any discontinuity in the area of interest in the radiograph. Such blemishes include, but are not limited to:

(1) fogging

(2) processing defects such as streaks, water marks, or chemical stains

(3) scratches, finger marks, crimps, dirtiness, static marks, smudges, or tears

(4) loss of detail due to poor screen-to-film contact

(5) false indications due to defective screens or internal faults

6.10.11 Density Limitations. Transmitted film density through the radiographic image of the body of the required IQI(s) and the area of interest shall be 1.8 minimum for single film viewing for radiographies made with an X-ray source and 2.0 minimum for radiographs made with a gamma-ray source. For composite viewing of double film exposures, the minimum density shall be

2.6. Each radiograph of a composite set shall have a minimum density of 1.3. The maximum density shall be 4.0 for either single or composite viewing.

6.10.11.1 The density measured shall be H&D density. H&D (radiographic) density is a measure of film blackening, expressed as:

$D = \log I_0/I$

where:
D = H&D (radiographic) density
I_0 = light intensity on the film, and
I = light transmitted through the film

6.10.11.2 When weld transitions in thickness are radiographed and the ratio of the thickness of the thicker section to the thickness of the thinner section is 3 or greater, radiographs shall be exposed to produce single film densities of 3.0 to 4.0 in the thinner section. When this is done, the minimum density requirements of 6.10.11 shall be waived unless otherwise provided in the contract documents.

6.10.12 A radiograph identification mark and two location identification marks shall be placed on the steel and each radiograph location. A corresponding radiograph identification mark and two location identification marks, all of which shall show in the radiograph, shall be produced by placing lead numbers or letters, or both, over each of the identical identification and location marks made on the stainless steel to provide a means for matching the developed radiograph to the weld. Additional identification information may be pre-printed no less than 3/4 in. [20 mm] from the edge of the weld or shall be produced on the radiograph by placing lead figures on the stainless steel.

Information required to show on the radiograph shall include the owner's contract identification, initials of the radiographic inspection company, initials of the fabricator, the fabricator shop order number, the radiographic identification mark, the date, and the weld repair number, if possible.

6.10.13 Edge Blocks. Edge blocks shall be used when radiographing butt welds greater than 1/2 in. [12 mm] thickness. The edge blocks shall have a length sufficient to extend beyond each side of the weld centerline for a minimum distance equal to the weld thickness, but no less than 2 in. [50 mm], and shall have a thickness equal to or greater than the thickness of the weld. The minimum width of the edge blocks shall be equal to half the weld thickness, but not less than 1 in. [25 mm]. The edge blocks shall be centered on the weld with a snug fit against the plate being radiographed, allowing no more than 1/16 in. [2 mm] gap for the minimum specified length of the edge blocks. Edge blocks shall be made of radiographically clean stainless steel, and the surface shall have a finish of approximately 125 µin. [3 µm or smoother], in accordance with ANSI/ASME B46.1-2002, *Surface Texture (Surface Roughness, Waviness, and Lay)* (see Figure 6.7 for application).

6.11 Acceptability of Welds

Welds inspected by radiographic examination that do not meet the requirements of this code, or alternate acceptance criteria per 1.7, shall be repaired in accordance with 5.12.

6.12 Examination, Report, and Disposition of Radiographs

6.12.1 The contractor shall provide a suitable variable intensity illuminator (viewer) with spot review or masked spot review capability. The viewer shall incorporate a means for adjusting the size of the spot under examination. The viewer shall have sufficient capacity to properly illuminate radiographs with an H&D density of 4.0. Film review shall be done in an area of subdued light.

6.12.2 Before a weld subject to radiographic testing by the contractor for the owner is accepted, all of its radiographs, including any that show unacceptable quality prior to repair, and a report interpreting them shall be submitted to the verification Inspector.

6.12.3 A full set of radiographs for welds subject to radiographic testing by the contractor for the owner, including any that show unacceptable quality prior to repair, shall be delivered to the owner upon completion of the work. The contractor's obligation to retain radiographs shall cease: (1) upon delivery of this full set to the owner, or (2) one full year after the completion of the contractor's work, provided the owner is given prior written notice.

Part C
Ultrasonic Testing (UT) of Groove Welds

6.13 General

6.13.1 The procedures and standards set forth in Part C are to govern the ultrasonic testing of groove welds and heat-affected zones in austenitic stainless steel, when such testing is required in accordance with 6.7 of this code. The basic UT procedure, instrumentation and operator requirements contained in this Part C are necessary to ensure maximum accuracy in discontinuity evaluation and sizing. For maximum control of discontinuity sizing, emphasis has been placed upon: the UT procedure which must be written and qualified; UT technician special requirements; and UT instrumentation and calibration requirements. AWS recognizes the inherent limitations and inconsistencies of ultrasonic examination for discontinuity characterization and sizing. The accuracies obtainable are required to be proven by the UT technician using the applicable procedures and equipment. Procedure qualification results shall be furnished to the Engineer. AWS makes no claim for accuracies possible when using the methods contained herein.

6.13.2 Variations in testing procedures, equipment, and acceptance standards not included in Part C of Clause 6 may be used upon agreement with the Engineer. Such variations include other types of stainless steel, other thicknesses, weld geometries, transducer sizes, frequencies, couplant, coated surfaces, testing techniques, etc. Such approved variations shall be recorded in the contract records.

6.13.3 Base Metal. These procedures are not intended to be employed for the procurement testing of base metals. However, welding related discontinuities (cracking, lamellar tearing, delaminations, etc.) in the adjacent base metal which would not be acceptable under the provisions of this code shall be reported to the Engineer for disposition.

6.14 UT Operator Requirements

6.14.1 In satisfying the requirements of 6.2.7, the qualification of the ultrasonic testing operator shall include a specific and practical examination which shall be based on the requirements of this code. This examination shall require the ultrasonic operator to demonstrate ability to apply the rules of this code in the accurate detection and disposition of flaws.

6.14.2 The ultrasonic operator shall, prior to making the examination, be furnished or have access to relevant information regarding base metal type, weld joint geometry, material thickness, and welding processes used in making the weldment. Any subsequent record of repairs made to the weldment shall also be made available to the ultrasonic operator.

6.15 UT Equipment

6.15.1 The ultrasonic instrument shall be the pulse echo type suitable for use with transducers oscillating at frequencies between 1 and 6 MHz. The display shall be an "A" scan rectified video trace or other display acceptable to the Engineer or owner's Inspector.

6.15.2 The horizontal linearity of the test instrument shall be qualified over the full sound path distance to be used in testing in accordance with 6.15.9.1 and 6.15.10.

6.15.3 Test instruments shall include internal stabilization so that after warm-up, no variation in response greater than ±1 dB occurs with a supply voltage change of 15% nominal or, in the case of a battery, throughout the charge operating life. There shall be an alarm or meter to signal a drop in battery voltage prior to instrument shutoff due to battery exhaustion.

6.15.4 The test instrument shall have a calibrated gain control (attenuator) adjustable in discrete 1 or 2 dB steps over a range of at least 60 dB. The accuracy of the attenuator settings shall be within plus or minus 1 dB. The procedure for qualification shall be as described in 6.15.9.1 and 6.15.9.2.

6.15.5 The cyclic range of the instrument's display shall be such that a difference of 1 dB of amplitude can be easily detected on the display.

6.15.6 The optimum transducer size and frequency shall be selected by the UT technician in accordance with the written procedure. The transducer size may be as small as 1/4 in. [6.4 mm]; the frequency up to 6 MHz. Selection shall be based on the weldment design, material type, and discontinuity size rejection/acceptance requirements defined by the contract specification.

6.15.7 Straight beam (longitudinal wave) search unit transducers shall be round or square.

6.15.8 Angle beam search units shall consist of a transducer and an angle wedge. The unit may be comprised of the two separate elements or may be an integral unit.

6.15.8.1 The transducer crystal may be round, square or rectangular in shape. If rectangular, the maximum width to height ratio shall be 1.2 to 1.0 and the minimum width to height ratio shall be 1.0 to 1.0 (see Figure 6.8).

6.15.8.2 The search unit shall produce a sound beam in the material being tested within ±2° of that required by the written procedure.

6.15.8.3 Each search unit shall be marked to clearly indicate the frequency of the transducer, nominal angle of refraction, and index point.

6.15.8.4 The dimensions of the search unit shall be such that the distance from the leading edge of the search unit to the index point shall not exceed 1 in. [25 mm].

6.15.9 Equipment Qualification

6.15.9.1 The horizontal linearity of the test instrument shall be requalified after each 40 hours of instrument use in each of the distance ranges that the instrument will be used. The qualification procedure shall be in accordance with 6.15.10.

6.15.9.2 The instrument's gain control (attenuator) shall meet the requirements of 6.15.4 and shall be checked for correct calibration at two month intervals in accordance with 6.15.11. Alternative methods may be used for calibrated gain control (attenuator) qualification if proven at least equivalent with 6.15.11.

6.15.9.3 With the use of an approved calibration block, each angle beam search unit shall be checked after each eight hours of use to determine that the contact face is flat, that the sound entry point is correct, and that the beam angle is within the permitted plus or minus 2° tolerance. Search units which do not meet these requirements shall be corrected or replaced.

6.15.10 Horizontal Linearity: Procedure

Note: Since this qualification procedure is performed with a straight beam search unit which produces longitudinal waves with a sound velocity of almost double that of shear waves, it is necessary to double the shear wave distance ranges to be used in applying this procedure.

Example: The use of a 10 in. [250 mm] screen calibration in shear wave would require a 20 in. [500 mm] screen calibration for this qualification procedure. The following procedure shall be used for instrument qualification.

(1) A straight beam search unit shall be coupled meeting the requirements of 6.15.6 to the IIW or DS block in Position G, T, or U (see Annex H Figure H-1) as necessary to attain five back reflections in the qualification range being certified. The last of the five back reflections shall be located within the 80 to 100% portion of the screen width.

(2) The first and fifth back reflections shall be adjusted to their proper locations with use of the distance calibration and zero delay adjustments.

(3) Each indication shall be adjusted to reference level with the gain or attenuation control for horizontal location examination.

(4) Each intermediate trace deflection location shall be correct within 2% of the screen width.

6.15.11 dB Accuracy: Procedure

Note: In order to attain the required accuracy (±1%) in reading the indication height, the display must be graduated vertically at 2% intervals at horizontal mid-screen. These graduations shall be placed on the display between 60% and 100% of screen height. This may be accomplished with use of a graduated transparent screen overlay. If this overlay is applied as a permanent part of the ultrasonic unit, care shall be taken that the overlay does not obscure normal testing displays.

(1) A straight beam search unit shall be coupled, meeting the requirements of 6.15.6 at the DS block shown in Annex O Figure O.2 and position "T," Annex O Figure O.1.

(2) The distance calibration shall be adjusted so that the first 2 in. [50 mm] back reflection indication (hereafter called "the indication") is at horizontal mid-screen.

(3) The calibrated gain or attenuation control shall be adjusted so that the indication is exactly at or slightly above 40% screen height.

(4) The search unit shall be moved toward position U, see Annex O Figure O.1, until the indication is at exactly 40% screen height.

(5) The sound amplitude shall be increased 6 dB with the calibrated gain or attenuation control. The indication level theoretically shall be exactly at 80% screen height.

(6) The dB reading shall be recorded under "a" and actual % screen height under "b" from step 5 on the certification report (Annex O Form O-1, Line 1).

(7) The search unit shall be moved further toward position U, Annex O Figure O.1, until the indication is at exactly 40% screen height.

(8) Step 5 shall be repeated.

(9) Step 6 shall be repeated; except, information shall be applied to the next consecutive line on Annex O Form O-1.

(10) Steps 7, 8, and 9 shall be repeated consecutively until the full range of the gain control (attenuator) is reached (60 dB minimum).

(11) The information from columns "a" and "b" shall be applied to equation 6.15.11.1 or the nomograph described in 6.15.11.2 to calculate the corrected dB.

(12) Corrected dB from step 11 to column "c" shall be applied.

(13) Column "c" value shall be subtracted from Column "a" value and the difference in Column "d," dB error shall be applied.

Note: These values may be either positive or negative and so noted. Examples of Application of Forms O-1, O-2, and O-3 are found in Annex O.

(14) Information shall be tabulated on a form, including minimum equivalent information as displayed on Form O-1, and the unit evaluated in accordance with instruments shown on that form.

(15) Form O-2 provides a relatively simple means of evaluating data from item (14). Instructions for this evaluation are given in (16) through (18).

(16) The dB information from column "e" (Form O-1) shall be applied vertically and dB reading from column "a" (Form O-1) horizontally as X and Y coordinates for plotting a dB curve on Form O-2.

(17) The longest horizontal length, as represented by the dB reading difference, which can be inscribed in a rectangle representing 2 dB in height, denotes the dB range in which the equipment meets the code requirements. The minimum allowable range is 60 dB.

(18) Equipment that does not meet this minimum requirement may be used, provided correction factors are developed and used for flaw evaluation outside the instrument acceptable linearity range, or the weld testing and flaw evaluation is kept within the acceptable vertical linearity range of the equipment. Note: The dB error figures (Column "d") may be used as correction factor figures.

6.15.11.1 The following equation is used to calculate decibels:

$$dB_2 - dB_1 = 20 \times \text{Log}\left(\frac{\%_2}{\%_1}\right)$$

or

$$dB_2 = 20 \times \text{Log}\left(\frac{\%_2}{\%_1}\right) + dB_1$$

As related to Annex O Form O-1:

dB_1 = Column a
dB_2 = Column c
$\%_1$ = Column b
$\%_2$ = Defined on Form O-1

6.15.11.2 The following notes apply to the use of the nomograph in Annex O Form O-3:

(1) Columns a, b, c, d, and e are on certification sheet, Annex O Form O-1.

(2) The A, B, and C scales are on the nomograph, Annex O Form O-3.

(3) The zero points on the C scale must be prefixed by adding the necessary value to correspond with the instrument settings; i.e., 0, 10, 20, 30, etc.

6.15.11.3 Internal Reflections: Procedure

(1) Calibrate the equipment in accordance with 6.18.

(2) Remove the search unit from the calibration block without changing any other equipment adjustments.

(3) Increase the calibrated gain or attenuation 20 dB more sensitive than reference level.

(4) The screen area beyond 1/2 in. [12 mm] sound path and above reference level height shall be free of any indication.

6.16 UT Procedure

All UT shall be performed in accordance with a written procedure which shall contain, as a minimum, the following information regarding the UT method and examination techniques:

(1) The types of weld joint configurations to be examined

(2) Acceptance criteria for the types of weld joints to be examined

(3) Type of UT equipment (manufacturer, model and serial number)

(4) Type of transducer, including frequency, size, shape, angle and type of wedge

(5) Scanning surface preparation and couplant requirements

(6) Type of calibration test block(s) with the appropriate reference reflectors

(7) Method of calibration and calibration interval

(8) Method for examining for laminations prior to weld evaluation

(9) Weld root index marking and other preliminary weld marking methods

(10) Scanning pattern and sensitivity requirements

(11) Methods for determining discontinuity location, height, length and amplitude level

(12) Transfer correction methods for surface roughness, surface coatings and part curvature, if applicable

(13) Method of verifying the accuracy of the completed examination. This verification may be by retesting by UT, by others (audits), other NDT methods, macroetch specimen, gouging or other visual techniques, as may be approved by the Engineer

(14) Documentation requirements for examinations, including any verifications performed

(15) Documentation retention requirements

(16) Test data supporting the adequacy of the procedure

(17) Date, approval of procedure by the Engineer/ Level III

The written procedure shall be qualified by testing mock-up welds made by the same welding process and made from the same type of material, joint configuration and material thickness, which represent the production welds to be examined. The mock-up welds (Figure 6.11) shall be sectioned, properly examined, and documented to prove satisfactory performance of the procedure. The procedure and all qualifying data shall be approved by an individual who has been certified Level III in UT by testing in accordance with ASNT SNT-TC-1A and who is further qualified by experience in examination of the specific types of weld joints to be examined.

6.17 Reference Standard

The calibration block shall be of the same base metal type (see 1.2) and heat treatment condition as the material that will be used in production. The standard reflector shall be a 1.6 mm diameter side drilled hole or equivalent. The reflector may be placed in any design of calibration block, weld mock-up or actual production part at the option of the user. Orientation and tolerances for placement of the reflector are shown in Figure 6.9. Caution should be used in drilling the hole to make certain the hole is drilled with a sharp bit and is done by machine, not by hand. A recommended calibration block is shown in Figure 6.10. Alternate possible uses of the reflector are shown in Figure 6.11. When placed in weld mock-ups and sections of production weldments, the reflector shall be in locations where it is difficult to direct sound beams and through areas of largest expected metal grains, thereby ensuring detection of discontinuities in all areas of interest.

6.18 Calibration Methods

Calibration methods described herein are considered acceptable and are to be used for accomplishing these UT procedures. The code recognizes that other calibration methods may be preferred by the individual user. If other methods are used, they shall be at least equal to the methods recommended herein. The standard reflector described in 6.17 shall be considered the standard reflector for these and all other methods which might be used.

6.18.1 Standard Sensitivity. Standard sensitivity shall consist of the sum of the following:

(1) *Basic Sensitivity.* The maximized indication from the standard reflector, plus;

(2) *Distance Amplitude Correction.* Determined from indications from multiple standard reflectors at depths representing the minimum, middle and maximum to be examined, plus;

(3) *Transfer Correction.* Adjustment for material type, shape and scanning surface conditions as described below:

For precise sensitivity standardization, transfer correction shall be performed. This will ensure that the differences in acoustical properties, surfaces and part shape between the calibration standard the calibration block are utilized when performing the standard sensitivity calibration. Transfer correction values shall be determined initially before examination and when material type, shape, thickness and scanning surfaces vary such that different values exceeding ±25% of the original values are expected. Determine the transfer correction values as shown in Figure 6.12.

6.18.1.1 Scanning Sensitivity. Scanning sensitivity shall be standard sensitivity plus approximately 6 to 12 dB or as required to verify sound penetration from indications of surface reflections. Indication evaluation shall be performed with reference to the standard sensitivity except that standard sensitivity is not required if higher or lower sensitivity is more appropriate for determining the maximum discontinuity size (height and length).

6.18.2 Compression Wave

6.18.2.1 Depth (Horizontal Sweep). Use indications from multiple reflections obtained from the thickness of the calibration standard or from a gaged area of a mock-up or production weldment, as shown in Figure 6.13. Accuracy of calibration shall be within ±5% of actual thickness for examination of base metal for laminations and ±2% for determining discontinuity size (height) and location.

6.18.2.2 Sensitivity Calibration (Standard). Place the search unit over the standard reflectors at a minimum of 3 depths to ensure coverage throughout the thickness to be examined in accordance with Figure 6.14. Record the dB values obtained from the maximized indications from each reflector. Establish a distance amplitude curve (DAC) or use electronic methods to show the display indication locations which represent the standard reflector at the various thicknesses to be examined.

6.18.3 Shear Wave

6.18.3.1 Depth (Horizontal Sweep). Use indications from the selected standard reflectors to cover the maximum depth to be used during examination in accordance with Figure 6.15. Accuracy shall be within ±1% to facilitate the most accurate discontinuity height measurement. Use the delay technique for discontinuities with depth greater than approximately 1.5 in. [40 mm] to maximize the most accurate discontinuity depth reading (and discontinuity height) accuracy.

6.18.3.2 Sensitivity (Standard). Use standard reflectors located at the minimum, middle and maximum depths below the surface to be used for examination in accordance with Figure 6.15. Maximize indications and establish a DAC or use electronic methods to know the display indication locations which represent the standard reflector at the various depths selected. Adjust the DAC based upon the results of the transfer correction. The sensitivity calibration methods described herein are not essential when actual discontinuity size (height and length) is required. In this case, it is only necessary to maintain sufficient sensitivity throughout the part being examined so that all discontinuities are found and properly evaluated.

6.18.4 Recalibration. Recalibration shall be made after a change of operators, each 30 minute maximum time interval, or when the electrical circuitry is disturbed in any way which includes the following:

(1) Transducer change

(2) Battery change

(3) Electrical outlet change

(4) Coaxial cable change

(5) Power outage (failure)

6.19 Scanning Patterns and Methods

See Figure 6.16 for patterns and Figure 6.17 for methods.

6.19.1 Longitudinal Discontinuities

6.19.1.1 Scanning Movement A. Rotation angle a = 10°.

6.19.1.2 Scanning Movement B. Scanning distance b shall be such that the section of weld being tested is covered.

6.19.1.3 Scanning Movement C. Progression distance c shall be approximately one-half the transducer width.

6.19.2 Transverse Discontinuities

6.19.2.1 Scanning Pattern D is to be used when welds are ground flush.

6.19.2.2 Scanning Pattern E is to be used when the weld reinforcement is not ground flush. Scanning angle e = 15° max.

Note: The scanning pattern is to be such that the full weld section is covered.

6.20 Weld Discontinuity Characterization Methods

6.20.1 Discontinuities shall be characterized as follows:

(1) Spherical (individual pores and widely spaced porosity, nonelongated slag)

(2) Cylindrical (elongated slag, aligned pores of porosity, hollow beads)

(3) Planar (incomplete fusion, inadequate joint penetration, cracks)

6.20.2 The following methods shall be used for determining basic discontinuity characteristics:

6.20.2.1 Spherical. Sound is reflected equally in all directions. Indication remains basically unchanged as the search unit is moved around the spherical discontinuity as shown in Figure 6.18.

6.20.2.2 Cylindrical. Sound is reflected equally in one direction but is changed in other directions. Indication remains basically unchanged when the search unit is moved in one direction but is drastically changed when moved in other directions as shown in Figure 6.19.

6.20.2.3 Planar. Sound is reflected at its maximum from only one angle of incidence with one plane. Indication is changed with any angular movement of the search unit as shown in Figure 6.20. Indications from cracks typically have multiple peaks as a result of the many discontinuity facets usually present.

6.21 Weld Discontinuity Sizing and Location Methods

6.21.1 Calibration. Calibration shall be based upon depth from the surface in accordance with 6.18. Discontinuities may be sized with the highest achievable level of accuracy using the methods described in this clause; however, the user is reminded that UT, like all other NDT methods, provides relative discontinuity dimensions. Discontinuity orientation and shape, coupled with the limitations of the NDT method, may result in significant variations between relative and actual dimensions.

6.21.2 Height. Determine the discontinuity height (depth dimension) using the following methods:

6.21.2.1 Maximize the indication height by moving the search unit to and from the discontinuity in accordance with Figure 6.21(A). Adjust the indication height to a known value [e.g., 80% of full screen height (FSH)].

6.21.2.2 Move the search unit towards the discontinuity until the indication height begins to drop rapidly and continuously towards the base line. Stop and note the location of the leading (left) edge of the indication at location Figure 6.21(B) in relation to the display horizontal baseline scale. A 0.10 in. [2.54 mm] division scale or metric scale shall be used.

6.21.2.3 Move the search unit away from the discontinuity until the indication height begins to drop rapidly and continuously towards the baseline. Stop and note the location of the leading edge of the indication at location Figure 6.21(C) in relation to the display horizontal baseline scale.

6.21.2.4 Obtain the mathematical difference between B and C to determine the height dimension of the discontinuity.

6.21.3 Length. Determine the discontinuity length using the following methods:

6.21.3.1 Determine the orientation of the discontinuity by manipulation of the search unit to determine the plane and direction of the strongest indication in accordance with Figure 6.22(A).

6.21.3.2 Move the search unit to one end of the discontinuity while keeping part of the indication visible on the display at all times until the indication drops completely to the baseline. Move the search unit back towards the discontinuity until the indication height reaches 50% of the maximum height originally obtained near the end in accordance with Figure 6.22(B). Mark the location on the end of the discontinuity on the scanning surface or weld in line with the search unit maximum indication mark. Perform this marking carefully using a fine line marking method.

6.21.3.3 Repeat steps above for locating the opposite end of the discontinuity in accordance with Figure 6.22(C).

6.21.3.4 Obtain the length of the discontinuity by measuring the distance between the two marks in accordance with Figure 6.22.

6.21.4 Location-Depth Below the Scanning Surface. The depth location of discontinuities can be read directly from the display horizontal baseline scale when using the methods described above for determining discontinuity height. The reported location shall be the deepest point determined, unless otherwise specified, to assist in removal operations.

6.21.5 Location-Along the Length of the Weld. The location of the discontinuity from a known reference point can be determined by measuring the distance from the reference point to the discontinuity length marks established for the length. Measurement shall be made to the beginning of the discontinuity unless otherwise specified.

6.22 Interpretation Problems with Discontinuities

Users of UT for examination of welds should be aware of the following potential interpretation problems associated with weld discontinuity characteristics:

6.22.1 Type of Discontinuity. Ultrasonic sound has variable sensitivity to weld discontinuities depending upon their type. Relative sensitivity is shown in the following tables and shall be considered during evaluation of discontinuities. The UT technician can change sensitivity to all discontinuity types by changing UT instrument settings, search unit frequency, and size and scanning methods, including scanning patterns and coupling.

Discontinuity Type	Relative UT Sensitivity
(1) Incomplete fusion	Highest
(2) Cracks (surface)	.
(3) Inadequate penetration	.
(4) Cracks (sub-surface)	.
(5) Slag (continuous)	.
(6) Slag (scattered)	.
(7) Porosity (piping)	.
(8) Porosity (cluster)	.
(9) Porosity (scattered)	Lowest

6.22.2 General Classification of Discontinuities

General Classification of Discontinuity	Relative UT Sensitivity
(1) Planar	Highest
(2) Linear	.
(3) Spherical	Lowest

Note: The above tabulation assumes best orientation for detection and evaluation.

6.22.3 Size. Discontinuity size affects accurate interpretation. Planar-type discontinuities with large height or very little height may provide less accurate interpretation than those of medium height. Small, spherical pores are difficult to size because of the rapid reflecting surface changes which occur as the sound beam is moved across the part.

6.22.4 Orientation. Discontinuity orientation affects UT sensitivity since the highest sensitivity is one that reflects sound more directly back to the search unit. Relative sensitivities in regards to orientation and discontinuity types are opposite those shown in the previous tables. The UT technician can increase sensitivity to discontinuity orientation by selecting a sound beam angle which is more normal to the discontinuity plane and reflecting surface. The selection of angles which match the groove angle will increase sensitivity for planar- and linear-type discontinuities which are most likely to occur along that plane.

6.22.5 Location. Discontinuity location within the weld and adjacent base metal can influence the capability of detection and proper evaluation. Discontinuities near the surface are often more easily detected but may be more difficult to size.

6.22.6 Weld Joint Type and Groove Design. The weld joint and groove design are important factors affecting the capabilities of UT for detecting discontinuities. The following are design factors which can cause problems and shall be considered for their possible affects:

(1) Backings

(2) Bevel angles

(3) Joint member angles of intercept

(4) Partial penetration welds

(5) T-welds

(6) Tubular members

(7) Weld surface roughness and contour

6.23 Weld Classes and Amplitude Level

6.23.1 Weld Classes. Welds are classified by four categories:

(1) Statically loaded

(2) Cyclically loaded

(3) Tubular Class R, Statically Loaded

(4) Tubular Class X, Cyclically Loaded

6.23.2 Discontinuity Amplitude Levels. The following discontinuity amplitude level categories should be applied in evaluation of acceptability:

Level	Description
1	Equal to or greater than SSL (see Figure 6.23)
2	Between the SSL and the DRL (see Figure 6.23)
3	Equal to or less than the DRL (see Figure 6.23)

Standard Sensitivity Level = SSL—per 6.18.1
Disregard Level = DRL = 6 dB less than SSL

6.24 Acceptance-Rejection Criteria

6.24.1 Amplitude. The acceptance-rejection criteria of Table 6.4 shall apply when amplitude and length are the major factors and maximum discontinuity height is not known or specified.

6.24.2 Size. When maximum allowable discontinuity size (height and length) are known and are specified by the Engineer, the actual size (both height and length) along with location (depth and distance along the weld) shall be determined and reported. Final evaluation and acceptance/rejection shall be by the Engineer or his/her designee.

6.25 Preparation and Disposition of Reports

A report shall be made which clearly identifies the work and the area of examination by the ultrasonic operator at the time of examination. The report, as a minimum, shall contain the information shown on the sample report form, Figure 6.24. UT discontinuity characterization and subsequent categorization and reporting shall be limited to spherical, cylindrical, and planar only.

When specified, discontinuities approaching rejectable size, particularly those about which there is some doubt in their evaluation, shall be reported.

Before a weld subject to ultrasonic examination by the contractor for the owner is accepted, all report forms pertaining to the weld, including any that show unacceptable quality prior to repair, shall be submitted to the owner upon completion of the work. The contractor`s obligation to retain ultrasonic reports shall cease (1) upon delivery of a full set to the owner, or (2) one full year after completion of the contractor`s work, provided the owner is given prior written notice.

Part D
Other Examination Methods

6.26 General

6.26.1 This part contains Nondestructive Testing (NDT) methods not contained in Parts B and C of Clause 6 of this code. The NDT methods set for this Part D require written procedures, qualifications, and specific written approval of the Engineer.

6.27 Radiation Imaging Systems Including Real-Time Imaging

6.27.1 General. Examination of welds may be performed using ionizing radiation methods other than radiography, such as electronic imaging, including real-time imaging systems, when so approved by the Engineer. Sensitivity of such examination as seen on the monitoring equipment (when used for acceptance and rejection) and the recording medium shall be no less than that required for radiography.

6.27.2 Procedures. Written procedures shall contain the following essential variables:

(1) Specific equipment identification including manufacturer, make, model, and serial number

(2) Specific radiation and imaging control settings for each combination of variables established herein

(3) Weld thickness ranges

(4) Weld joint types

(5) Scanning speed

(6) Radiation source to weld distance

(7) Image conversion screen to weld distance

(8) Angle of X-rays through the weld (from normal)

(9) IQI location (source side or screen side)

(10) Type of recording medium (video recording, photographic still film)

(11) Computer enhancement (if used)

(12) Width of radiation beam

6.27.3 Procedure Qualification. Procedures shall be qualified by testing the radiation, imaging, and recording system to establish and record all essential variables and conditions. Qualification testing shall consist of demonstrating that each combination of essential variables or ranges of variables can provide the minimum required sensitivity. Test results shall be recorded on the medium that is to be used for production examination. Procedures shall be approved by an individual qualified as ASNT SNT-TC-1A, Level III (see 6.27.4) and by the Engineer.

6.27.4 Personnel Qualifications. In addition to the personnel qualifications of 6.2, the following qualifications shall apply:

(1) Level III—shall have a minimum of six months experience using the same or similar equipment and procedures for examination of welds in structural or piping stainless steel.

(2) Levels I and II—shall be certified by the Level III above and have a minimum of three months experience using the same or similar equipment and procedures for examination of welds in structural or piping stainless steel. Qualification shall consist of written and practical examinations for demonstrating capability to use the specific equipment and procedures to be used for production examination.

6.27.5 Image Quality Indicator. The wire type image quality indicator (IQI), as described in Part B, shall be used. IQI placement shall be as specified in Part B for static examination. For in-motion examination, placement shall be as follows:

(1) Two IQIs positioned at each end of area of interest and tracked with the run.

(2) One IQI at each end of the run and positioned at a distance no greater than 10 ft [3 m] between any two IQIs during the run.

6.27.6 Image Enhancement. Computer enhancement of images is acceptable for improving the image and obtaining additional information providing required minimum sensitivity is maintained. Recorded enhanced images shall be clearly marked that enhancement was used and give the enhancement procedures.

6.27.7 Records. Radiation imaging examinations which are used for acceptance or rejection of welds shall be recorded on an acceptable medium. The recorded images shall be in-motion or static, whichever are used to accept or reject the welds. A written record shall be included with the recorded images giving the following information as a minimum.

(1) Identification and description of welds examined

(2) Procedure(s) used

(3) Equipment used

(4) Locations of the welds within the recorded medium

(5) Results, including a list of unacceptable welds and repairs and their locations within the recorded medium

Part E
Quality of Welds

6.28 Quality of Welds—Statically Loaded

The weld quality acceptance/rejection criteria of this subclause is limited to austenitic stainless steel. When inspecting other types/grades of stainless steel, the acceptance/rejection criteria shall be defined by the Engineer. For material approved by this code other than austenitic types/grades see nonmandatory Annex H for additional information.

6.28.1 Visual Inspection. All welds shall be visually inspected and shall be acceptable if the following conditions are satisfied:

6.28.1.1 The weld shall have no cracks.

6.28.1.2 Thorough fusion shall exist between adjacent layers of weld metal and between weld metal and base metal.

6.28.1.3 All craters shall be filled to the full cross section of the weld, except for the ends of fillet welds outside their effective length.

6.28.1.4 Weld profiles shall be in accordance with 5.11.

6.28.1.5 Undercut shall not exceed the following dimensions:

(1) 0.01 in. [0.25 mm] for material less than 3/16 in. [5 mm]

(2) 1/32 in. [1 mm] for material equal to or greater than 3/16 in. [5 mm] and less than 1 in. [25 mm]

(3) 1/16 in. [2 mm] is permitted for an accumulated length of 2 in. [50 mm] in any 12 in. [300 mm] in material greater than 1/2 in. [12 mm]

(4) 1/16 in [2 mm] for material equal to or greater than 1 in. [25 mm]

6.28.1.6 The sum of diameters of visible piping porosity 1/32 in. [1 mm] or greater in fillet welds shall not exceed 3/8 in. [10 mm] in any linear inch of weld and shall not exceed 3/4 in. [20 mm] in any 12 in. [300 mm] length of weld. *Note: Visible piping porosity may not be acceptable due to corrosion or appearance considerations or the need for a leak proof weld.*

6.28.1.7 The fillet weld in any single continuous weld may be less than the specified fillet size by up to and including 1/16 in. [2 mm] without correction, provided that the undersize portion of the weld does not exceed 10% of the length of the weld. On web-to-flange welds on girders, fillet weld sizes less than the specified size shall be prohibited at the end for a length equal to twice the width of the flange.

6.28.1.8 Complete joint penetration groove welds in butt joints transverse to the direction of computed tensile stress shall have no visible piping porosity. For all other groove welds, the sum of the visible piping porosity 1/32 in. [1 mm] or greater in diameter shall not exceed 3/8 in. [10 mm] in any linear inch of weld and shall not exceed 3/4 in. [20 mm] in any 12 in. [300 mm] length of weld.

6.28.1.9 Visual inspection of welds in all steels may begin immediately after the completed welds have cooled to ambient temperature.

6.28.2 Radiographic Testing

6.28.2.1 When subject to radiographic testing in addition to visual inspection, welds shall have no cracks. Other discontinuities shall be evaluated on the basis of being either elongated or rounded. Regardless of the type of discontinuity, an elongated discontinuity is one in which its length exceeds three times its width. A rounded discontinuity is one in which its length is three times its width or less and may be round or irregular and may have tails.

6.28.2.2 Discontinuities as shown on radiographs that exceed the following limitations shall be unacceptable (E = weld size.)

(1) Elongated discontinuities exceeding the maximum size of Annex E Figure E.1.

(2) Discontinuities closer than the minimum clearance allowance of Annex E Figure E.1.

(3) Rounded discontinuities greater than a maximum of size of E/3, not to exceed 1/4 in. [6 mm]. However, when the thickness is greater than 2 in. [50 mm], the maximum rounded indication may be 3/8 in. [10 mm]. The minimum clearance of this type of discontinuity greater than or equal to 3/32 in. [2.5 mm] to an acceptable elongated or rounded discontinuity or to an edge or end of an intersecting weld shall be three times the greatest dimension of the larger of the discontinuities being considered.

(4) Isolated discontinuities such as a cluster of rounded indications, having a sum of their greatest dimensions exceeding the maximum size single discontinuity permitted in Annex E Figure E.1. The minimum clearance to another cluster or an elongated or rounded discontinuity or to an edge or end of an intersecting weld shall be three times the greatest dimension of the larger of the discontinuities being considered.

(5) The sum of individual discontinuities each having a greater dimension of less than 3/32 in. [2.5 mm] shall not exceed 2E/3 or 3/8 in. [10 mm], whichever is less, in any linear 1 in. [25 mm] of weld. This requirement is independent of (1), (2), and (3) above.

(6) In-line discontinuities, where the sum of the greatest dimensions exceeds E in any length of 6E. When the length of the weld being examined is less than 6E, the permissible sum of the greatest dimension shall be proportionally less.

6.28.2.3 Annex E Figure E.2 and Annex E Figure E.3 illustrate the application of the requirements given in 6.28.2.2.

6.28.3 Ultrasonic Testing. Welds that are subject to ultrasonic testing, in addition to visual inspection, shall be acceptable if they meet the requirements of Table 6.4.

6.28.4 Liquid Penetrant Testing. Welds that are subject to liquid penetrant testing, in addition to visual inspection, shall be evaluated on the basis of the requirement for visual inspection. The testing shall be performed in accordance with 6.7.6.

When welds are subject to nondestructive testing, the testing may begin immediately after the completed welds have cooled to ambient temperature.

6.29 Quality of Welds—Cyclically Loaded

The weld quality acceptance/rejection criteria of this subclause is limited to austenitic stainless steel. When inspecting other types/grades of stainless steel, the acceptance/rejection criteria shall be defined by the Engineer. For material approved by this code other than austenitic types/grades, see nonmandatory Annex H for additional information.

6.29.1 Visual Inspection. All welds shall be visually inspected and shall be acceptable if the following conditions are satisfied:

6.29.1.1 The weld shall have no cracks.

6.29.1.2 Thorough fusion shall exist between adjacent layers of weld metal and between weld metal and base metal.

6.29.1.3 All craters shall be filled to the full cross section of the weld, except for the ends of intermittent fillet welds outside of their effective length.

6.29.1.4 Weld profiles shall be in accordance with 5.11.

6.29.1.5 In primary members, as defined in contract documents, undercut shall be no more than 0.01 in. [0.25 mm] deep when the weld is transverse to tensile stress under any design loading condition, as shown on the drawing. Undercut shall be no more than 1/32 in. [1 mm] deep for all other cases.

6.29.1.6 The frequency of piping porosity in fillet welds shall not exceed one in each 4 in. [100 mm] of weld length and the maximum diameter shall not exceed 3/32 in. [2.5 mm]. Exception: for fillet welds connecting stiffeners to web, the sum of the diameters of piping porosity shall not exceed 3/8 in. [10 mm] in any linear inch of weld and shall not exceed 3/4 in. [20 mm] in any 12 in. [300 mm] length of weld.

6.29.1.7 A fillet weld in any single continuous weld shall be permitted to underrun the nominal fillet weld size specified by 1/16 in. [2 mm] without correction, provided that the undersize portion of the weld does not exceed 10% of the length of the weld. On the web-to-flange welds on girders, no underrun is permitted at the ends for a length equal to twice the width of the flange.

6.29.1.8 Complete joint penetration groove welds in butt joints transverse to the direction of computed tensile stress shall have no piping porosity. For all other groove welds, the frequency of piping porosity shall not exceed one in 4 in. [100 mm] of length and the maximum diameter shall not exceed 3/32 in. [2.5 mm].

6.29.1.9 Visual inspection of welds in all steels may begin immediately after the completed welds have cooled to ambient temperature.

6.29.2 Radiographic Testing. Welds that are subject to radiographic testing in addition to visual inspection shall have no cracks and shall be unacceptable if the radiograph shows any of the types of discontinuities listed.

6.29.2.1 For welds subject to tensile stress under any condition of loading, the greatest dimension of any porosity of fusion type discontinuity that is 1/16 in. [2 mm] or larger in greatest dimension shall not exceed the size, B, indicated in Annex E Figure E.4, for the weld size involved. The distance from any porosity or fusion type discontinuity described above to such discontinuity, to an edge, or to the toe or root of any intersecting flange-to-web weld shall be not less than the minimum clearance allowed, C, indicated in Annex E Figure E.4 for the size of discontinuity under examination.

6.29.2.2 For welds subject to compressive stress only and specifically indicated as such on the design drawings, the greatest dimension of porosity or a fusion type discontinuity that is 1/8 in. [3 mm] or larger in greatest dimension shall not exceed the size, B, nor shall the space between adjacent discontinuities be less than the minimum clearance allowed, C, indicated by Annex E Figure E.5 for the size of discontinuity under examination.

6.29.2.3 Independent of the requirements of 6.29.2.1 and 6.29.2.2, discontinuities having a great dimension of less than 1/16 in. [2 mm] shall be unacceptable if the sum of their greatest dimensions exceeds 3/8 in. [10 mm] in any linear inch of weld.

6.29.2.4 The limitations given by Annex E Figures E.4 and E.5 for 1-1/2 in. [40 mm] weld size shall apply to all weld sizes greater than 1-1/2 in. [40 mm] in thickness.

6.29.2.5 Annex E illustrates the application of the requirements given in 6.29.2.1.

6.29.3 Ultrasonic Testing

6.29.3.1 Welds that are subject to ultrasonic testing in addition to visual inspection are acceptable if they meet the requirements of Table 6.4.

6.29.4 Liquid Penetrant Testing. Welds that are subject to liquid penetrant testing, in addition to visual inspection, shall be evaluated on the basis of the requirements for visual inspection.

6.29.5 When welds are subject to nondestructive testing, in accordance with 6.29.2, 6.29.3, and 6.29.4, the testing may begin immediately after the completed welds have cooled to ambient temperature.

Table 6.1
Hole-Type Image Quality Indicator (IQI) Requirements (see 6.10.7)

Nominal Material Thickness[a] Range, in.	Nominal Material Thickness[a] Range, mm	Source Side Designation	Source Side Essential Hole	Film Side[a] Designation	Film Side[a] Essential Hole
Up to 0.25 incl.	Up to 6 incl.	10	4T	7	4T
Over 0.25 to 0.375	Over 6 through 10	12	4T	10	4T
Over 0.375 to 0.50	Over 10 through 12	15	4T	12	4T
Over 0.50 to 0.625	Over 12 through 16	15	4T	12	4T
Over 0.625 to 0.75	Over 16 through 20	17	4T	15	4T
Over 0.75 to 0.875	Over 20 through 22	20	4T	17	4T
Over 0.875 to 1.00	Over 22 through 25	20	4T	17	4T
Over 1.00 to 1.25	Over 25 through 32	25	4T	20	4T
Over 1.25 to 1.50	Over 32 through 38	30	2T	25	2T
Over 1.50 to 2.00	Over 38 through 50	35	2T	30	2T
Over 2.00 to 2.50	Over 50 through 65	40	2T	35	2T
Over 2.50 to 3.00	Over 65 through 75	45	2T	40	2T
Over 3.00 to 4.00	Over 75 through 100	50	2T	45	2T
Over 4.00 to 6.00	Over 100 through 150	60	2T	50	2T
Over 6.00 to 8.00	Over 150 through 200	80	2T	60	2T

[a] Single-wall radiographic thickness (for tubulars).
[b] Applicable to tubular structures only.

Table 6.2
Wire Image Quality Indicator (IQI) Requirements (see 6.10.7)

Nominal Material Thickness[a] Range, in.	Nominal Material Thickness[a] Range, mm	Source Side Maximum Wire Diameter in.	Source Side Maximum Wire Diameter mm	Film Side[b] Maximum Wire Diameter in.	Film Side[b] Maximum Wire Diameter mm
Up to 0.25 incl.	Up to 6 incl.	0.010	0.25	0.008	0.20
Over 0.25 to 0.375	Over 6 to 10	0.013	0.33	0.010	0.25
Over 0.375 to 0.625	Over 10 to 16	0.016	0.41	0.013	0.33
Over 0.625 to 0.75	Over 16 to 20	0.020	0.51	0.016	0.41
Over 0.75 to 1.50	Over 20 to 38	0.025	0.63	0.020	0.51
Over 1.50 to 2.00	Over 38 to 50	0.032	0.81	0.025	0.63
Over 2.00 to 2.50	Over 50 to 65	0.040	1.02	0.032	0.81
Over 2.50 to 4.00	Over 65 to 100	0.050	1.27	0.040	1.02
Over 4.00 to 6.00	Over 100 to 150	0.063	1.60	0.050	1.27
Over 6.00 to 8.00	Over 150 to 200	0.100	2.54	0.063	1.60

[a] Single-wall radiographic thickness (for tubulars).
[b] Applicable to tubular structures only.

Table 6.3
IQI Selection and Placement

	Equal ≥ 10 in. [250 mm] L		Equal T < 10 in. [250 mm] L		Unequal ≥ 10 in. [250 mm] L		Unequal T < 10 in. [250 mm] L	
IQI Types	Hole	Wire	Hole	Wire	Hole	Wire	Hole	Wire
Number of IQIs								
Nontubular	2	2	1	1	3	2	2	1
Pipe Girth (Notes c, d)	3	3	3	3	3	3	3	3
ASTM Standard Selection	E 1025	E 747	E 1025	E 747	E 1025	E 747	E 1025	E 747
Table	6.1	6.2	6.2	6.2	6.1	6.2	6.1	6.2
Figures	6.1		6.2		6.3		6.4	

T = Nominal base metal thickness (T1 and T2 of Figures) (see Notes a and b, below).
L = Weld Length in area of interest of each radiograph.

[a] Steel backing shall not be considered part of the weld or weld reinforcement in IQI selection.
[b] T may be increased to provide for the thickness of allowable weld reinforcement provided shims are used under hole IQIs per 6.10.3.
[c] When a complete circumferential pipe weld is radiographed with a single exposure and the radiation source is placed at the center of the curvature, at least three equally spaced hole type IQIs shall be used.
[d] Optimal film-side placement may be used with the application of a one value decrease of the IQI.

Table 6.4
UT Acceptance-Rejection Criteria (see 6.24.1)

Maximum Discontinuity Amplitude Level Obtained	Maximum Discontinuity Lengths by Weld Classes: Statically Loaded	Cyclically Loaded	Tubular Class R—Statically Loaded	Tubular Class X—Cyclically Loaded
Level 1—Equal to or greater than SSL (see 6.18.1 and Figure 6.24)	> 5 dB above SSL = none allowed 0 through 5 dB above SSL = 3/4 in. [20 mm]	> 5 dB above SSL = none allowed 0 through 5 dB above SSL = 1/2 in. [12 mm]	See Figure E.6, Annex E	See Figure E.7 (Utilizes height), Annex E
Level 2—Between the SSL and the DRL (see Figure 6.24)	2 in. [50 mm]	Middle 1/2 of weld = 2 in. [50 mm] Top and bottom 1/4 of weld = 3/4 in. [20 mm]	See Figure E.6, Annex E	See Figure E.7 (Utilizes height), Annex E
Level 3—Equal to or less than the DRL (see Figure 6.24)	Disregard (when specified by the Engineer, record for information)			

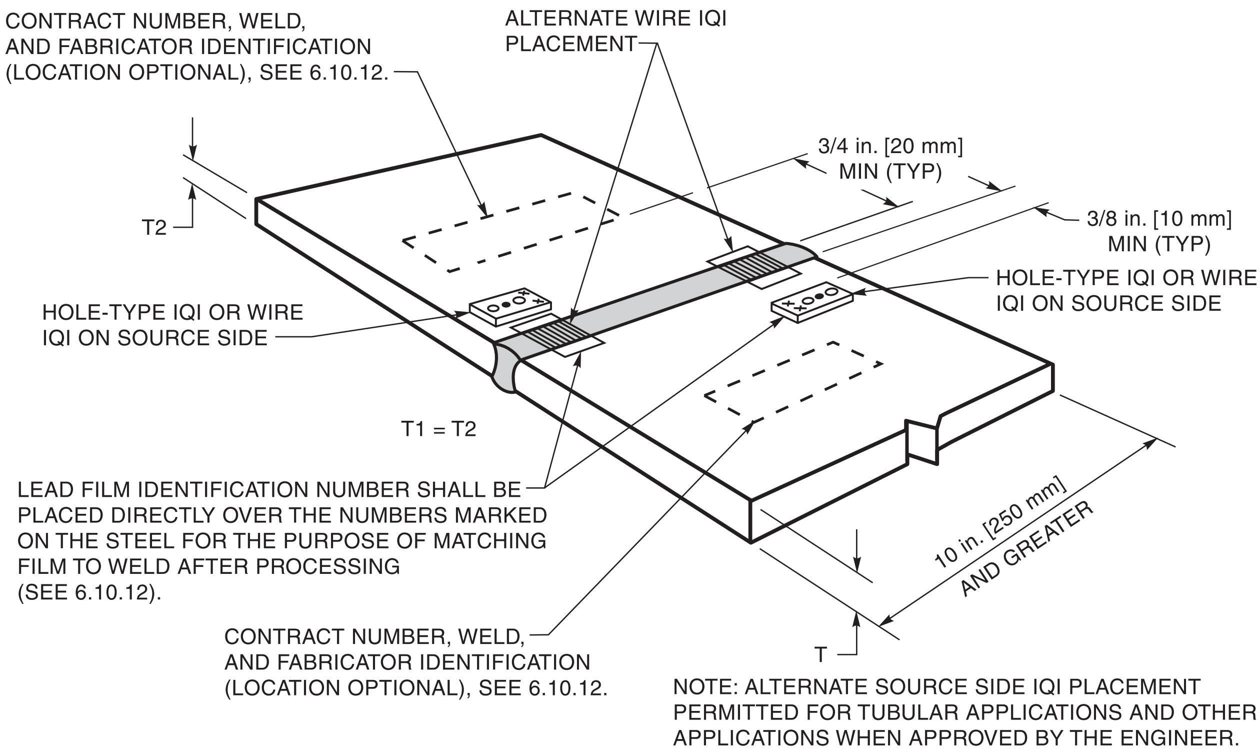

Figure 6.1—Radiographic Identification and Hole-Type or Wire IQI Locations on Approximately Equal Thickness Joints 10 in. [250 mm] and Greater in Length (see 6.10.7)

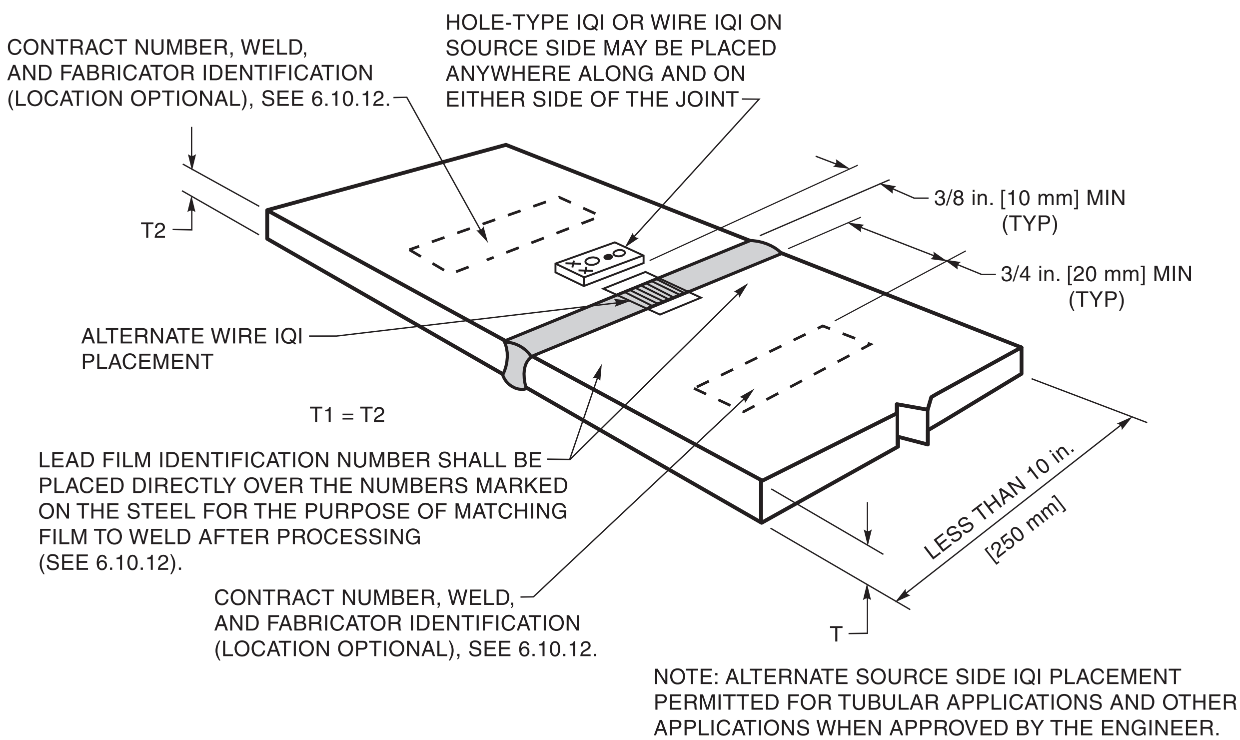

Figure 6.2—Radiographic Identification and Hole-Type or Wire IQI Locations on Approximately Equal Thickness Joints Less Than 10 in. [250 mm] in Length (see 6.10.7)

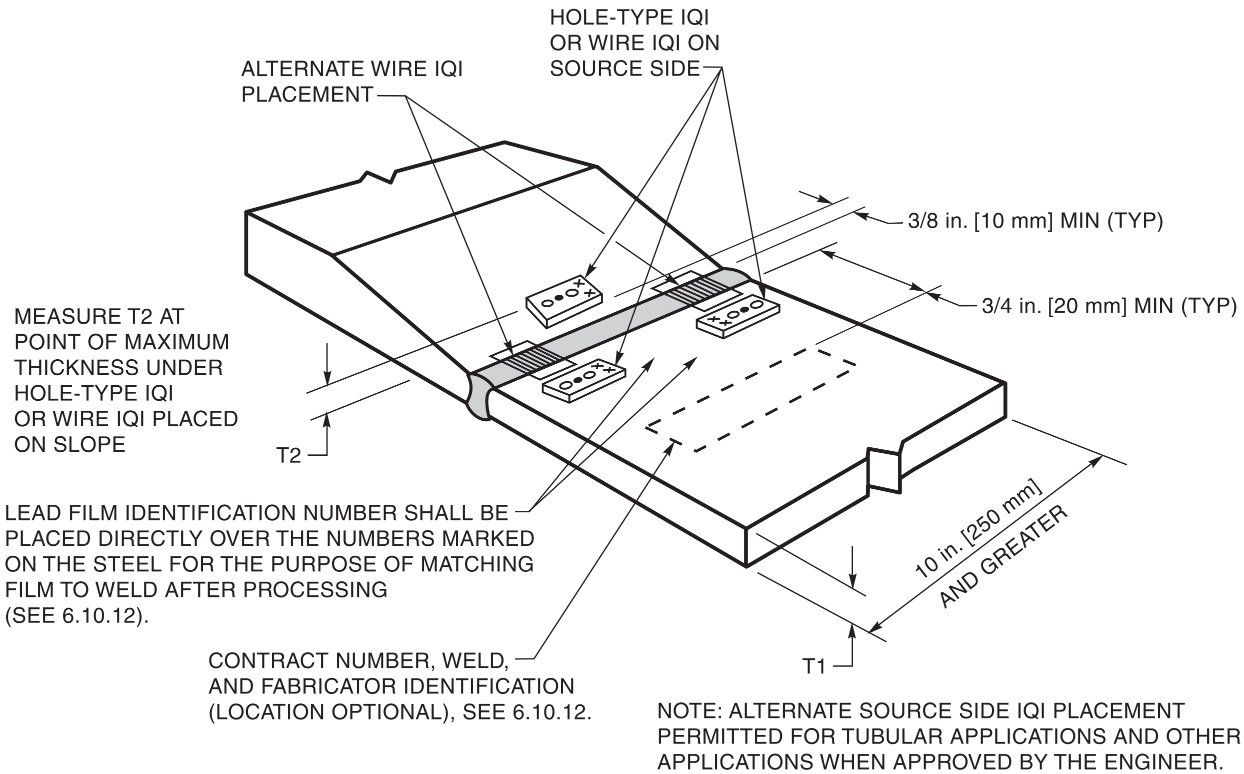

Figure 6.3—Radiographic Identification and Hole-Type or Wire IQI Locations on Transition Joints 10 in. [250 mm] and Greater in Length (see 6.10.7)

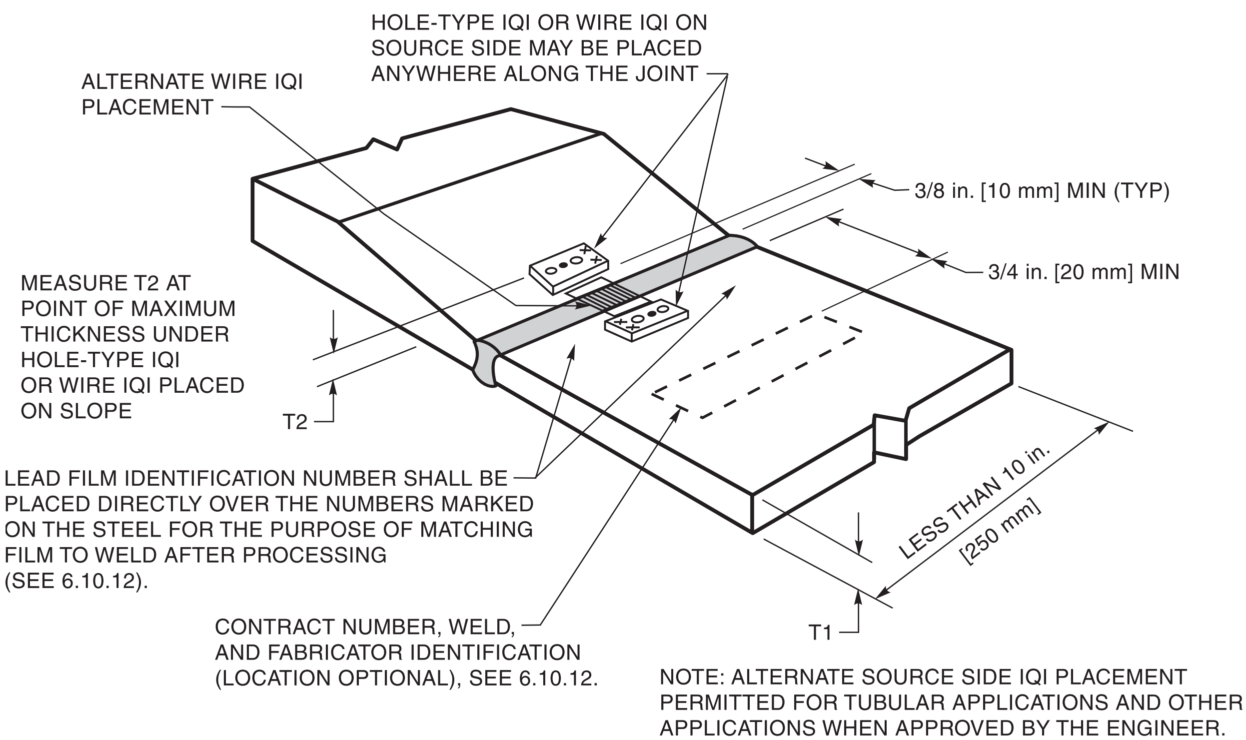

Figure 6.4—Radiographic Identification and Hole-Type or Wire IQI Locations on Transition Joints Less Than 10 in. [250 mm] in Length (see 6.10.7)

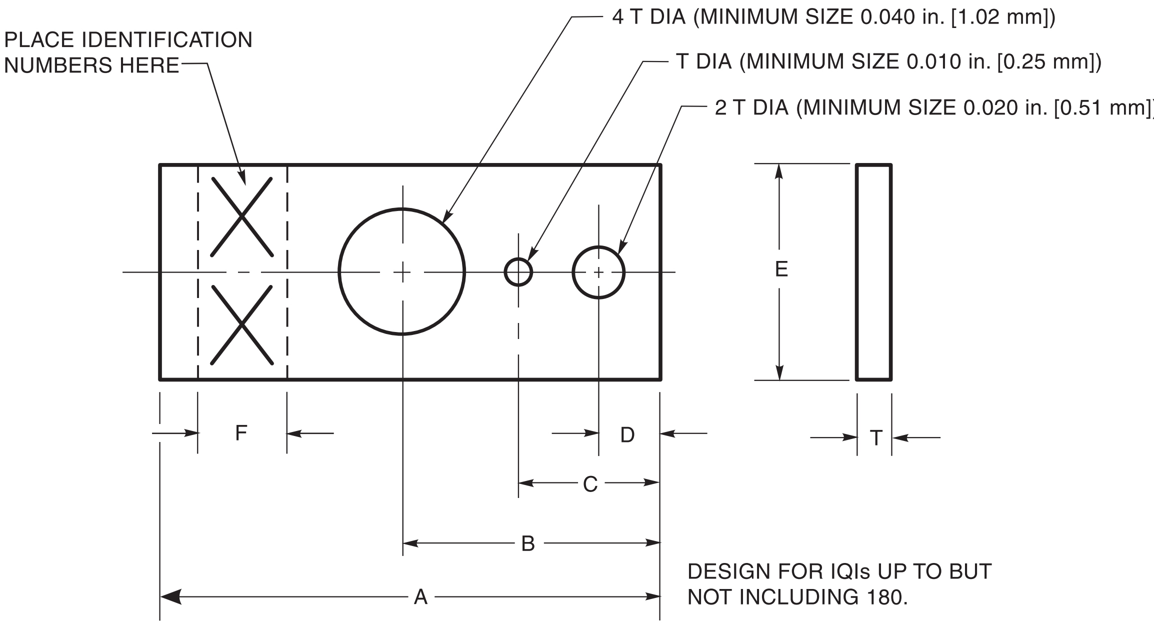

Table of Dimensions of IQI (in.)

Number	A	B	C	D	E	F	IQI Thickness and Hole Diameter Tolerances
5–20	1.500 ±0.015	0.750 ±0.015	0.438 ±0.015	0.250 ±0.015	0.500 ±0.015	0.250 ±0.030	±0.0005
21–59	1.500 ±0.015	0.750 ±0.015	0.438 ±0.015	0.250 ±0.015	0.500 ±0.015	0.250 ±0.030	±0.0025
60–179	2.250 ±0.030	1.375 ±0.030	0.750 ±0.030	0.375 ±0.030	1.000 ±0.030	0.375 ±0.030	±0.005

Table of Dimensions of IQI (mm)

Number	A	B	C	D	E	F	IQI Thickness and Hole Diameter Tolerances
5–20	38.10 ±0.38	19.05 ±0.38	11.13 ±0.38	6.35 ±0.38	12.70 ±0.38	6.35 ±0.80	±0.013
21–59	38.10 ±0.38	19.05 ±0.38	11.13 ±0.38	6.35 ±0.38	12.70 ±0.38	6.35 ±0.80	±0.06
60–179	57.15 ±0.80	34.92 ±0.80	19.05 ±0.80	9.52 ±0.80	25.40 ±0.80	9.52 ±0.80	±0.13

Notes:
1. IQIs No. 5 through 9 are not 1T, 2T, and 4T.
2. Holes shall be true and normal to the IQI. Do not chamfer.

Figure 6.5—Hole-Type Image Quality Indicator (IQI) Design (see 6.10.1)

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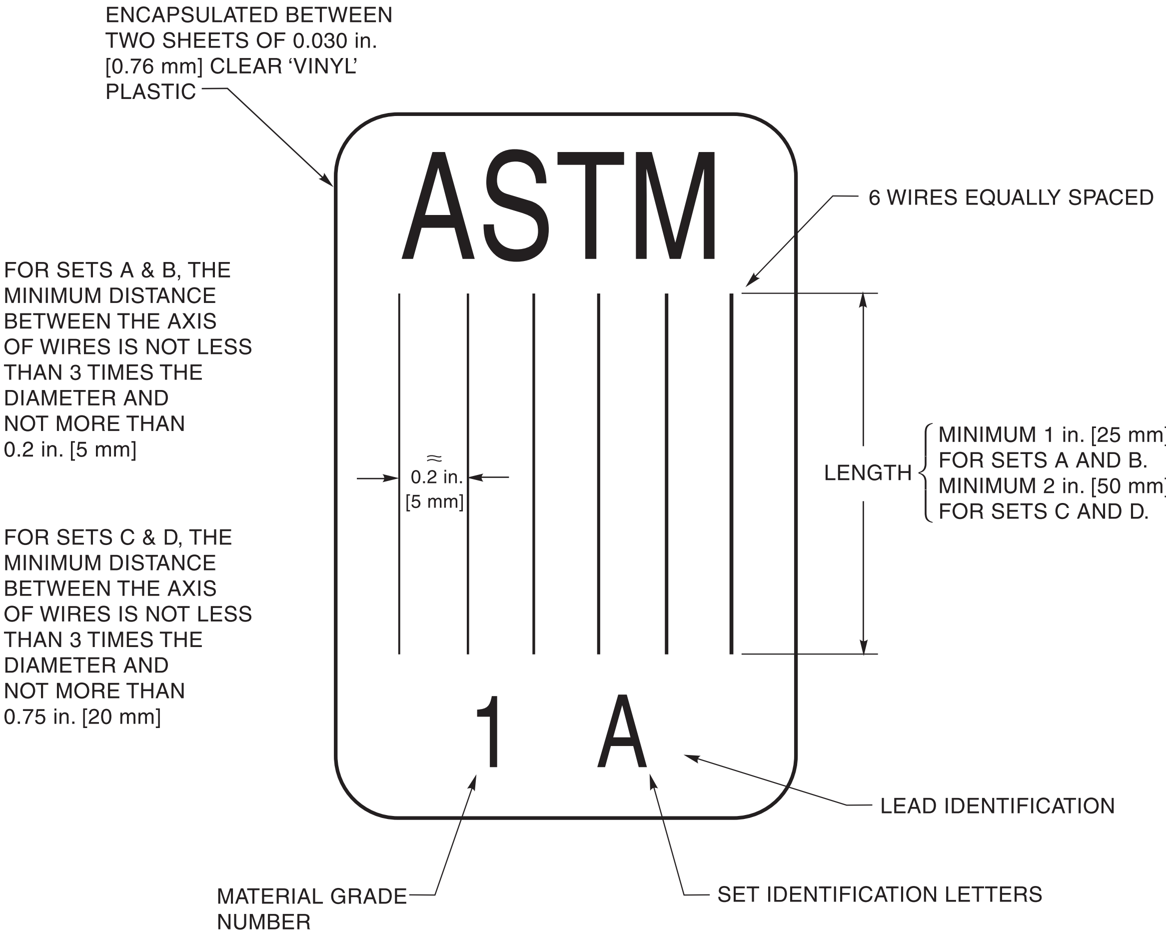

Image Quality Indicator Sizes

Wire Diameter, in. [mm]			
Set A	Set B	Set C	Set D
0.0032 [0.08]	0.010 [0.25]	0.032 [0.81]	0.10 [2.5]
0.004 [0.1]	0.013 [0.33]	0.040 [1.02]	0.125 [3.2]
0.005 [0.13]	0.016 [0.4]	0.050 [1.27]	0.160 [4.06]
0.0063 [0.16]	0.020 [0.51]	0.063 [1.6]	0.20 [5.1]
0.008 [0.2]	0.025 [0.64]	0.080 [2.03]	0.25 [6.4]
0.010 [0.25]	0.032 [0.81]	0.100 [2.5]	0.32 [8]

Figure 6.6—Wire Image Quality Indicator (see 6.10.1)

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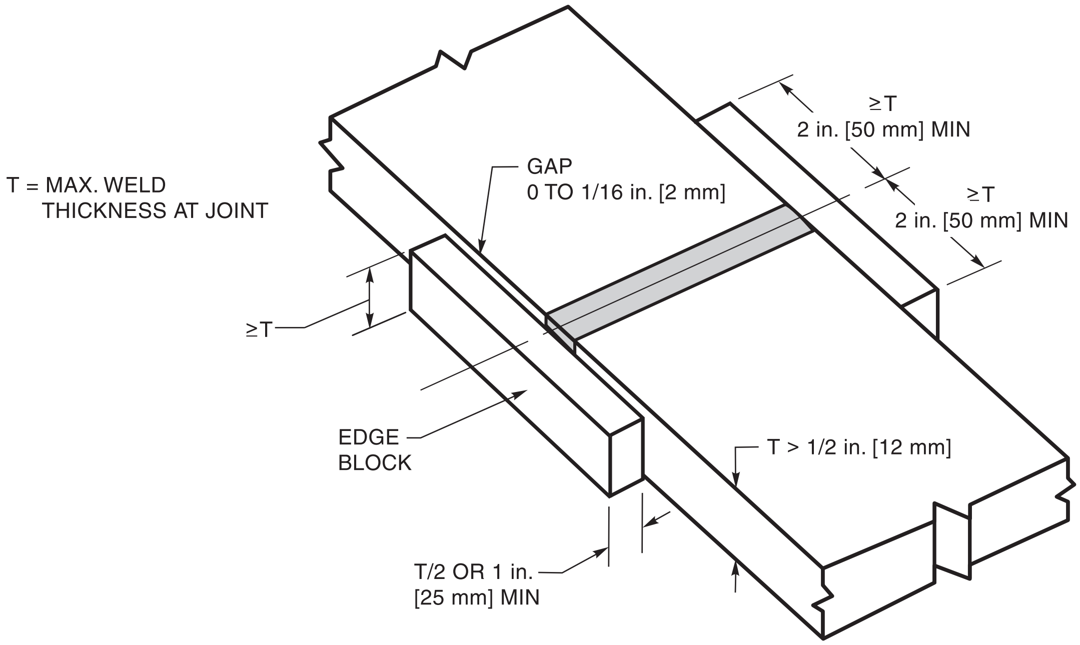


Figure 6.7—Radiographic Edge Blocks (see 6.10.13)

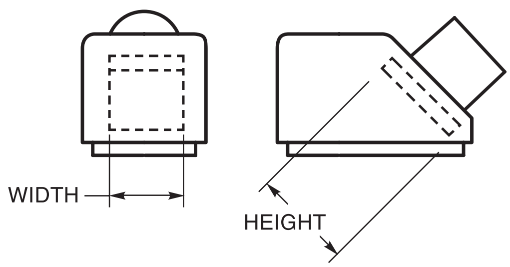
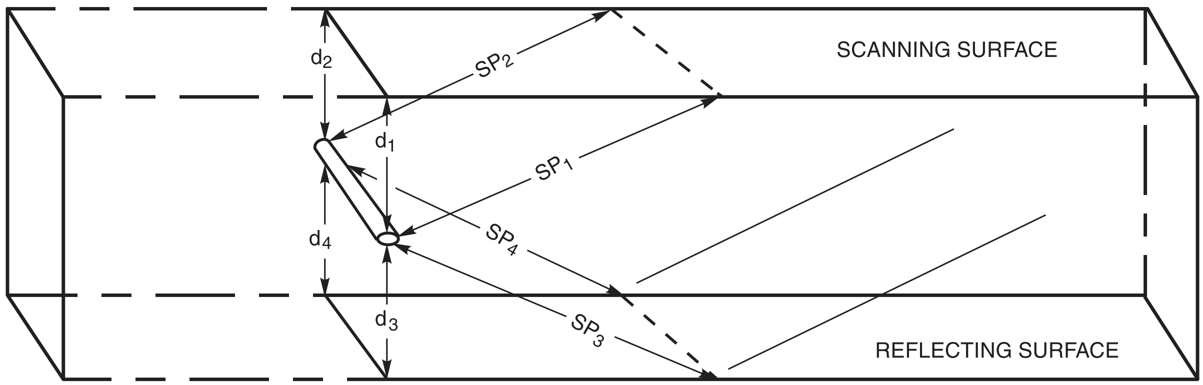
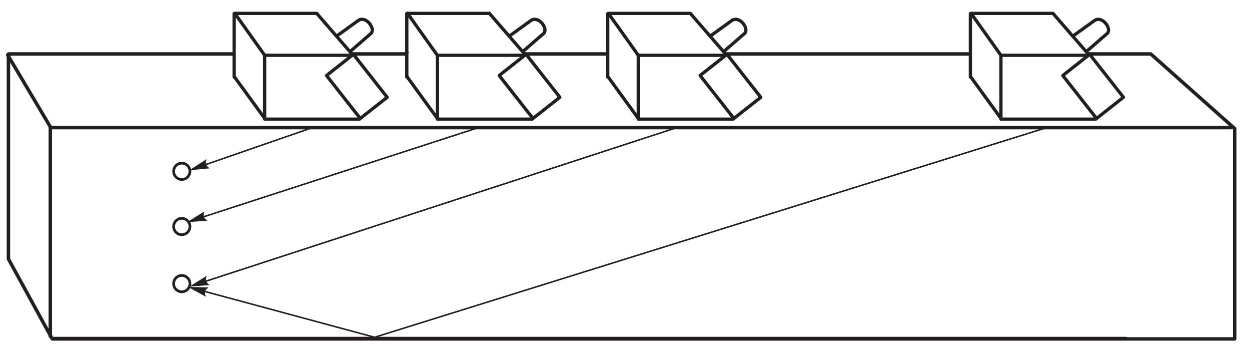


Figure 6.8—Transducer Crystal (see 6.15.8.1)



Notes:
1. $d_1 = d_2 \pm 0.5$ mm $d_3 = d_4 = \pm 0.5$ mm
   $SP_1 = SP_2 \pm 1$ mm $SP_3 = SP_4 \pm 1$ mm
2. The above tolerances should be considered as appropriate. The reflector should, in all cases, be placed in a manner to permit maximizing the reflection ant UT indication.

Figure 6.9—Standard Reference Reflector (see 6.17)



Note: Dimensions should be required to accommodate search units for the sound path distances required.

Figure 6.10—Recommended Calibration Block (see 6.17)

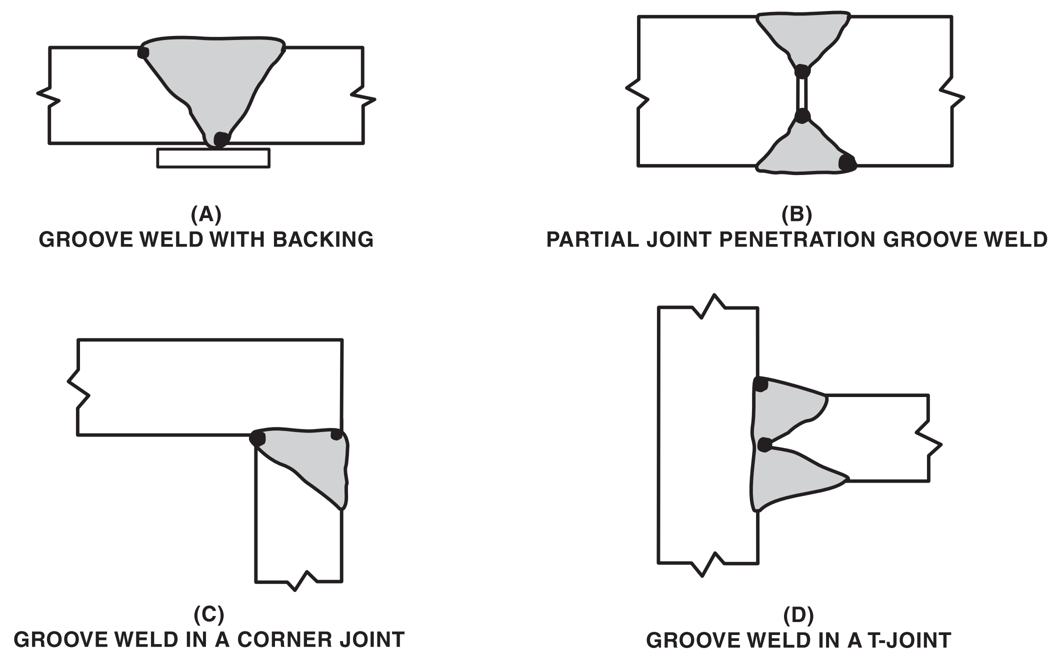
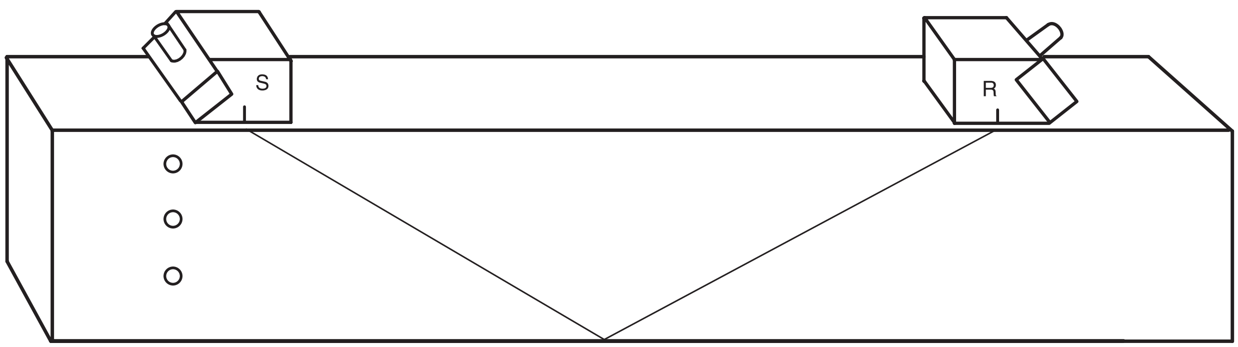


Figure 6.11—Typical Alternate Reflectors (see 6.17)
(Located in Weld Mock-ups and Production Welds)



Procedure: Place two similar angle beam search units on the calibration block or mock-up to be used in the position shown above. Using through transmission methods, maximize the indication obtained and obtain a dB value of the indication. Transfer the same two search units to the part to be examined and orient in the same direction in which scanning will be performed and obtain a dB value of indications as explained above from at least three locations. The difference in dB between the calibration block or mock-up and the average of that obtained from the part to be examined should be recorded and used to adjust the standard sensitivity.

Figure 6.12—Transfer Correction (see 6.18.1)

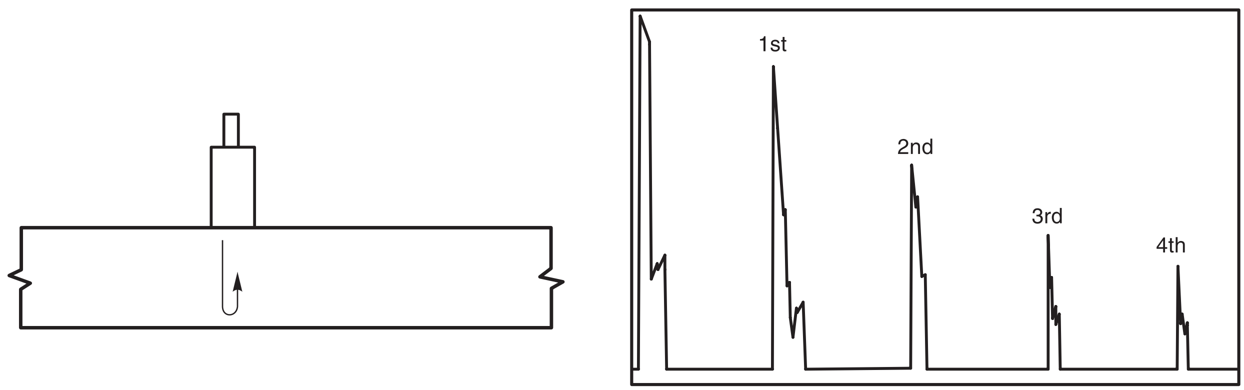


Figure 6.13—Compression Wave Depth (Horizontal Sweep Calibration) (see 6.18.2.1)

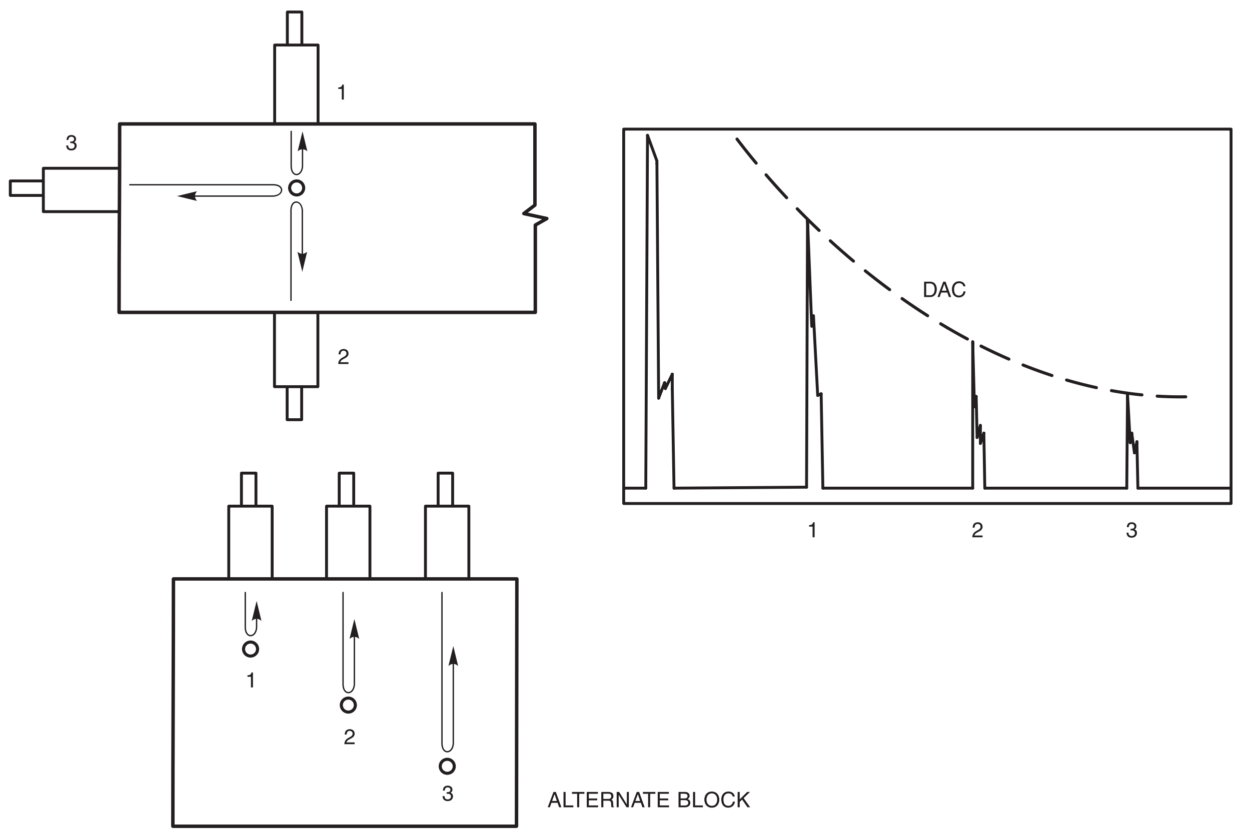


Figure 6.14—Compression Wave Sensitivity Calibration (see 6.18.2.2)

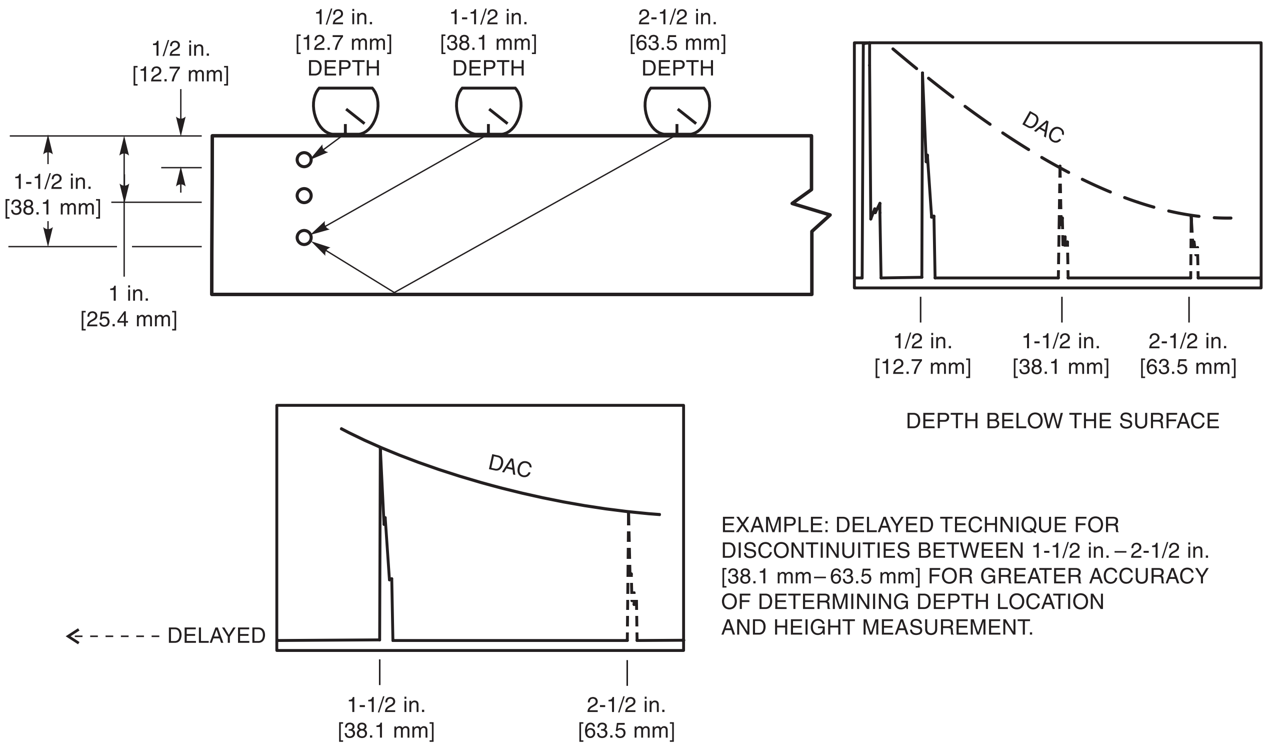
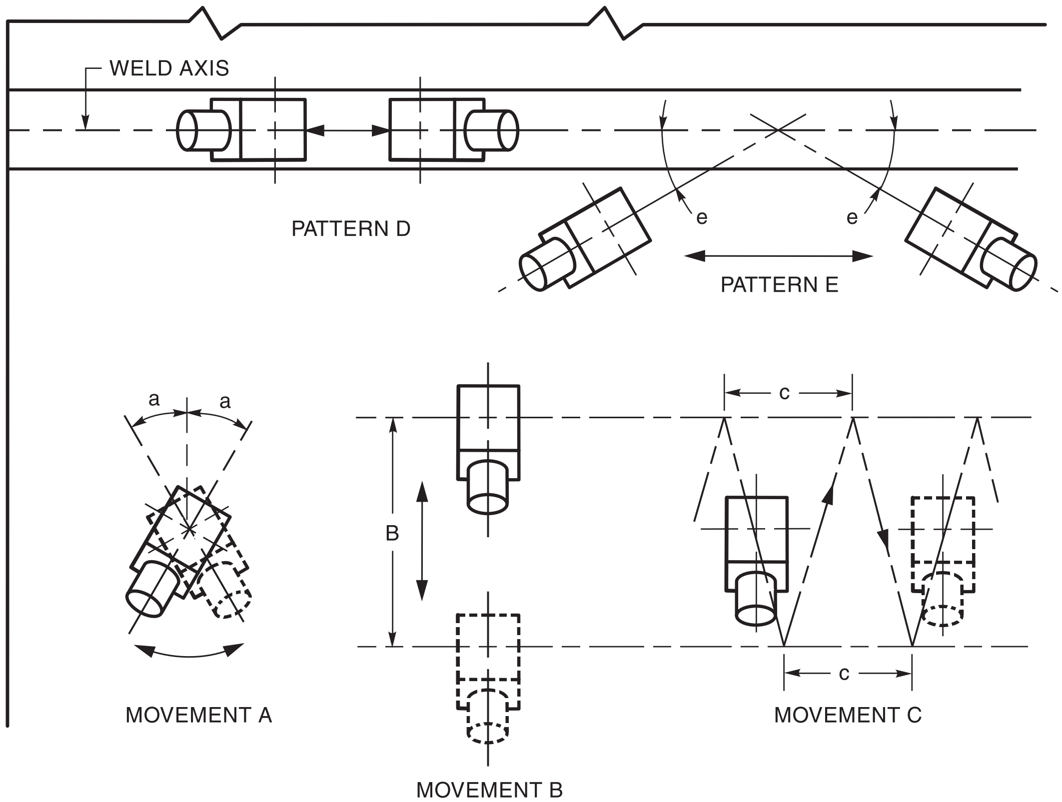
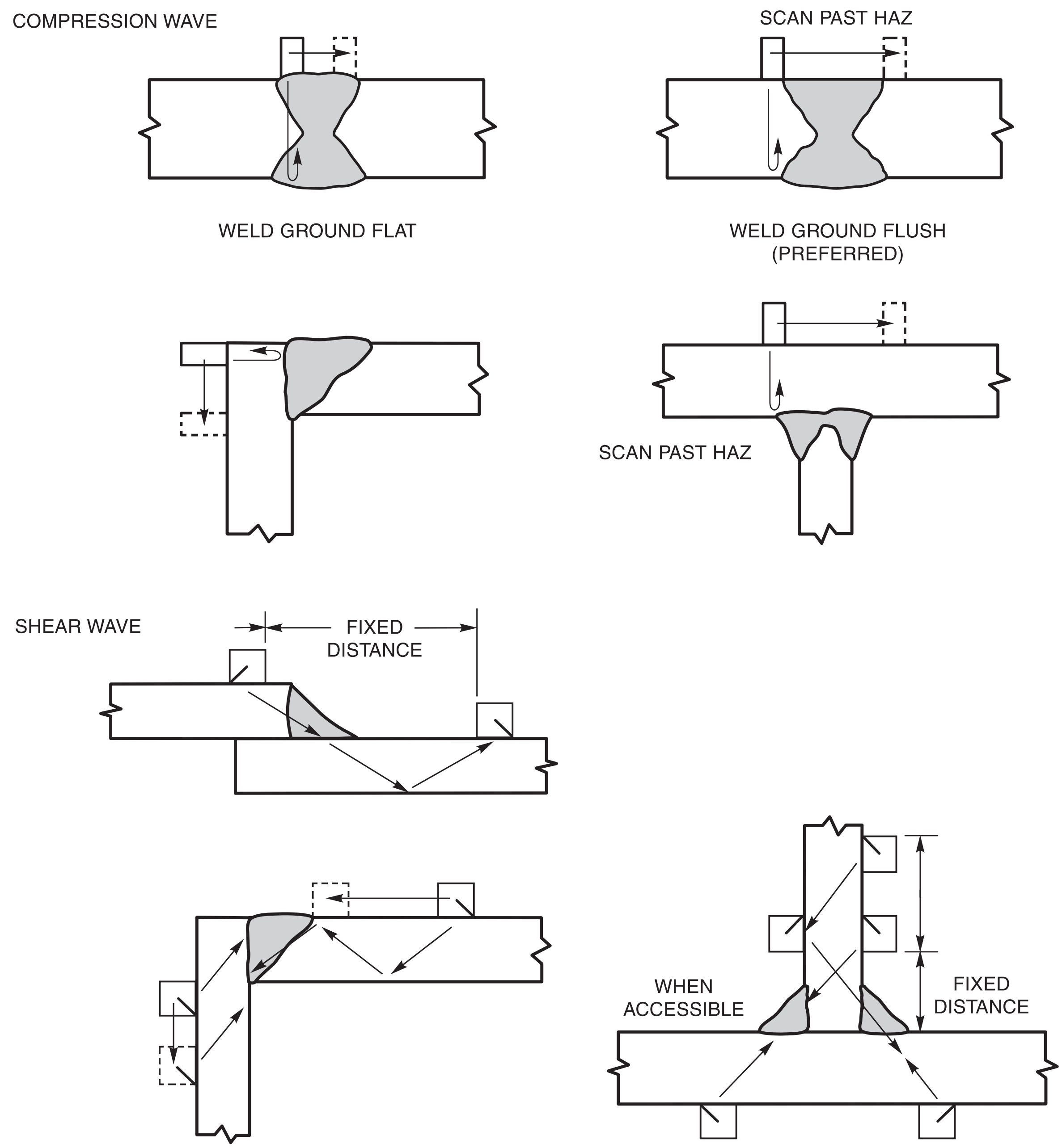


Figure 6.15—Shear Wave Distance and Sensitivity Calibration (see 6.18.3.1)



Notes:
1. Testing patterns are all symmetrical around the weld axis with the exception of pattern D which is conducted directly over the weld axis.
2. Testing from both sides of the weld axis is to be made wherever mechanically possible.

Figure 6.16—Plan View of UT Scanning Patterns (6.19)



Notes:

1. Denote scanning, otherwise search unit should be at a fixed distance from the weld while scanninc down the weld.
2. Cross-section scanning is shown. It is assumed that scanning will also be performed completely down the length of the welc with a minimum of 25% overlap to ensure 100% coverage. All scanning positions shown may not be required for full coverag Optional positions are given in case that inaccessibility prevents use of some positions.

Figure 6.17—Scanning Methods (see 6.19)

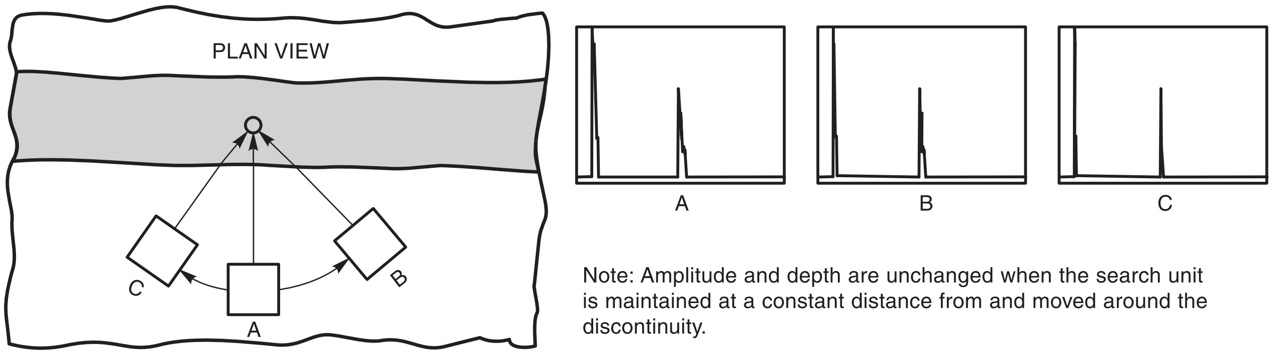


Figure 6.18—Spherical Discontinuity Characteristics (see 6.20.2.1)

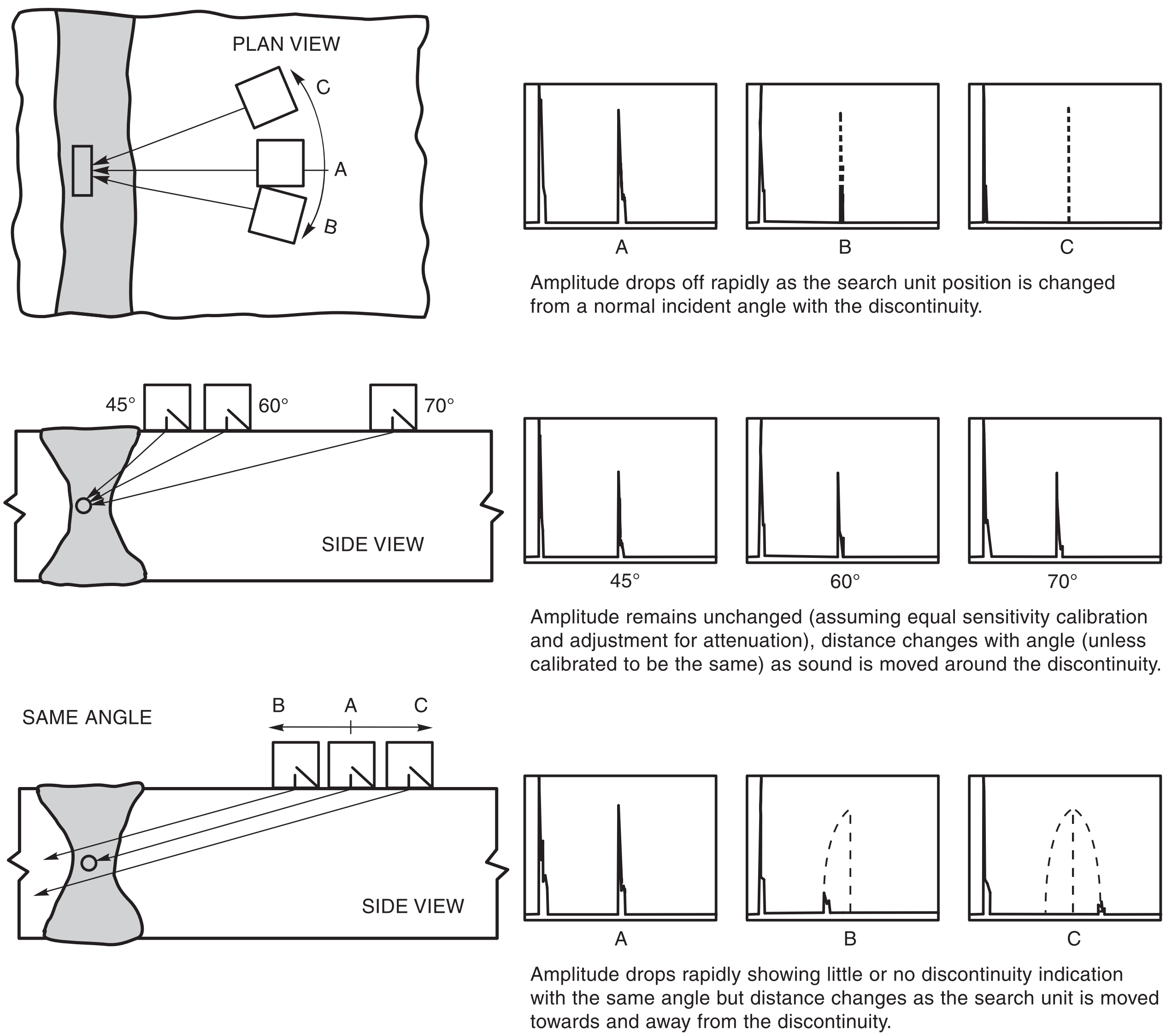


Figure 6.19—Cylindrical Discontinuity Characteristics (see 6.20.2.2)

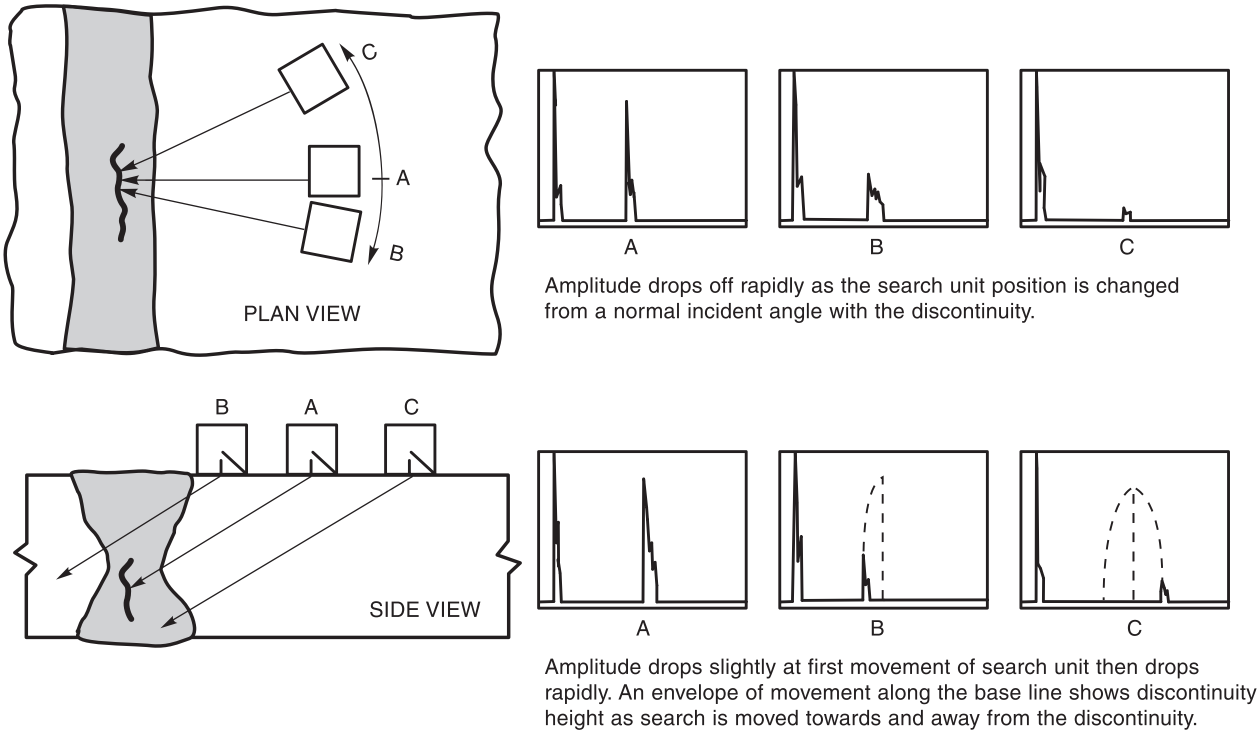


Figure 6.20—Planar Discontinuity Characteristics (see 6.20.2.3)

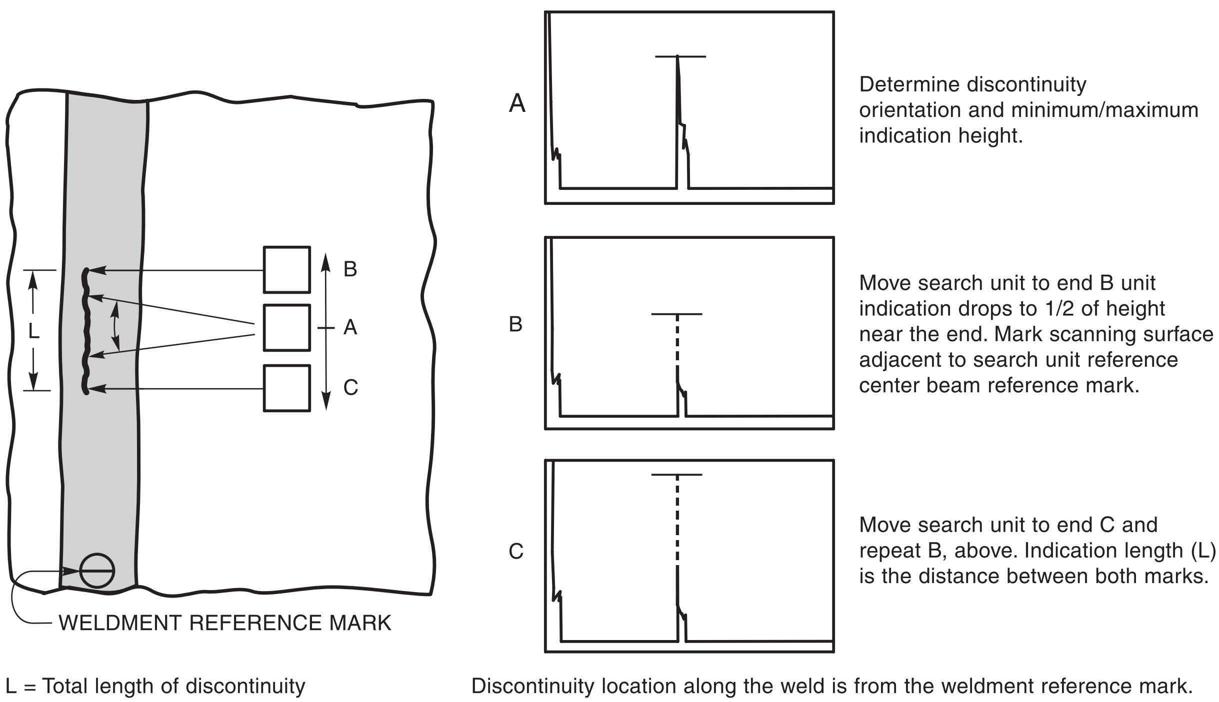
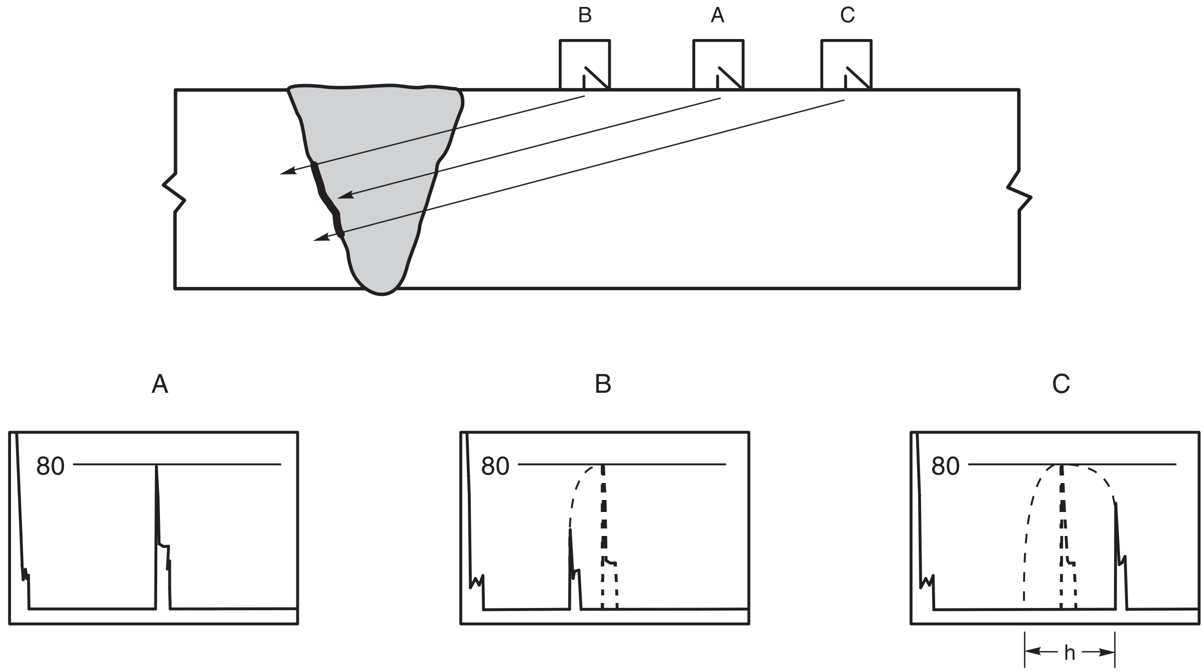


Figure 6.21—Discontinuity Height Dimension (see 6.21.2.1)



Maximize indication height and adjust to a known value.

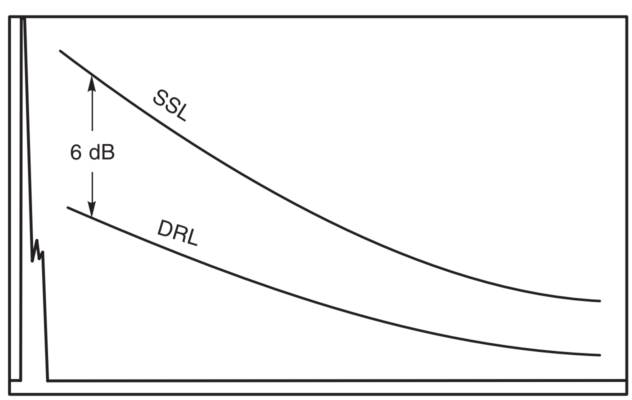
Move search unit towards discontinuity until point where indication drops rapidly to the base line. Mark or note the location.

Move search unit away from the discontinuity until point where indication drops rapidly to the base line. Mark or note the location.

h = Discontinuity height dimension.

Discontinuity location is from scanning surface as measured along the display.

Figure 6.22—Discontinuity Length Dimension (see 6.21.3.1, 6.21.3.2, 6.21.3.3, 6.21.3.4)



The screen may be marked to show SSL established during sensitivity calibration with the DRL located 6 dB below.

Figure 6.23—Screen Marking (see 6.23.2)

Page __________ of _________

Project ____ Report No. _________________

Weld I.D. _______________________ Thickness ______________________ Class __________________________

UT Procedure No. ________________________________ Technique ______________________________________

UT Instrument ____

Search Unit: No. ____________ Angle ________________ Freq. _________________ Size _________________

RESULT (identify and describe each discontinuity)

No.	Location from	Ampl. Level	Length	Height	Comments

Sketch (identify each discontinuity listed above)

NDT Tech. ______________________________________ Contractor ______________________________________

Date Examined __________________________________ Approved ____

Date Approved ___________________________________

Figure 6.24—Report of Ultrasonic Examination (see 6.25)

7. Stud Welding

7.1 Scope

Clause 7 contains general requirements for the welding of stainless steel studs to stainless steel and low carbon ferritic steels, and in addition it stipulates specific requirements:

(1) For workmanship, pre-production testing, operator qualification and application qualification testing when required, all to be performed by the contractor.

(2) For fabrication/erection and verification inspection of stud welding during production.

(3) For mechanical properties of stainless steel studs, and requirements for qualification of stud bases, all tests and documentation to be furnished by the stud manufacturer.

Note: Approved stud materials; see 7.2.6. For base materials see 7.2.7.

7.2 General Requirements

7.2.1 Stud Design. Studs shall be of suitable design for arc welding to stainless steel and low carbon steel members with the use of automatically timed stud welding equipment. The type and size of the stud shall be as specified by the drawings, specifications, or special provisions. For headed studs, see Figure 7.1. Alternate head configurations shall be permitted with proof of mechanical and embedment tests confirming full strength development of the design, and with the approval of the Engineer.

7.2.2 Arc Shields. An arc shield (ferrule) of heat resistant ceramic or other suitable material shall be furnished with each stud.

7.2.3 Flux. A suitable deoxidizing and arc stabilizing flux for welding shall be furnished with each stud of 5/16 in. [8.0 mm] diameter or larger. Studs less than 5/16 in. [8.0 mm] diameter may be furnished with or without flux.

7.2.4 Stud Bases. A stud base, to be qualified, shall have passed the test prescribed in Annex D. Only studs with qualified stud bases shall be used. Qualification of stud bases in conformance with Annex D shall be at the manufacturer's expense. The arc shield used in production shall be the same as used in qualification tests, or as recommended by the stud manufacturer. When requested by the Engineer, the contractor shall provide the following information:

(1) A description of the stud and arc shield.

(2) Certification from the manufacturer that the stud base is qualified in conformance with Annex D.

(3) Qualification test data.

7.2.5 Stud Finish. Finished studs shall be produced by heading, rolling, or machining. Finished studs shall be of uniform quality and condition, free of injurious laps, seams, fins, cracks, twists, bends, or other injurious discontinuities. Radial cracks or bursts in the head of a stud shall not be the cause for rejection, provided that the cracks or bursts do not extend more than half the distance from the head periphery to the shank, as determined by visual inspection. Heads of shear connectors or anchor studs are subject to cracks or bursts, which are names for the same thing.

Cracks or bursts designate an abrupt interruption of the periphery of the stud head by radial separation of the metal. Such interruptions do not adversely affect the structural strength, corrosion resistance, or other functional requirements of headed studs.

7.2.6 Stud Material. Stud shall be made from cold drawn bar stock conforming to ASTM A 493, *Specification for Stainless Steel Wire and Wire Rods for Cold Heading and Cold Forging* or ASTM A 276, *Specification for Stainless Steel Bars and Shapes*. The following 300-Series alloys may be used; XM-7, 304, 305, 309, 310, and 316 or the low carbon version thereof. Other Type 300 series alloys may be used with the approval of the Engineer; however, Type 303 shall not be used. Where studs arc to be cyclically loaded, they shall be tested and furnished in the annealed condition.

7.2.7 Base Materials. Base materials to be stud welded shall be of an alloy acceptable per 7.2.6. Other materials, such as low carbon steels, may also be stud welded. Any other material to be stud welded must have the approval of the Engineer.

7.3 Mechanical Requirements

7.3.1 Standard Mechanical Requirements. At the manufacturer's option, mechanical properties of studs shall be determined by testing either the stainless steel after cold finishing or the full diameter finished studs. In either case, the studs shall conform to the properties shown in Table 7.1.

7.3.2 Testing. Mechanical properties shall be determined in accordance with the applicable sections of ASTM A 370, *Test Methods and Definitions of Mechanical Testing of Steel Products*. A typical test fixture is used, similar to that shown in Figure 7.2.

7.3.3 Engineer's Request. Upon request by the Engineer, the contractor shall furnish:

(1) The stud manufacturer's certification that the studs, as delivered, conform to the applicable requirements of 7.2 and 7.3.

(2) Certified copies of the stud manufacturer's test reports covering the last completed set of in-plant quality control mechanical tests, required by 7.3 for each diameter delivered. The quality control test shall have been made within the six month period before delivery of the studs.

(3) Certified material test reports (CMTR) from the stainless steel supplier indicating the diameter, chemical properties, and grade on each heat delivered.

7.3.4 Absence of Quality Control Tests. When quality control tests are not available, the contractor shall furnish mechanical test reports conforming to the requirements of 7.3. The mechanical tests shall be on finished studs provided by the manufacturer of the studs. The number of tests to be performed shall be specified by the Engineer.

7.3.5 Engineer's Option to Select Studs. The Engineer may select studs of each type and size used under the contract as necessary for checking the requirements of 7.2 and 7.3. Furnishing these studs shall be at the contractor's expense. Testing shall be done at the owner's expense.

7.4 Workmanship

7.4.1 Cleanliness. At the time of welding the studs shall be free from rust, rust pits, scale, oil, moisture, or other deleterious matter that would adversely affect the welding operation.

7.4.2 Base Metal Preparation. The areas to which the studs are to be welded shall be free of scale, rust, moisture, paint, or other injurious material to the extent necessary to obtain satisfactory welds and prevent objectionable fumes. These areas shall be cleaned by wire brushing, scaling, prick-punching, or grinding. Extreme care should be exercised when welding through metal decking.

7.4.3 Moisture. The arc shields (ferrules) shall be kept dry. Any arc shields which show signs of surface moisture from dew or rain shall be oven dried at 250°F (120°F) for two hours before use.

7.4.4 Spacing Requirements. Longitudinal and lateral spacing of stud shear connectors (type B) with respect to each other and to edges of beam or girder flanges may vary a maximum of 1 in. [25 mm] from the locations shown in the drawings. The minimum distance from the edge of a stud base to the edge of the flange shall be the diameter plus 1/8 in. [3 mm], but preferably not less than 1-1/2 in. [40 mm].

7.4.5 Arc Shield Removal. After welding arc shields shall be broken free from studs to be embedded in concrete, and where practical, from all other studs.

7.4.6 Acceptance Criteria. The studs, after welding, shall be free of any discontinuities or substances that would interfere with their intended function and have a full 360° flash. However, nonfusion on the legs of the flash and small shrink fissures are acceptable. The weld fillet profiles shown in Figure 5.2 do not apply to the flash of automatically timed stud welds.

7.5 Technique

7.5.1 Automatic Machine Welding. Studs shall be welded with automatically timed stud welding equipment connected to a suitable source of direct current, electrode (stud) negative, power. Welding voltage, current, time, and gun settings for lift and plunge should be set at optimum settings based on past practice, recommendations of stud and equipment manufacturer, or both. AWS C5.4-93, *Recommended Practices for Stud Welding*, should also be used for technique guidance.

7.5.2 Multiple Welding Guns. If two or more welding guns are to be operated from the same power source, they shall be interlocked so that only one gun can operate at a time, and so that the power source has fully recovered from making one weld before another weld is started.

7.5.3 Movement of Welding Gun. While in operation, the welding gun shall be held in position until the weld metal has solidified.

7.5.4 Ambient and Base Metal Temperature Requirements. Welding shall not be done when the base metal temperature is below 0°F [–18°C] or when the surface is wet or exposed to falling rain or snow. When the temperature of the base metal is below 32°F [0°C], one additional stud in each 100 studs welded shall be tested by methods specified in 7.7.1.3 and 7.7.1.4, except that the angle of testing shall be approximately 15°. This is in addition to the first two studs tested for each start of a new production period or change in set-up.

7.5.5 FCAW, GMAW, SMAW Fillet Weld Option. At the option of the contractor studs may be welded using prequalified FCAW, GMAW, or SMAW processes, provided the following requirements are met:

7.5.5.1 Surfaces. Surfaces to be welded and surfaces adjacent to a weld shall be free from loose or thick scale, slag, rust, moisture, grease, and other foreign material that would prevent proper welding or produce objectionable fume.

7.5.5.2 Stud End. For fillet welds, the end of the stud shall also be clean.

7.5.5.3 Stud Fit (Fillet Welds). For fillet welds, the stud base shall be prepared so that the base of the stud fits against the base metal.

7.5.5.4 Fillet Weld Minimum Size. When fillet welds are used, the minimum size shall be as required in Table 7.2.

7.5.5.5 SMAW Electrodes. SMAW welding shall be performed using electrodes 5/32 or 3/16 in. [4.0 or 4.8 mm] in diameter, except that a smaller diameter electrode may be used on studs 7/16 in. [11.1 mm] or less in diameter for out-of-position welds.

7.5.5.6 Visual Inspection. FCAW, GMAW, and SMAW welded studs shall be visually inspected per 6.28.1 or 6.29.1 as applicable.

7.6 Stud Application Qualification Requirements

7.6.1 Studs of materials acceptable per 7.2.6 which are shop or field applied in the 1S position per Figure 7.3 to base materials acceptable per 7.2.7 are deemed prequalified by virtue of the manufacturer's base qualification tests (Annex D) and no further application testing is required. All other stud materials, base materials and weld positions shall be qualified in accordance with 7.6 and a welding procedure specification (WPS) shall be qualified in accordance with 7.6 of this code.

7.6.1.1 Operator Qualification. Personnel using such automatic welding equipment shall be qualified in accordance with 7.7 of this code.

7.6.2 Responsibilities for Test. The contractor or stud applicator shall be responsible for the performance of these tests. Tests may be performed by the contractor or stud applicator, and stud manufacturer, or by another testing agency suitable to all parties involved.

7.6.3 Preparation of Specimens. Tests shall be conducted by welding the studs being qualified to a test plate of base metal listed on the qualified WPS. Weld position, nature of surface welded to, current, and time shall be recorded (see Figure 7.3 for positions).

7.6.4 Number of Specimens. Ten specimens shall be welded consecutively using recommended procedures and settings for each diameter, position, and surface geometry.

7.6.5 Test Required. The ten specimens shall be tested using one or more or the following methods: bending, torquing, or tensioning.

7.6.6 Test Methods

7.6.6.1 Bend Test. Studs shall be bend tested by being bent 90° from the original axis. A stud application shall be considered qualified if the studs are bent 90° and fracture occurs in the parent material or in the shank of the stud and not in the weld.

7.6.6.2 Torque Test. Studs shall be torque tested using a torque test arrangement that is substantially in accordance with Figure 7.4. The stud application shall be considered qualified if all test specimens are torqued to destruction without failure in the weld.

7.6.6.3 Tension Test. Studs shall be tension tested to destruction using any machine capable of supplying the required force. A stud application shall be considered qualified if the test specimens do not fail in the weld.

7.6.7 Application Qualification Test Data. Application qualification test data shall include the following:

(1) Drawings that show the shapes and dimensions of studs and arc shields.

(2) A complete description of stud and base materials, and a description (part number) of the arc shield.

(3) Welding position and settings (current, time, lift).

(4) A record shall be made for each qualification.

7.7 Production Control

7.7.1 Pre-Production Testing

7.7.1.1 Start of Shift. Before production welding with a particular set-up and with a given size and type of stud, and at the beginning of each day's or shift's production, testing shall be performed on the first two studs that are welded. The stud technique may be developed on a piece of material similar to the production member in thickness and properties. If actual production thickness is not available, the thickness may vary ±25%. All test studs shall be welded in the same general position as required on the production member (flat, vertical, or overhead). Set-up includes stud gun, power source, stud diameter, gun lift and plunge, total welding lead length, and changes greater than ±5% in current (amperage) and time.

7.7.1.2 Production Member Option. Instead of being welded to separate material, the test studs may be welded on the production member, except when separate plates are required by 7.7.1.5.

7.7.1.3 Flash Requirement. The test studs shall be visually examined. They shall exhibit full 360° flash.

7.7.1.4 Bending. In addition to visual examination, the test shall consist of bending the studs after the studs are allowed to cool, to an angle of approximately 30° from their original axis by either striking the studs with a hammer on the unwelded end or placing a pipe or other suitable hollow device over the stud and manually or mechanically bending the stud. At temperatures below 50°F [10°C] bending shall preferably be done by continuous slow application of load. For threaded studs the torque test of Figure 7.4 shall be substituted for the bend test.

7.7.1.5 Event of Failure. If on visual examination, the test studs do not exhibit a full 360° flash, or if testing failure occurs in the weld heat-affected zone of either stud, the procedure shall be corrected, and two more studs shall be welded to separate material or on the production member and tested in accordance with the provisions of 7.7.1.3 and 7.7.1.4. If either of the second two studs fails, additional welding shall be continued on separate plates until two consecutive studs are tested and found to be satisfactory before any more production studs are welded to the member.

7.7.2 Production Welding. Once production welding has begun, any changes made to the welding set-up, as determined in 7.7.1, shall require that the testing in 7.7.1.3 and 7.7.1.4 be performed prior to resuming production welding.

7.7.3 Repair of Studs. In production, studs on which a full 360° flash is not obtained may, at the option of the contractor, be repaired by adding the minimum fillet weld as required by 7.5.5 in place of the missing flash. The repair weld shall extend at least 3/8 in. [10 mm] beyond each end of the discontinuity being repaired.

7.7.4 Operator Qualification. A stud welding operator is qualified if the pre-production tests listed below are successful.

7.7.4.1 Before production welding with a particular set-up and with a given type and size of stud, and at the beginning of each day's or shift's production, testing shall be performed on the first two studs that are welded. The stud technique may be developed on a piece of material similar to the production member in thickness and properties. Actual production thickness may vary ±25%. All test studs shall be welded in the same general position as required on the production member (flat, vertical, or overhead).

7.7.4.2 Instead of being welded to separate material, the test studs may be welded on the production member, except where separate plates are required by 7.7.4.5.

7.7.4.3 The test studs shall be visually examined. They shall exhibit full 360° flash.

7.7.4.4 In addition to visual examination, the test shall consist of bending the studs after the studs are allowed to cool, to an angle of approximately 30° from their original axis by either striking with a hammer or placing a pipe or other suitable hollow device over the stud and manually or mechanically bending the stud. At temperatures below 50°F [10°C] bending shall preferably done by continuous slow application of load. See Figure 7.5 for stud-welding bend jig.

7.7.4.5 If on visual examination the test studs do not exhibit full 360° flash, or if on testing failure occurs in the weld heat-affected zone of either stud, the procedure shall be corrected, and two more studs shall be welded to separate material or on the production member and tested in accordance with the provisions in 7.7.4.3 and 7.7.4.4. If either of the second two studs fails, additional welding shall be continued on separate plates until two consecutive studs are tested and found to be satisfactory before any more production studs are welded to the member.

7.7.4.6 Before any production studs are welded by an operator not involved in the pre-production set-up stated above, the operator shall have the first two studs welded by him or her tested in accordance with the provisions of 7.7.4.3 and 7.7.4.4. When the two welded studs have been tested and found acceptable, the operator may then weld production studs.

7.7.5 Removal and Repair. If an unacceptable stud has been removed from a component subject to tensile stress, the area from which the stud was removed shall be made smooth and flush. Where in such areas the base metal has been pulled out in the course of stud removal, arc welding in conformance with the requirements of this code shall be used to fill the pockets, and the weld surface shall be flush.

In compression areas of members, if stud failures are confined to shanks or fusion zones of studs, a new stud may be welded adjacent to each unacceptable area in lieu of repair and replacement on the existing weld area (see 7.4.4). If base metal is pulled out during stud removal, the repair provisions shall be the same as for tension areas, except that when the depth of discontinuity is the lesser of 1/8 in. [3 mm] or 7% of the base metal thickness, the discontinuity may be repaired by grinding in lieu of filling with weld metal. When a replacement stud is to be provided, the base metal repair shall be made prior to welding the replacement stud. Replacement studs (other than the threaded type which should be torque tested) shall be tested by bending to an angle of 15° from their original axis. The areas of components exposed to view in completed structures shall be made smooth and flush where a stud has been removed.

7.8 Fabrication and Verification Inspection Requirements

7.8.1 Visual Inspection. If a visual inspection reveals any stud that does not show a full 360° flash or any stud that has been repaired by welding, such stud shall be bent to an angle of approximately 15° from its original axis. Threaded studs shall be torque tested. The method of bending shall be in conformance with 7.7.1.4. The direction of bending for studs with less than 360° flash shall be opposite to the missing portion of the flash. Torque testing shall be in conformance with Figure 7.4.

7.8.2 Additional Tests. The verification inspector, where conditions warrant, may select a reasonable number of additional studs to be subjected to the tests specified in 7.8.1.

7.8.3 Bent Stud Acceptance Criteria. The bent stud shear connectors (Type B) and other studs to be embedded in concrete (Type A) that show no sign of failure shall be acceptable for use and left in the bent position. All bending and straightening for fabrication and inspection requirements, when required, shall be done without heating, before completion of the production stud welding operation, except as otherwise provided in the contract, and approved by the Engineer.

7.8.4 Torque Test Acceptance Criteria. Threaded studs (Type A) torque tested to the proof load torque level in Table 7.3 (Table 7.4 for metric) that show no sign of failure shall be acceptable for use.

7.8.5 Engineering Judgment. If, in the judgement of the Engineer, studs welded during the progress of the work are not in conformance with code provisions, as indicated by inspection and testing, corrective action shall be required of the contractor. At the contractor's expense, the contractor shall make the set-up changes necessary to ensure that studs subsequently welded will meet code requirements.

7.8.6 Owner's Option. At the option and expense of the owner, the Contractor may be required, at any time, to submit studs of the types used under the contract for a qualification check in accordance with the procedures of Annex D.

Table 7.1
Mechanical Property Requirements of Studs (see 7.3.1)

	Type A Studs[a]	Type B Studs[b]
Tensile Strength	70 ksi [490 MPa] min.	80 ksi [552 MPa] min.
Yield Strength	35 ksi [245 MPa] min.	70 ksi [490 MPa] min.
Elongation	40% min. in 2 in. [50 mm]	—

[a] Type A. Studs shall be for general purpose and studs that are headed, bent or of other configuration used as an essential component for composite design or construction or for anchorage in concrete.

[b] Type B. Studs shall be cold-worked deformed bar anchors manufactured in accordance with ASTM A 1022. Bar sizes greater than 0.757 in [19.22 mm] shall be manufactured from the materials described in 7.26, with mechanical properties and physical deformation characteristics as required by ASTM A 1022.

Table 7.2
Minimum Fillet Weld Size for Small Diameter Studs (see 7.5.5.4)

Stud Diameter		Minimum Size Fillet	
in.	mm	in.	mm
1/4–7/16	6.4–11.1	3/16	5
1/2	12.7	1/4	6
5/8–7/8	15.9–22.2	5/16	8
1	25.4	3/8	10

Table 7.3
Stud Torque Values[a] (UNC) (see 7.8.4)

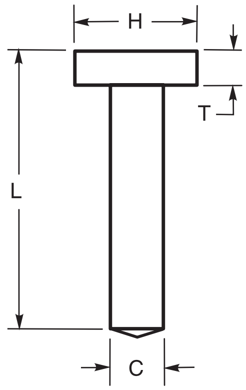
Stud Size, in.	Proof Torque in ft-lbs (J)
1/4 – 20	4
3/8 – 16	14
7/16 – 14	22
1/2 – 13	33
5/8 – 11	66
3/4 – 10	117
7/8 – 9	189
1 – 8	283

[a] Proof load torque values based on 80% of yield value shown in Table 7.1.

Table 7.4
Stud Torque Values[a] (Metric) (see 7.8.4)

Stud Size, mm	Proof Torque in J
M6	4.6
M10	23
M12	39.3
M16	97.6
M20	190.4
M22	259.0
M24	329.2

[a] Proof load torque values based on 80% of yield value shown in Table 7.1.



NOTE L: MANUFACTURED LENGTH BEFORE WELDING

Shank Diameter (C)		Length Tolerances (L)	Head Diameter (H)	Minimum Head Height (T)
Standard Dimensions, in.				
1/2	+0.000 –0.010	± 1/16	1 ± 1/64	9/32
5/8	+0.000 –0.010	± 1/16	1-1/4 ± 1/64	9/32
3/4	+0.000 –0.015	± 1/16	1-1/4 ± 1/64	3/8
7/8	+0.000 –0.015	± 1/16	1-3/8 ± 1/64	3/8
1	+0.000 –0.015	± 1/16	1-5/8 ± 1/64	1/2
Standard Dimensions, mm				
12.7	+0.00 –0.25	± 1.6	25.4 ± 0.4	7.1
15.9	+0.00 –0.25	± 1.6	31.7 ± 0.4	7.1
19.0	+0.00 –0.38	± 1.6	31.7 ± 0.4	9.5
22.1	+0.00 –0.38	± 1.6	34.9 ± 0.4	9.5
25.4	+0.00 –0.38	± 1.6	41.3 ± 0.4	12.7

Figure 7.1—Dimension and Tolerances of Standard-Type Shear Connectors (see 7.2.1)

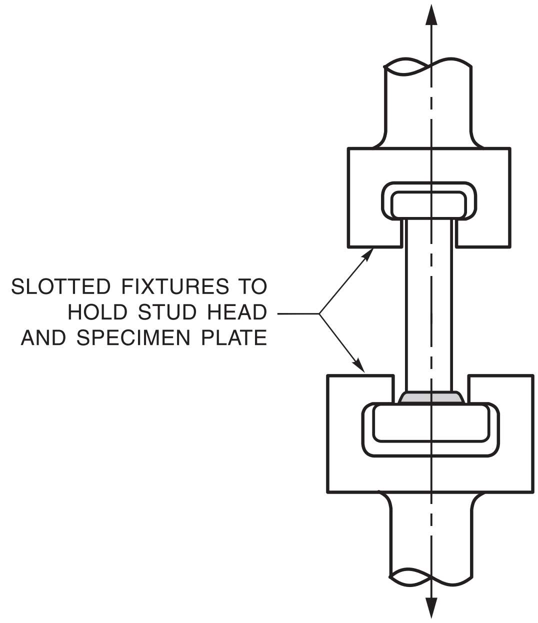


Figure 7.2—Typical Tensile Test Fixture for Stud Welds (see 7.3.2)

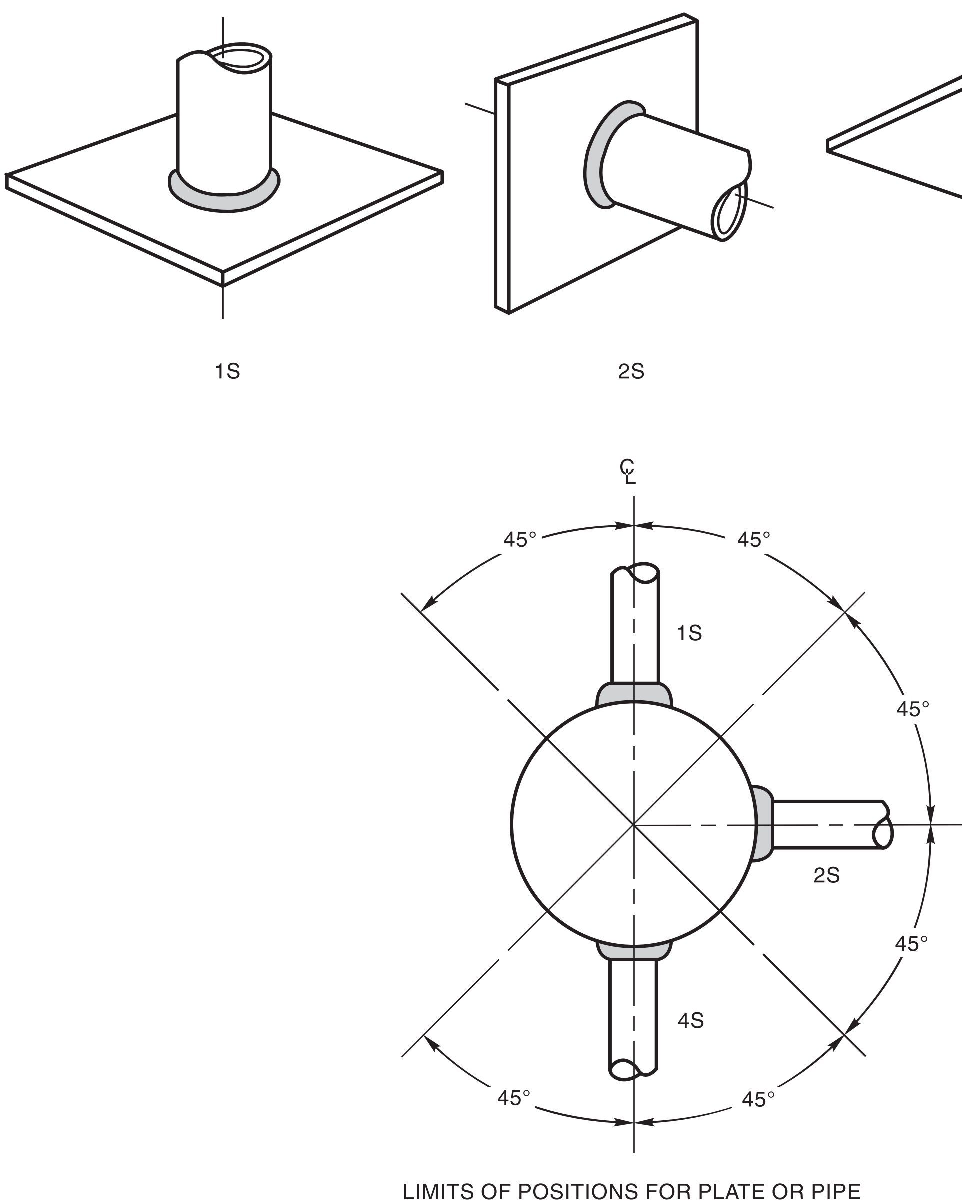
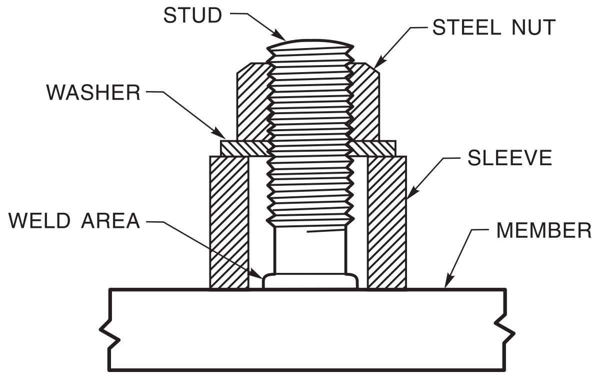
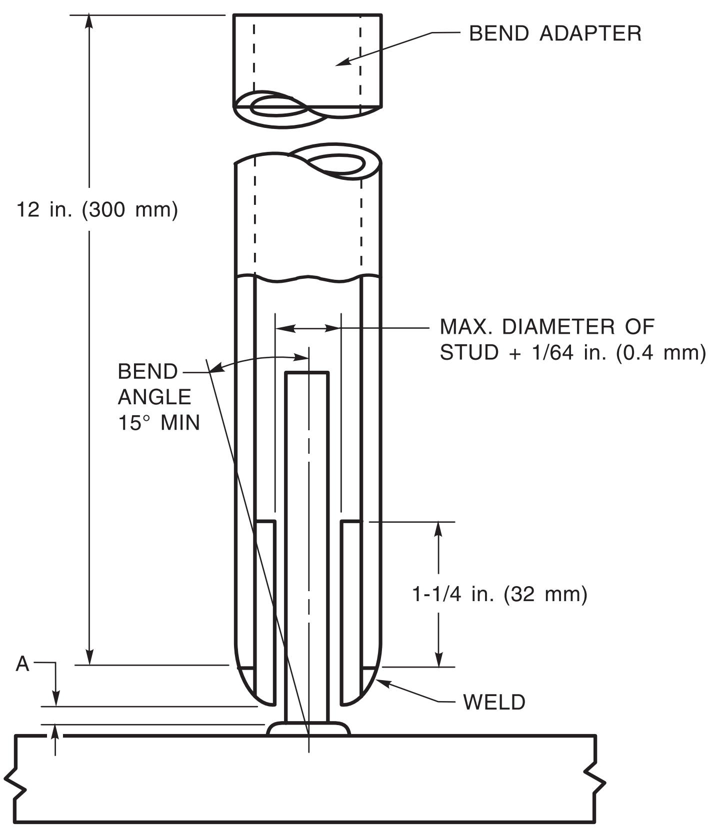


Figure 7.3—Position of Test Stud Welds (see 7.6.3)



Notes:
1. Dimensions are appropriate to the size of the stud.
2. Threads of the studs shall be clean and free of lubricant other than residual cutting oil.

Figure 7.4—Torque Testing Arrangement for Stud Welds (see 7.6.6.2)



FOR STUD DIAMETER (in.)	1/8	3/16	1/4	3/8	1/2	5/8	3/4	7/8	1
USE ADAPTER GAP "A" (in.)	1/8	1/8	3/16	7/32	5/16	11/32	15/32	15/32	19/32
FOR STUD DIAMETER (mm)	3.2	4.8	6.4	9.5	12.7	15.9	19.0	22.2	25.4
USE ADAPTER GAP "A" (mm)	3	3	5	6	8	9	12	12	15

Figure 7.5—Stud Weld Bend Fixture (see 7.7.4.4)

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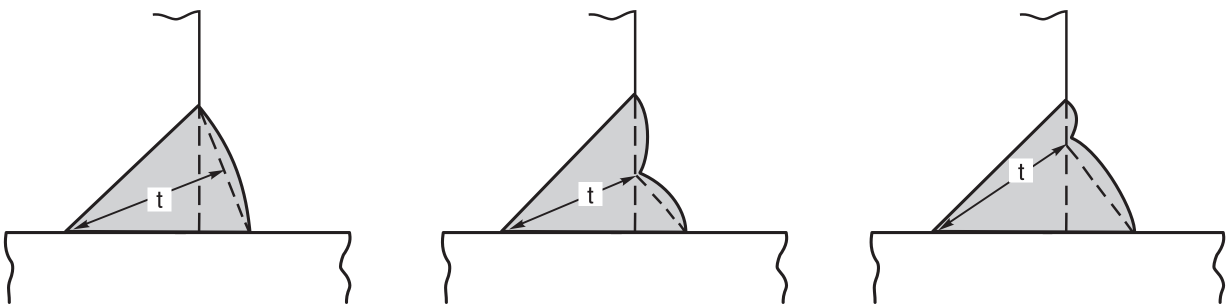
Annex A (Normative)

Effective Throat

This annex is part of AWS D1.6/D1.6M:2007, *Structural Welding Code—Stainless Steel*, and includes mandatory elements for use with this standard.



Note: The effective throat of a weld is the minimum distance from the root of the joint to its face, less any convexity.

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Annex B (Normative)

Effective Throats of Fillet Welds in Skewed T-Joints

This annex is part of AWS D1.6/D1.6M:2007, *Structural Welding Code—Stainless Steel*, and includes mandatory elements for use with this standard.

Table B.1 is a tabulation showing equivalent leg size factors for the range of dihedral angles between 60° and 135°, assuming no root opening. Root opening(s) 1/16 in. [2 mm] or greater, but not exceeding 3/16 in. [5 mm], shall be added directly to the leg size. The required leg size for fillet welds in skewed joints is calculated using the equivalent leg size factor for correct dihedral angle, as shown in the example.

EXAMPLE
(U.S. customary units)

Given: Skewed T-joint, angle: 75°; root opening: 1/16 in.
Required: Strength equivalent to 90° fillet weld of size: 5/16 in.
Procedure: (1) Factor for 75° from Table B.1: 0.86
(2) Equivalent leg size, W, of skewed joint, without root opening:
$W = 0.86 \times 0.313$ = 0.269 in.
(3) With root opening of: 0.063 in.
(4) Required leg size, W of skewed fillet weld: [(2) + (3)] = 0.332 in.
(5) Rounding up to a practical dimension: W = 3/8 in.

EXAMPLE
(SI units)

Given: Skewed T-joint, angle: 75°; root opening: 2 mm
Required: Strength equivalent to 90° fillet weld of size: 8.0 mm
Procedure: (1) Factor for 75° from Table B.1: 0.86
(2) Equivalent leg size, W, of skewed joint, without root opening:
$W = 0.86 \times 8.0$ = 6.9 mm
(3) With root opening of: 2.0 mm
(4) Required leg size, W, of skewed fillet weld: [(2) + (3)] 8.9 mm
(5) Rounding up to a practical dimension: W = 9.0 mm

For fillet welds having equal measured legs (W_n), the distance from the root of the joint to the face of the diagrammatic weld (t_n) may be calculated as follows:

For root openings > 1/16 in. [2 mm] and ≤ 3/16 in. [5 mm], use

$$t_n = \frac{W_n - R_n}{2 \sin\frac{\Psi}{2}}$$

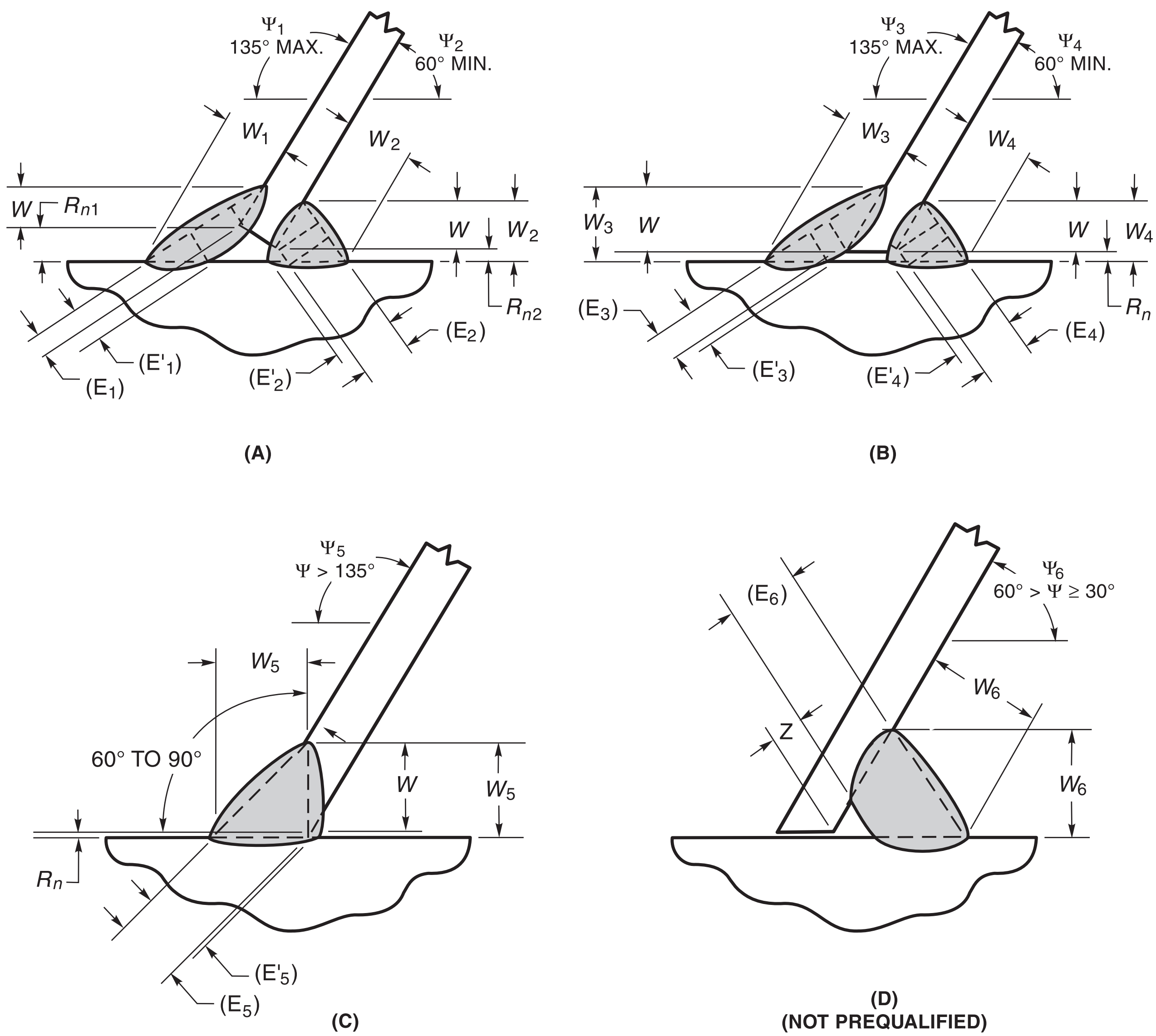
For root openings < 1/16 in. [2 mm], use

$$R_n = 0 \text{ and } t'_n = t_n$$

where the measured leg of such fillet weld (W_n) is the perpendicular distance from the surface of the joint to the opposite toe, and (R) is the root opening, if any, between parts (see Figure 3.6). Acceptable root openings are defined in 5.4.1.

Table B.1
Equivalent Fillet Weld Leg Size Factors for Skewed T-Joints (see Annex B)

Dihedral angle, Ψ	60°	65°	70°	75°	80°	85°	90°	95°
Comparable fillet weld size for same strength	0.71	0.76	0.81	0.86	0.91	0.96	1.00	1.03
Dihedral angle, Ψ	100°	105°	110°	115°	120°	125°	130°	135°
Comparable fillet weld size for same strength	1.08	1.12	1.16	1.19	1.23	1.25	1.28	1.31



Notes:
1. $(E)_{(n)}$, $(E')_{(n)}$ = Effective throat dependent on magnitude of root opening (R_n) (see 5.4.1). (n) represents 1 through 5.
2. t = thickness of thinner part.
3. Not prequalified for gas metal arc welding using short circuiting transfer.

Figure B.1—Details for Skewed T-Joints[1,2,3] (see 2.17)

Annex C

There is no Annex C. Annex C was omitted in order to avoid potential confusion with references to Commentary clauses.

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Annex D (Normative)

Manufacturers' Stud Base Qualification Requirements

This annex is part of AWS D1.6/D1.6M:2007, *Structural Welding Code—Stainless Steel*, and includes mandatory elements for use with this standard.

D1. Purpose

The purpose of these requirements is to prescribe tests for the stud manufacturers' certification of a stud base for welding under shop or field conditions.

D2. Responsibility for Tests

The stud manufacturer shall be responsible for the performance of the qualification test. These tests may be performed by a testing agency satisfactory to the Engineer. The agency performing the tests shall submit a certified report to the manufacturer of the studs giving procedures and results for all tests including the information listed under D10.

D3. Extent of Qualification

Qualification of a stud base shall constitute qualification of stud bases with the same geometry, flux, and arc shield, having the same diameter and diameters that are smaller by less than 1/8 in. [3 mm]. A stud base qualified with an approved grade of Type 300 alloy stainless steel shall constitute qualification for all other approved grades of Type 300 alloy stainless steel (see 7.2.6), provided that all other provisions stated herein are complied with.

D4. Duration of Qualification

A size of stud base with arc shield, once qualified, is considered qualified until the stud manufacturer makes any change in the stud base geometry, material, flux, or arc shield which affects the welding characteristics.

D5. Preparation of Specimens

D5.1 Test specimens shall be prepared by welding representative studs to suitable specimen plates of ASTM A 36 steel or any of the other materials listed in AWS D1.1. Studs may also be welded to suitable specimen plates of any of the approved grades of Type 300 series stainless steels listed in 7.2.6. Welding shall be done in the flat position (plate surface horizontal). Tests for threaded studs shall be on blanks (studs without threads).

D5.2 Studs shall be welded with power source, welding gun, and automatically controlled equipment as recommended by the stud manufacturer. Welding voltage, current, and time (see D6) shall be measured and recorded for each specimen. Lift and plunge shall be at the optimum setting as recommended by the manufacturer.

D6. Number of Test Specimens

D6.1 For studs 7/8 in. [22.2 mm] or less in diameter, 30 test specimens shall be welded consecutively with constant optimum time, but with current 10% above optimum. For studs over 7/8 in. [22.2 mm] diameter, 10 test specimens shall be welded consecutively with constant optimum time. Optimum current and time shall be the midpoint of the range normally recommended by the manufacturer for production welding.

D6.2 For studs 7/8 in. [22.2 mm] or less in diameter, 30 test specimens shall be welded consecutively with constant optimum time, but with current 10% below optimum. For studs over 7/8 in. [22.2 mm] diameter, 10 test specimens shall be welded consecutively with constant optimum time, but with current 5% below optimum.

D7. Tests

D7.1 Tension Tests. Ten of the specimens welded in accordance with D6.1 and ten in accordance with D6.2 shall be subjected to a tension test in a fixture similar to that shown in Figure 7.2, except that studs without heads may be gripped on the unwelded end in the jaws of the tension testing machine. A stud base shall be considered as qualified if all test specimens have a tensile strength equal to or above the minimum specified in 7.3.1.

D7.2 Bend Tests (Studs 7/8 in. [22.2 mm] or less in diameter). Twenty of the specimens welded in accordance with D6.1 and twenty in accordance with D6.2 shall be bend tested by being bent alternately 30° from their original axes in opposite directions until failure occurs. Studs shall be bent in a bend testing device as shown in Figure D.1, except that studs less than 1/2 in. [12 mm] diameter, optionally, may be bent using a device as shown in Figure D.2. A stud base shall be considered as qualified if, on all test specimens, fracture occurs in the plate material or shank of the stud and not in the weld or heat-affected zone. All test specimens for studs over 7/8 in. [22.2 mm] shall only be subjected to tensile tests.

D8. Retests

If failure occurs in a weld or the heat-affected zone in any of the bend test groups of D7.2 or at less than specified minimum tensile strength of the stud in any of the tension groups in D7.1, a new test group (specified in D6.1 or D6.2, as applicable) shall be prepared and tested. If such failures are repeated, the stud base shall fail to qualify.

D9. Acceptance

For a manufacturer's stud base and arc shield combination to be qualified, each stud of each group of 30 studs shall, by test or retest, meet the requirements prescribed in D7. Qualification of a given diameter of stud base shall be considered qualification for stud bases of the same nominal diameter (see D3, stud base geometry, material, flux, and arc shield).

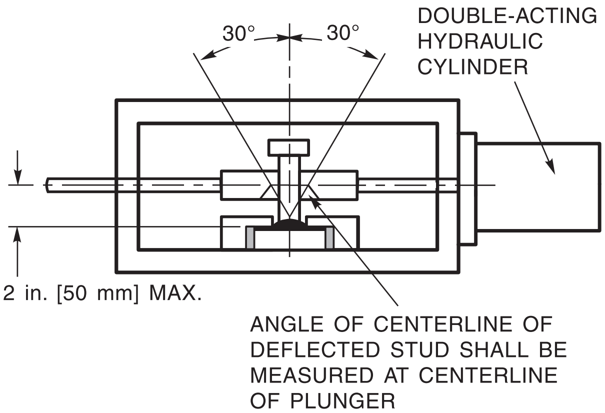
D10. Manufacturers' Qualification Test Data

The test data shall include the following:

(1) Drawings showing shapes and dimensions with tolerances of stud, arc shields, and flux

(2) A complete description of materials used in the studs, including the quantity and type of flux, and a description of the arc shields

(3) Certified results of laboratory tests required.



Notes:
1. Fixture holds specimen and stud is bent 30° alternately in opposite directions.
2. Load can be applied with hydraulic cylinder (shown) or fixture adapted for use with tension test machine.

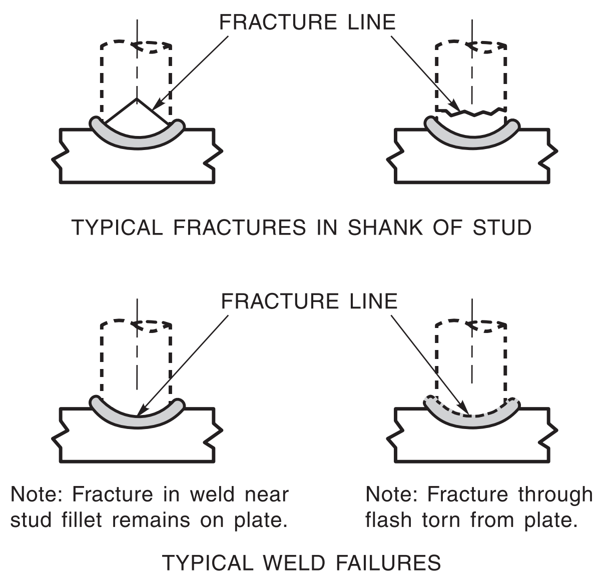


Figure D.1—Bend Testing Device (see D7.2)

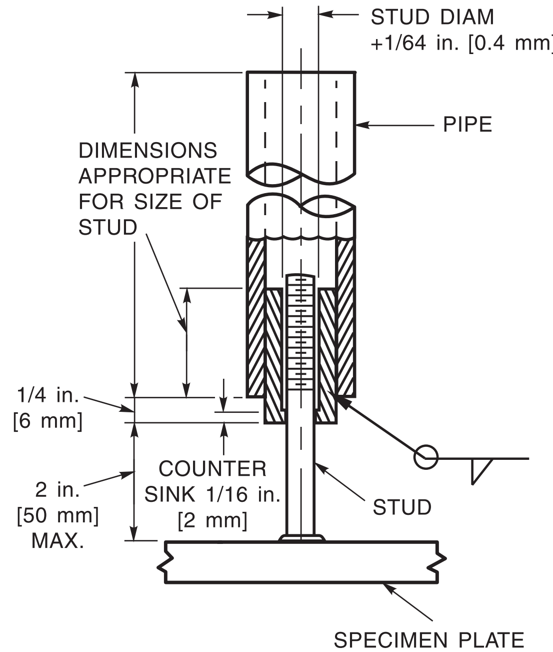


Figure D.2—Suggested Type of Device for Qualification Testing of Small Studs (see D7.2)

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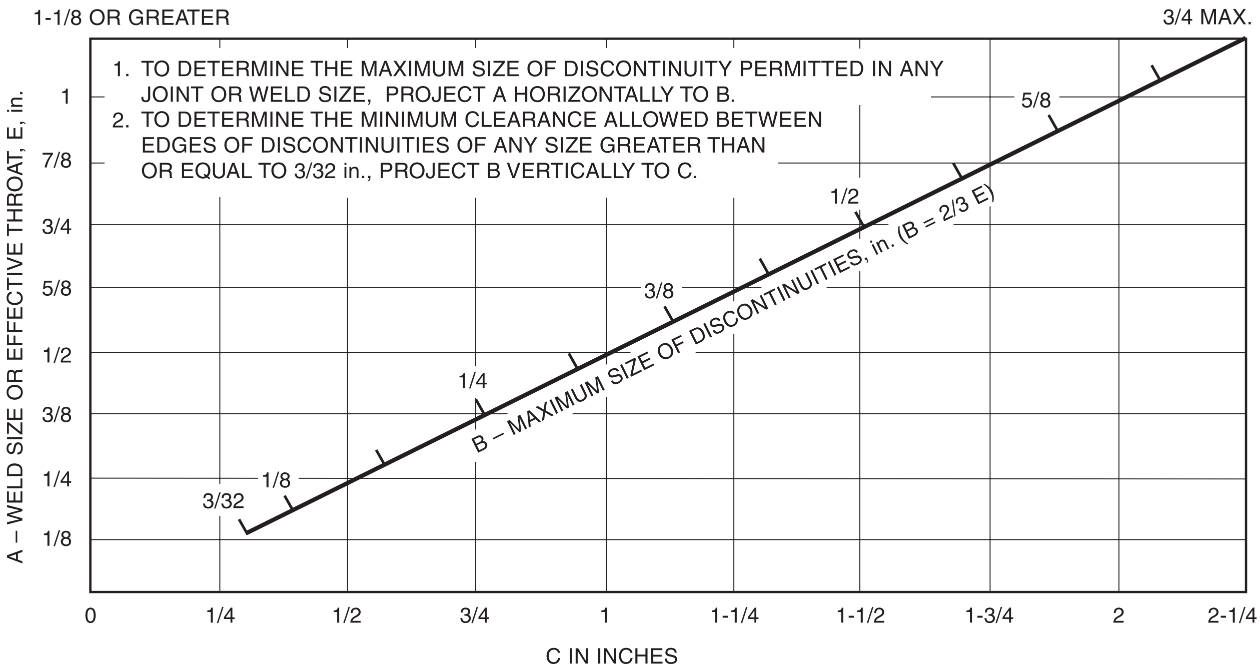
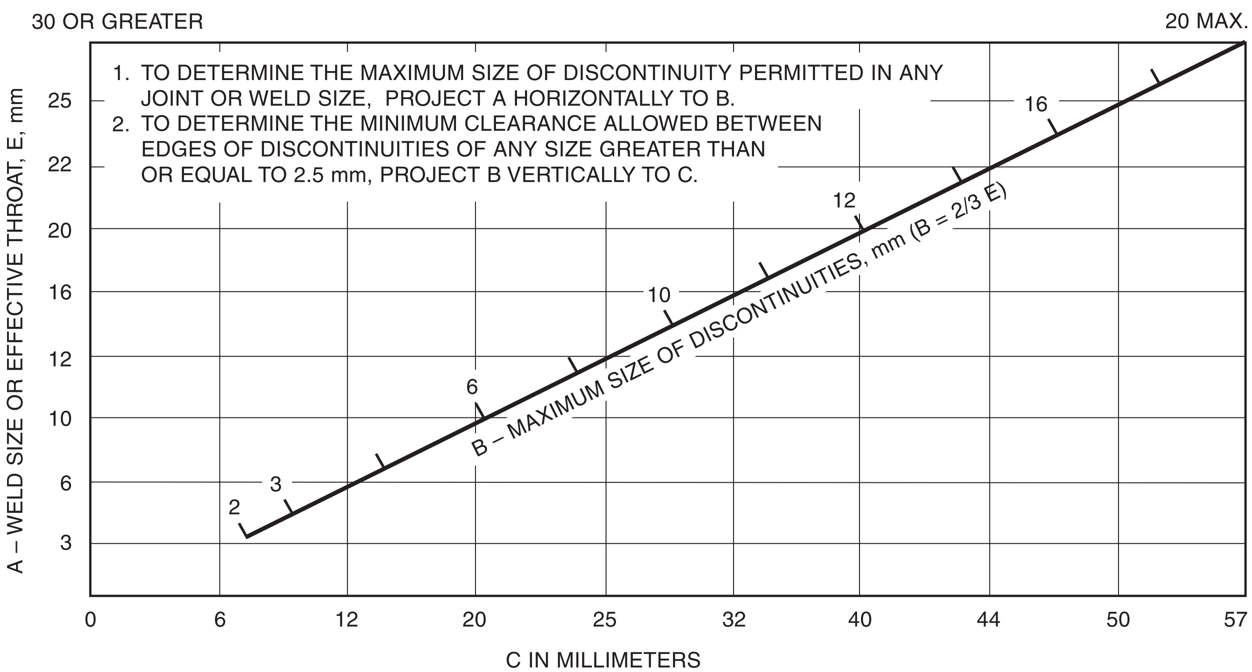
Annex E (Normative)

Discontinuity Acceptance Criteria

This annex is part of AWS D1.6/D1.6M:2007, *Structural Welding Code—Stainless Steel*, and includes mandatory elements for use with this standard.

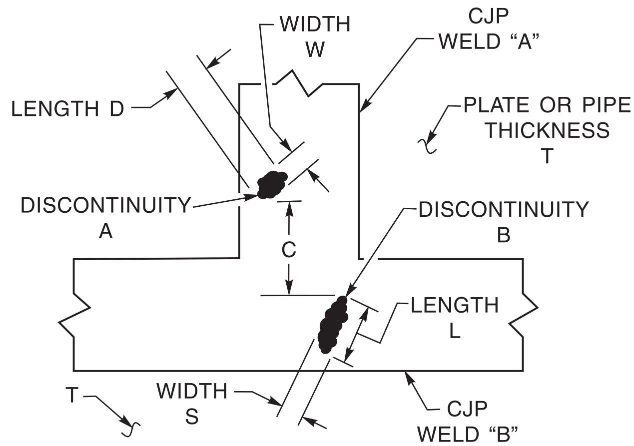




C – MINIMUM CLEARANCE MEASURED ALONG THE LONGITUDINAL AXIS OF THE WELD BETWEEN EDGES OF POROSITY OR FUSION-TYPE DISCONTINUITIES (LARGER OF ADJACENT DISCONTINUITIES GOVERNS), OR TO AN EDGE OR AN END OF AN INTERSECTING WELD.

(C = 3B = 2E)

Figure E.1—Weld Quality Requirements for Elongated Discontinuities as Determined by Radiography for Statically Loaded Structures [see 6.28.2.2(1)]



KEY:

WELD A = LONGITUDINAL TUBULAR CJP GROOVE WELD
WELD B = TUBULAR GIRTH CJP GROOVE WELD

DISCONTINUITY A = ROUNDED DISCONTINUITY LOCATED IN WELD A
DISCONTINUITY B = ROUNDED OR ELONGATED DISCONTINUITY LOCATED IN WELD B

D AND W = LARGEST AND SMALLEST DIMENSIONS, RESPECTIVELY, OF DISCONTINUITY A
L AND S = LARGEST AND SMALLEST DIMENSIONS, RESPECTIVELY, OF DISCONTINUITY B

T = THICKNESS OF TUBULAR MEMBER
C = SHORTEST DISTANCE PARALLEL TO THE WELD A AXIS, BETWEEN THE NEAREST DISCONTINUITY EDGES

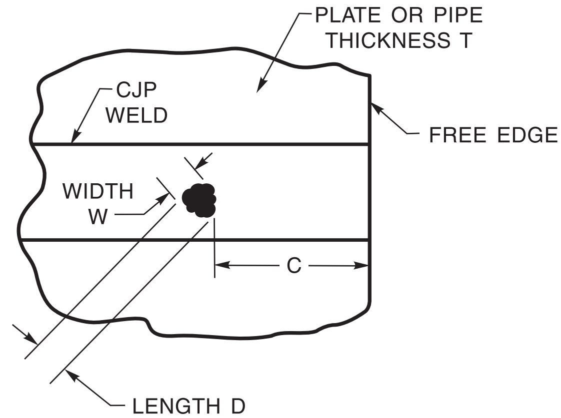
CASE I DISCONTINUITY LIMITATIONS[3]

DISCONTINUITY DIMENSION	LIMITATIONS	CONDITIONS
D	≤ 3W	ROUNDED DISCONTINUITY (NOTE 1)
L	≤ 3S	
D OR L	< T/3, ≤ 1/4 in. [6 mm]	T ≤ 2 in. [50 mm]
	≤ 3/8 in. [10 mm]	T > 2 in. [50 mm]
C	≥ 3D OR 3L, WHICHEVER IS GREATER	(A) ONE DISCONTINUITY ROUNDED, THE OTHER ROUNDED OR ELONGATED (NOTE 2) (B) D OR L ≥ 3/32 in. [2.5 mm]

Notes:
1. For elongated discontinuities (length > 3 × width), see Figure E.1 for maximum dimensions.
2. The elongated discontinuity may be located in either the longitudinal or girth weld. For the purposes of this illustration, discontinuity B was located in the girth weld.
3. See 6.28.2.2.

Case I—Discontinuity at Weld Intersection

Figure E.1 (Continued)—Weld Quality Requirements for Elongated Discontinuities as Determined by Radiography for Statically Loaded Structures [see 6.28.2.2(1)]



KEY:
D AND W = LENGTH AND WIDTH, RESPECTIVELY, OF CJP GROOVE WELD
C = CLEARANCE BETWEEN FREE EDGE AND CLOSEST EDGE OF DISCONTINUITY

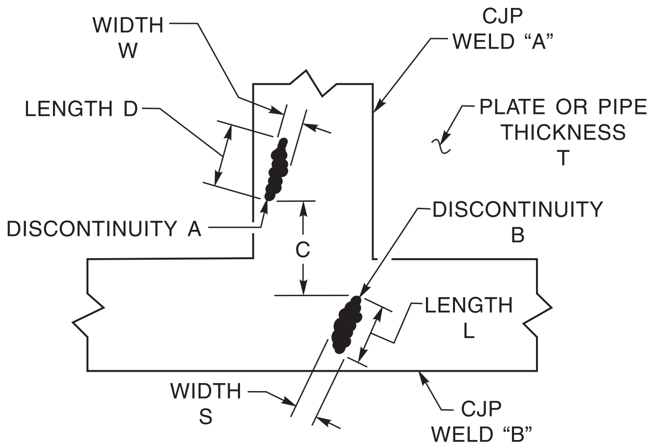
CASE II DISCONTINUITY LIMITATIONS[1,2]

DISCONTINUITY DIMENSION	LIMITATIONS	CONDITIONS
D	< T/3, ≤ 1/4 in. [6 mm]	T ≤ 2 in. [50 mm]
	≤ 3/8 in. [10 mm]	T > 2 in. [50 mm]
C	≥ 3D	D ≥ 3/32 in. [2.5 mm]

Notes:
1. See 6.28.2.2.
2. For elongated discontinuities (length > 3 × width), see Figure E.1 for maximum dimensions.

Case II—Discontinuity at Free Edge

Figure E.1 (Continued)—Weld Quality Requirements for Elongated Discontinuities as Determined by Radiography for Statically Loaded Structures [see 6.28.2.2(1)]



KEY:
SEE CASE I DEFINITIONS FOR WELDS A & B, DISCONTINUITY B, DIMENSIONS B, D, W, L, S, T, AND C.
DISCONTINUITY A = ROUNDED OR ELONGATED DISCONTINUITY IN WELD

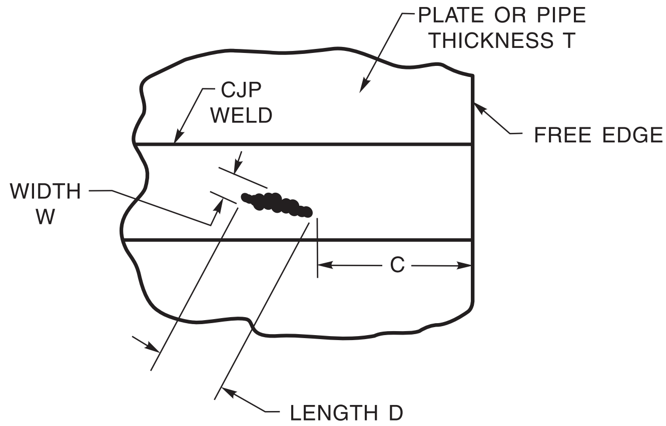
CASE III DISCONTINUITY LIMITATIONS[1,2]

DISCONTINUITY DIMENSION	LIMITATIONS	CONDITIONS
D	≤ 2T/3	D > 3W
C	≥ 3D OR 3L OR 2T, WHICHEVER IS GREATER	D OR L ≥ 3/32 in. [2.5 mm]

Notes:
1. See 6.28.2.2.
2. For elongated discontinuities, see Figure E.1 for maximum dimensions.

Case III—Discontinuity at Weld Intersection

Figure E.1 (Continued)—Weld Quality Requirements for Elongated Discontinuities as Determined by Radiography for Statically Loaded Structures [see 6.28.2.2(1)]



KEY:
D, W, C AS DEFINED IN CASE II.

CASE IV DISCONTINUITY LIMITATIONS[1,2]

DISCONTINUITY DIMENSION	LIMITATIONS	CONDITIONS
D	≤ 2T/3	D/W > 3
C	≥ 3D OR 2T, WHICHEVER IS GREATER	D ≥ 3/32 in. [2.5 mm]

Notes:
1. See 6.28.2.2.
2. For elongated discontinuities (length > 3 × width), see Figure E.1 for maximum dimensions.

Case IV—Discontinuity at Free Edge

Figure E.1 (Continued)—Weld Quality Requirements for Elongated Discontinuities as Determined by Radiography for Statically Loaded Structures [see 6.28.2.2(1)]

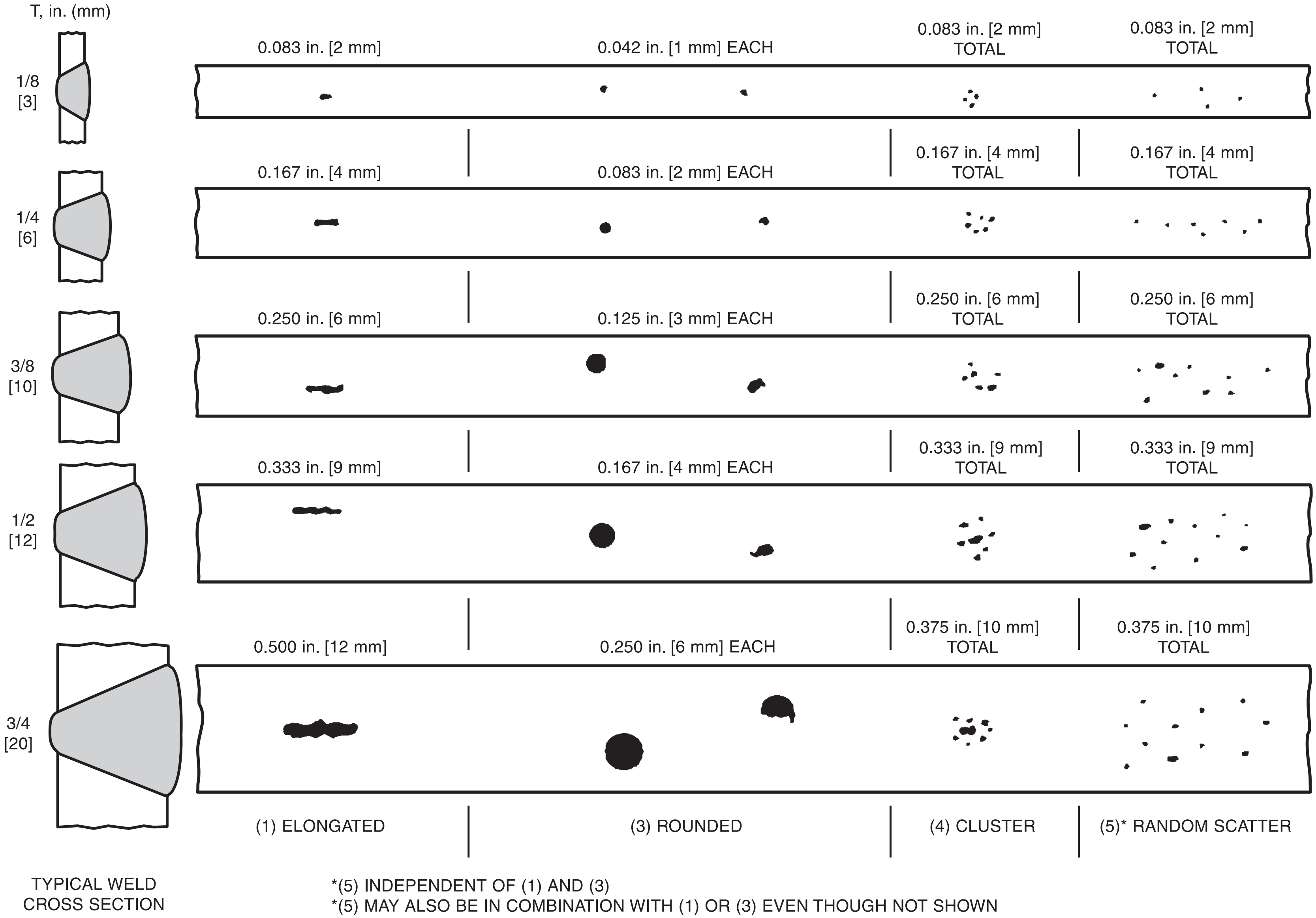
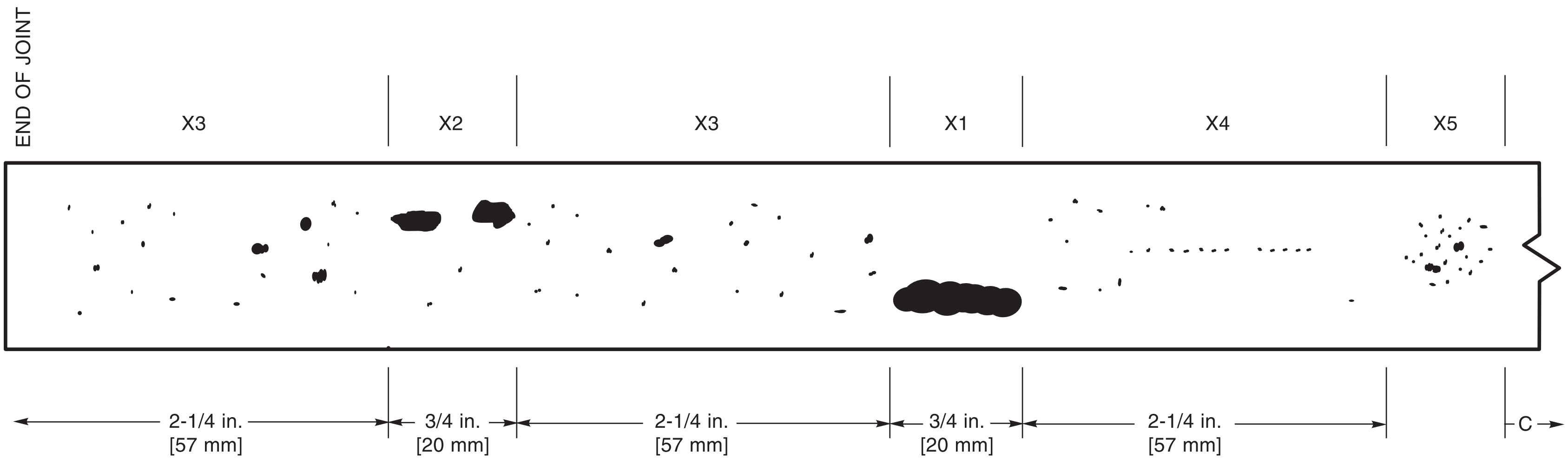


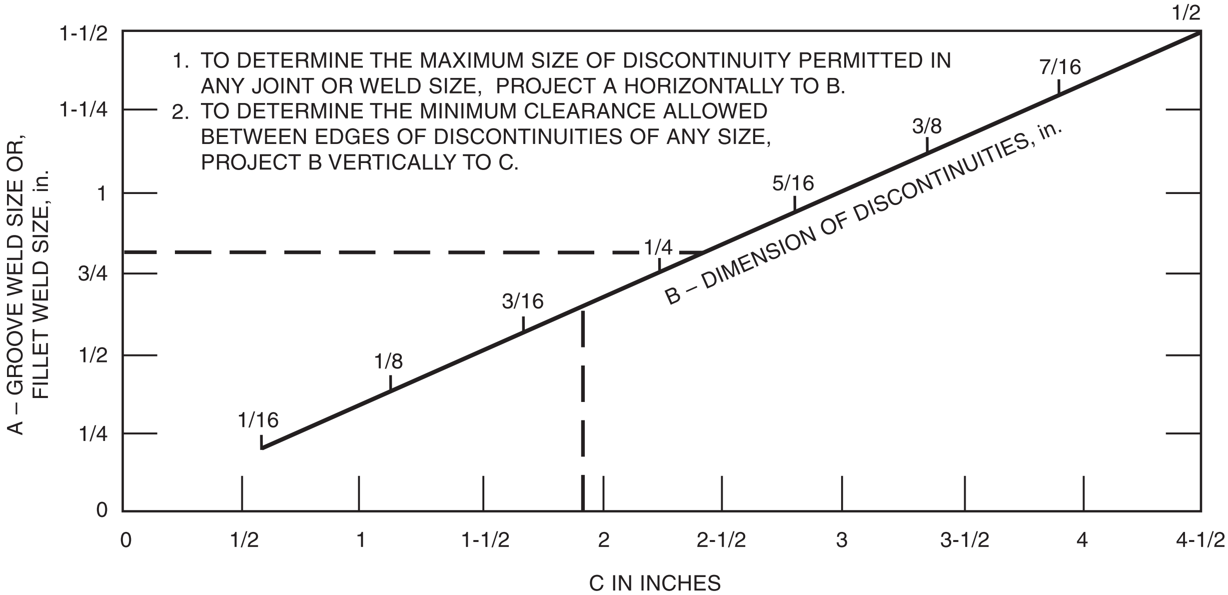
Figure E.2—Maximum Acceptable Radiographic Images (see 6.28.2.3)

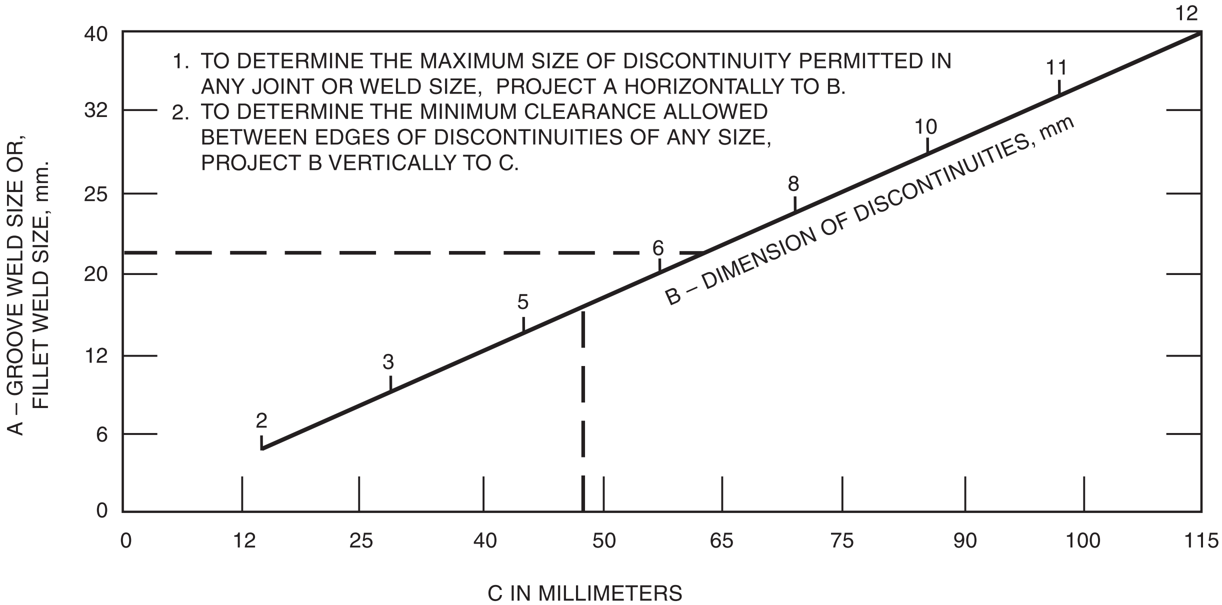


Notes:
1. C—Minimum clearance allowed between edges of discontinuities 3/32 in. [2.5 mm] or larger (per Figure E.1). Larger of adjacent discontinuities governs.
2. X1—Largest permissible elongated discontinuity for 1-1/8 in. [30 mm] joint thickness (see Figure E.1).
3. X2—Multiple discontinuities within a length permitted by Figure E.1 may be handled as a single discontinuity.
4. X3–X4—Rounded type discontinuity less than 3/32 in. [2.5 mm].
5. X5—Rounded type discontinuities in a cluster. Such a cluster having a maximum of 3/4 in. [20 mm] for all pores in the cluster shall be treated as requiring the same clearance as a 3/4 in. long discontinuity of Figure E.1.

Interpretation: Rounded and elongated discontinuities are acceptable as shown. All are within the size limits and the minimum clearance allowed between discontinuities or the end of a weld joint.

Figure E.3—For Radiography of Joints 1-1/8 in. [30 mm] and Greater, Typical Examples of Random Acceptable Discontinuities (see 6.28.2.3)

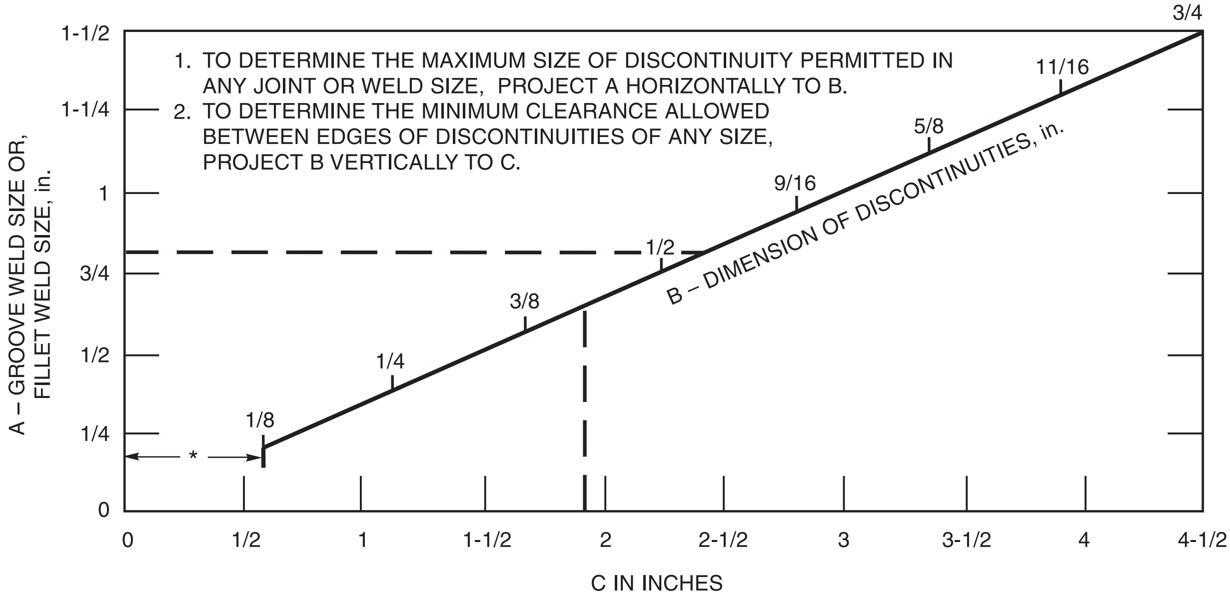


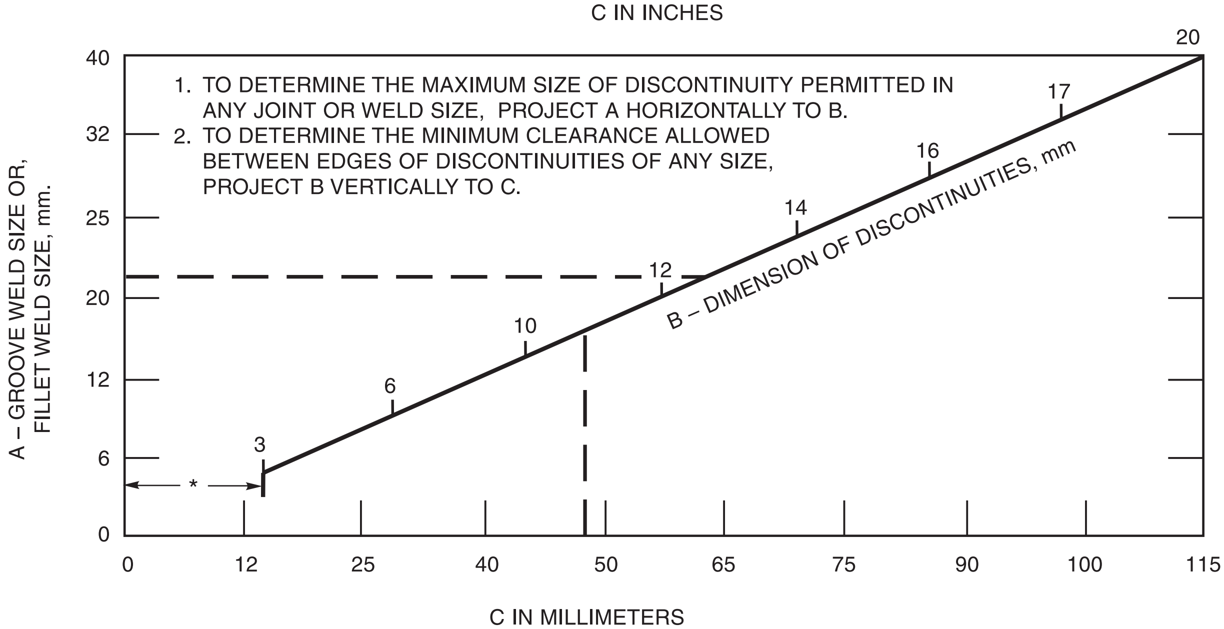


C – MINIMUM CLEARANCE MEASURED ALONG THE LONGITUDINAL AXIS OF THE WELD BETWEEN EDGES OF POROSITY OR FUSION TYPE DISCONTINUITIES. (LARGER OF ADJACENT DISCONTINUITIES GOVERNS)

NOTE: ADJACENT DISCONTINUITIES, SPACED LESS THAN THE MINIMUM SPACING REQUIRED BY FIGURE E.5, SHALL BE MEASURED AS ONE LENGTH EQUAL TO THE SUM OF THE TOTAL LENGTH OF THE DISCONTINUITIES PLUS THE LENGTH OF THE SPACE BETWEEN THEM AND EVALUATED AS A SINGLE DISCONTINUITY.

Figure E.4—Weld Quality Requirements for Discontinuities Occurring in Tension Welds (Limitations of Porosity and Fusion Characteristics) (see 6.29.2.1)

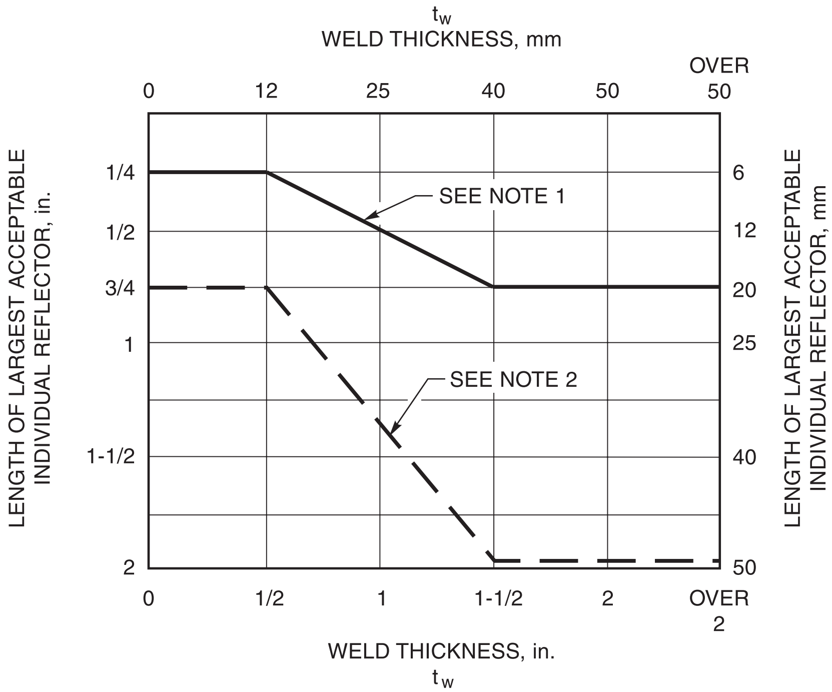




C – MINIMUM CLEARANCE MEASURED ALONG THE LONGITUDINAL AXIS OF THE WELD BETWEEN EDGES OF POROSITY OR FUSION TYPE DISCONTINUITIES. (LARGER OF ADJACENT DISCONTINUITIES GOVERNS)

* THE MAXIMUM SIZE OF A DISCONTINUITY LOCATED WITHIN THIS DISTANCE FROM AN EDGE OF PLATE SHALL BE 1/8 in. [3 mm], BUT A 1/8 in. [3 mm] DISCONTINUITY MUST BE 1/4 in. [6 mm] OR MORE AWAY FROM THE EDGE. THE SUM OF DISCONTINUITIES LESS THAN 1/8 in. [3 mm] IN SIZE AND LOCATED WITHIN THIS DISTANCE FROM THE EDGE SHALL NOT EXCEED 3/16 in. [5 mm]. DISCONTINUITIES 1/16 in. [2 mm] TO LESS THAN 1/8 in. [3 mm] WILL NOT BE RESTRICTED IN OTHER LOCATIONS UNLESS THEY ARE SEPARATED BY LESS THAN 2 L (L BEING THE LENGTH OF THE LARGER DISCONTINUITY); IN WHICH CASE, THE DISCONTINUITIES SHALL BE MEASURED AS ONE LENGTH EQUAL TO THE TOTAL LENGTH OF THE DISCONTINUITIES AND SPACE AND EVALUATED AS SHOWN IN FIGURE E.5.

Figure E.5—Weld Quality Requirements for Discontinuities Occurring in Compression Welds (Limitations of Porosity or Fusion Type Discontinuities) (see 6.29.2.2)



1. INTERNAL LINEAR OR PLANAR REFLECTORS ABOVE STANDARD SENSITIVITY (EXCEPT ROOT OF SINGLE WELDED T-, Y-, AND K-CONNECTIONS—SEE FIGURE E.7).
2. MINOR REFLECTORS* (ABOVE DISREGARD LEVEL UP TO AND INCLUDING STANDARD SENSITIVITY) (EXCEPT ROOT OF SINGLE WELDED T-, Y-, AND K-CONNECTIONS—SEE FIGURE E.7).

*ADJACENT REFLECTORS SEPARATED BY LESS THAN THEIR AVERAGE LENGTH SHALL BE TREATED AS CONTINUOUS.

Figure E.6—Class R Indications (see Table 6.4)

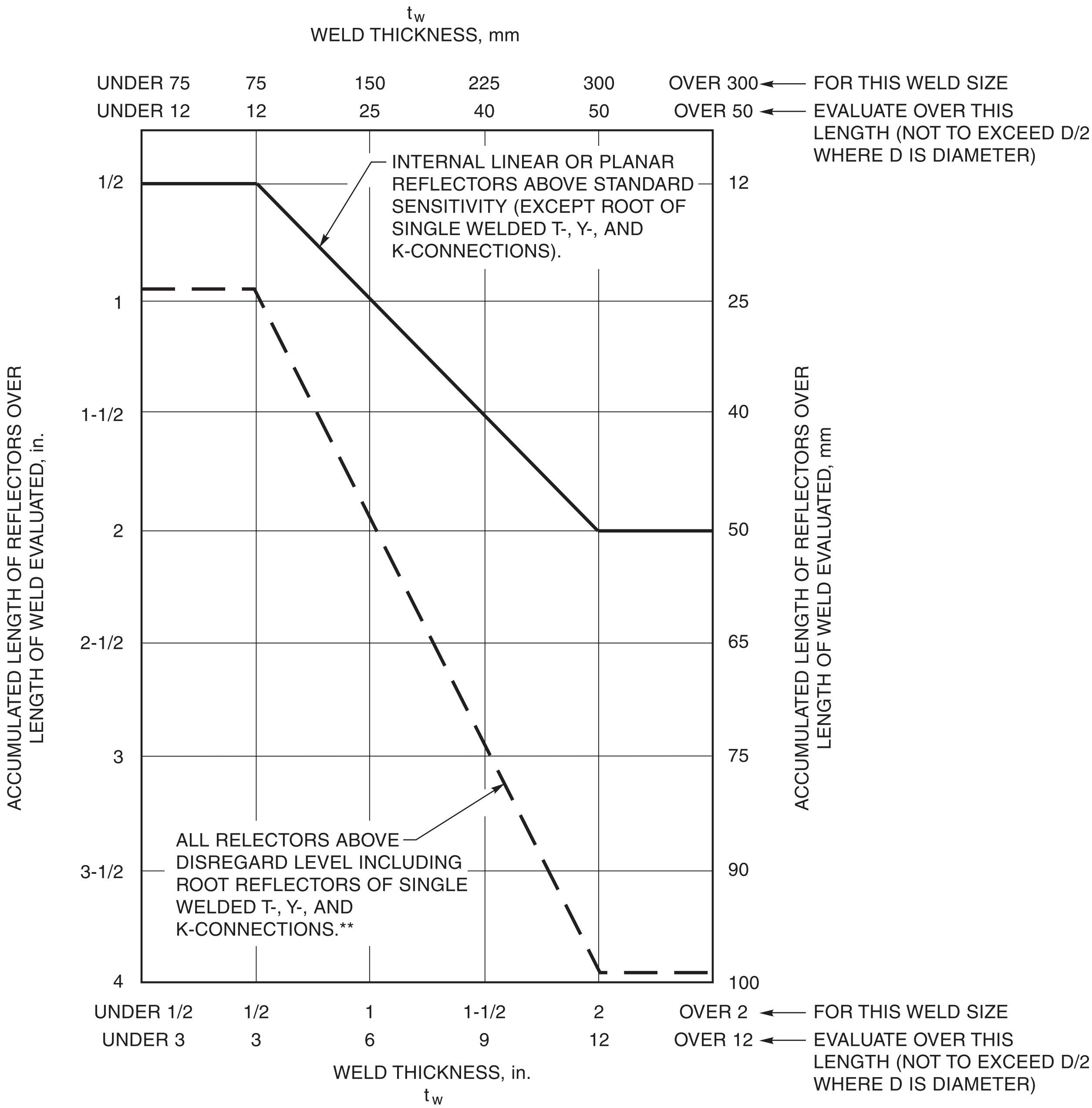
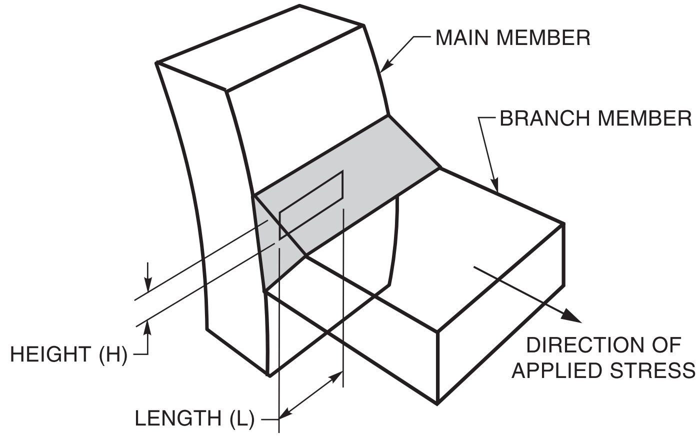


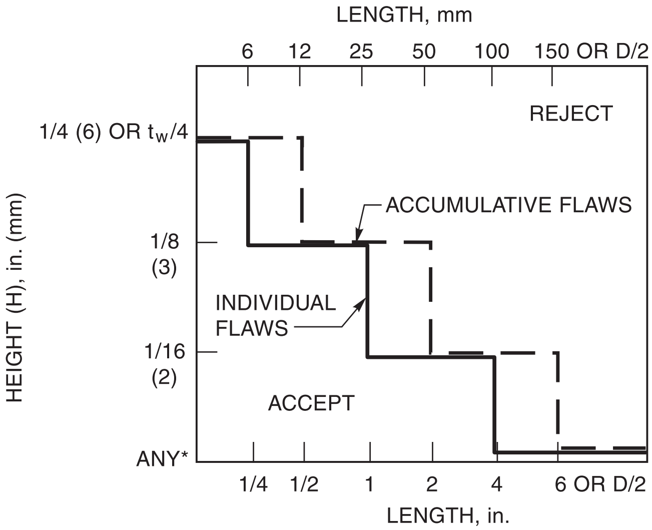
Figure E.6 (Continued)—Class R Indications (see Table 6.4)



ALIGNED DISCONTINUITIES SEPARATED BY LESS THAN (L1 + L2)/2 AND PARALLEL DISCONTINUITIES SEPARATED BY LESS THAN (H1 + H2)/2 SHALL BE EVALUATED AS CONTINUOUS.

ACCUMULATIVE FLAWS ARE EVALUATED OVER 6 in. [150 mm] OR D/2 LENGTH OF WELD (WHICHEVER IS LESS), WHERE TUBE DIAMETER = D.

L AND H BASED ON A RECTANGLE WHICH TOTALLY ENCLOSES INDICATED DISCONTINUITY



INTERNAL REFLECTORS AND ALL OTHER WELDS

DISCONTINUITIES THAT ARE WITHIN H OR $t_w/6$ OF THE OUTSIDE SURFACE SHALL BE SIZED AS IF EXTENDING TO THE SURFACE OF THE WELD.

*REFLECTORS BELOW STANDARD SENSITIVITY ARE TO BE DISREGARDED.

Figure E.7—Class X Indications (see Table 6.4)

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Annex F (Informative)

Suggested Filler Metal for Various Combinations of Stainless Steels and Other Ferrous Base Metals

This annex is not part of AWS D1.6/D1.6M:2007, *Structural Welding Code—Stainless Steel*, but is included for informational purposes only.

F1. General

A given grade of stainless steel may be welded to the same grade, to a large number of other grades of stainless steel, as well as to carbon steel or low alloy steel. When a given grade is welded to the same grade, the appropriate filler metal choice is likely, in most cases, to be a matching or nearly matching composition often with the same alloy designation. For example, 316L stainless would normally be welded with 316L filler metal, whether covered electrode (AWS A5.4 class E316L-XX), solid wire (AWS A5.9 class ER316L or ER316LSi), metal cored wire (AWS A5.9 class EC316L or EC316LSi), or flux cored electrode (AWS A5.22 class E316LTX-X). In these A5.4 and A5.22 classification designations, the "X" is used to indicate any one of several possible digits that relate characteristics of the electrode other than the alloy content of the deposit. Such a filler metal selection most commonly provides the best match in properties of the weld metal to those of the base metal. But it is not always the case.

There are certain instances where the appropriate filler metal may not have the same designation as the base metal. The most common example, by far, is that the appropriate filler metal for 304 stainless base metal is 308 (or, for 304L base metal, 308L filler metal). In this instance, the filler metal of nearly matching composition is slightly richer in alloy content, on the average, than is the base metal, as a result of a preference for weld metal containing a little ferrite to avoid hot cracking. Another example of a nonmatching designation, but a matching composition, is that the base metal 904L is commonly welded with 385 filler metal.

When a given grade of stainless steel is to be welded to another grade of stainless steel, then a number of filler metals may be appropriate choices. For example, if 304L is to be welded to 316L, either 308L filler metal or 316L filler metal is an appropriate choice. One might choose 308L because it is, in general, less expensive than 316L, or one might choose 316L because it happens to be on hand. Either choice is appropriate because the weld metal corrosion resistance will match that of the least corrosion resistant base metal (304L in most environments), because the strength of the weld metal will equal or exceed that of the weaker of the two base metals (316L in most situations; this may not apply if one or both base metals are in cold-worked condition), and because both filler metals can be expected, in this instance, to provide weld metal containing a little ferrite so that the weld metal will be crack resistant. So the choice of 308L or 316L filler metal is arbitrary in this example.

F2. Nonmatching Filler Metals

It is often not necessary or indicated for an appropriate filler metal to match the chemistry of either of two base metals to be welded together. In structural applications as considered in this code, the main considerations in filler metal selection are:

(1) weld metal strength equaling or exceeding the base metal strength (with possible exception for high strength base metals, such as cold-worked steels);

(2) weld metal corrosion resistance suitable for normal atmospheric exposure; and

(3) weld cracking resistance.

With only these three considerations, for the 304L to 316L example above, other common filler metals would also be appropriate choices in most cases, for example, 309L or 347 filler metals. This is the philosophy behind prequalification of a number of filler metals for a given base metal, as given in Tables 3.2 and 3.3 of this code.

However, when a filler metal of nonmatching chemical composition is being considered for an application, it is incumbent upon the Engineer to take into account possible aspects beyond these three considerations. For example, referring to Tables 3.2 and 3.3, for a 304 to 304 joint, 309MoL filler metal would be prequalified and quite appropriate, if a bit expensive. However, if the weldment were to require postweld heat treatment (PWHT), the selection of 309MoL filler metal would become inappropriate (and potentially dangerous) because PWHT normally causes 309MoL weld metal to suffer extensive transformation to sigma phase, a very brittle constituent. Or, if the weldment were intended for service involving cryogenic temperatures, 309MoL would likely be inappropriate because its toughness at cryogenic temperatures is very limited due to the large amount of ferrite normally found in 309MoL weld metal.

Appropriate filler metal selection can go further afield than 309MoL filler metal for 304 base metal. An example might be joining of 410 stainless steel in the mill-annealed condition. Matching 410 weld metal, in the as-welded condition, would be martensite, quite strong and hard, but not very ductile. So, if it were desired to use the weldment in the as-welded condition, 410 filler metal might be considered inappropriate for 410 base metal. However, 309 filler metal would likely be an appropriate choice because the resulting weld metal will contain a little ferrite for good resistance to hot cracking, it will at least match the strength of the mill-annealed 410, it will be ductile and tough, and it will easily exceed the corrosion resistance of the 410. The Engineer, in making this selection, should take into account the fact that the heat-affected zone of the 410 will be much harder than any other part of the weldment, but if this is acceptable, 309 is an appropriate filler metal.

F3. Suggestions for Filler Metals

Because there are so many stainless steels, and so many more possible combinations of two stainless steel grades or combinations of stainless steels with carbon steels or low alloy steels, it is virtually impossible to list all combinations of base metals and filler metals that might be considered appropriate. Nevertheless, some suggestions might be helpful. Table F.1 is limited to only one suggestion of a filler metal for a given combination of base metals, but that is not to imply that other choices are inappropriate. Again, reference is made to the multiple possibilities for prequalification as given in Tables 3.2 and 3.3, as well as to the examples discussed above. The suggestions in Table F.1 are based upon the three considerations listed above, with some engineering judgment, the criteria of which are as follows:

(1) The least costly filler metal, of several available choices, is suggested. But a more costly filler metal could be appropriate also.

(2) A readily available filler metal is suggested, as compared to one less readily available. But less readily available filler metals could be appropriate also.

(3) In solid wire and in metal cored wire classifications, a distinction is made for weldability purposes, between lower silicon filler metal and higher silicon filler metal (e.g., ER308L versus ER308LSi). From the point of view of performance of the weldment, this distinction is inconsequential and is, therefore, ignored. So, for example, when 308L is indicated in Table F.1, it means that ER308L, ER308LSi, E308L-XX covered electrodes, and E308LTX-X filler metals are equally appropriate.

(4) For the prequalified base metals of Table 3.2, any of the prequalified filler metals of Table 3.3 could be suggested.

(5) Martensitic stainless steels are likely to be given a PWHT. As a result of this consideration, the suggested filler metal in Table F.1 for a martensitic stainless steel, or for a combination of two martensitic stainless steels is, in most cases, a martensitic stainless steel with a similar response to PWHT.

(6) Precipitation hardening stainless steels are likely to be given one or two separate PWHTs. Filler metals whose weld deposits provide similar response after these more complex PWHTs are suggested.

(7) If a martensitic stainless or a precipitation hardening stainless is to be welded to a nonmartensitic stainless, and PWHT is likely, an austenitic stainless steel filler metal which is not adversely affected by PWHT is suggested.

(8) For certain stainless base metals, or joints of stainless steel to creep resisting low alloy steel, a nickel base alloy filler metal, as classified to AWS A5.11, A5.14, or the soon to be published A5.34 is much more appropriate than a stainless steel filler metal, so the nickel base alloy filler metal is suggested.

In order to make proper use of Table F.1, the Engineer needs to take into account any unusual or special conditions that could affect the performance of a particular weldment. Table F.1 should not be used as a substitute for engineering judgement.

Index for Table F.1

For the sole purpose of indexing Table F.1, base metals are arranged into the six groups shown below. These groupings are in no way indicative of weldability, type, or any other characteristics. These groupings are only a mechanism to establish an index for users of this standard so they may quickly find the suggested filler metal for a specific base metal combination.

Group 1	Group 2	Group 3	Group 4	Group 5	Group 6
17-4PH	309S	321H	439	CA-15M	CF-20
17-7PH	309H	329	440A	CA-28MWV	CG-3M
25-6MO	309Cb	330	440B	CA-40	CG-6MMN
26-1	309HCb	334	440C	CA-40F	CG-8M
29-4	310	347	440F	CB-6	CG-12
29-4-2	310S	347H	444	CB-30	CH-10
201	310H	348	446	CC-50	CH-20
202	310Cb	348H	630	CD3MCuN	CK-3MCuN
254SMo	310HCb	403	631	CD3MN	CK-20
255	310MoLN	405	632	CD3MWCuN	CK-35MN
301	314	409	633	CD4MCu	CN-3M
301L	316	410	634	CD4MCuN	CN-3MN
301LN	316L	410S	635	CD6MN	CN-7M
302	316H	410NiMo	660	CE3MN	CN-7MS
303	316Ti	414	662	CE8MN	Nitronic 30
303Se	316Cb	416	904L	CE-30	Nitronic 32
304	316N	416Se	1925 hMo	CF-3	Nitronic 33
304L	316LN	420	2205	CF-3M	Nitronic 40
304H	317	420F	2304	CF-3MN	Nitronic 50
304N	317L	420FSe	2507	CF-8	Nitronic 60
304LN	317LM	429	A286	CF-8C	Carbon Steel, <0.3% C
305	317LMN	430	AL-6XN	CF-8M	Carbon Steel, >0.3% C
306	317LN	431	CA-6N	CF-10SMnN	Cr-Mo Creep Resisting Steel
308	320	434	CA-6NM	CF-16F	Low Alloy Steel, <0.3% C
309	321	436	CA-15	CF-16Fa	Low Alloy Steel, >0.3% C

In order to find the suggested filler metal for a specific combination of base metals, find the group number of each material in the table above. Use the table below to find which page the combination can be found.

		Base Metal Groupings					
		Group 1	Group 2	Group 3	Group 4	Group 5	Group 6
Base Metal Groupings	Group 1	page 196	page 202	page 203	page 204	page 205	page 206
	Group 2		page 197	page 207	page 208	page 209	page 210
	Group 3			page 198	page 211	page 212	page 213
	Group 4				page 199	page 214	page 215
	Group 5					page 200	page 216
	Group 6						page 201

Notes for Table F.1

1. Filler metal should match corrosion resistance of weakest link.
2. Filler metal should at least match strength of weakest link, if possible.
3. If the combination is likely to be postweld heat treated, a filler metal which will not be embrittled by PWHT is indicated.
4. Filler metal should provide some ferrite in the deposit with dilution from the two sides of the joint.
5. Filler metal should not be crack sensitive, if possible.
6. NiCr-3 is a bare filler welding electrode or rod. The comparable welding electrode for SMAW is NiCrFe-2.
7. For similar metal welding of Cr-Mo Creep Resisting Steel, use a comparable chemical composition filler metal.

Table F.1
Suggested Filler Metals for Various Combinations of Stainless Steel and Other Ferrous Base Metals

	Base Metal																								
Base Metal	17-4PH	17-7PH	25-6MO	26-1	29-4	29-4-2	201	202	254SMo	255	301	301L	301LN	302	303	303Se	304	304L	304H	304N	304LN	305	306	308	309
17-4PH	630	630	308	308L	308L	308L	308	308	308L	2553	308	308L	308L	308	NCW	NCW	308	308L	308H	308	308L	308	308	308	308
17-7PH		630	308	308L	308L	308L	308	308	308L	2553	308	308L	308L	308	NCW	NCW	308	308L	308H	308	308L	308	308	308	308
25-6MO			NiCrMo-3	NiCrMo-3	NiCrMo-3	NiCrMo-3	309L	309L	NiCrMo-3	2593	309L	309L	309L	309L	NCW	NCW	309L	309L	309L	309L	309L	309L	385	309L	309L
26-1				446LMo	446LMo	446LMo	308L	308L	308L	308L	308L	308L	308L	308L	NCW	NCW	308L	308L	308L	308L	308L	308L	308L	308L	308L
29-4					WA	WA	308L	308L	308L	308L	308L	308L	308L	308L	NCW	NCW	308L	308L	308L	308L	308L	308L	308L	308L	308L
29-4-2						WA	308L	308L	308L	308L	308L	308L	308L	308L	NCW	NCW	308L	308L	308L	308L	308L	308L	308L	308L	308L
201							240	240	308L	308L	308	308L	308L	308	NCW	NCW	308	308L	308	308	308L	308	308	308	308
202								240	308L	308L	308	308L	308L	308	NCW	NCW	308	308L	308	308	308L	308	308	308	308
254SMo									NiCrMo-3	2553	308L	308L	308L	308L	NCW	NCW	308L	308L	308L	308L	308L	308L	308L	308L	308L
255										2553	308L	308L	308L	308L	NCW	NCW	308L	308L	308L	308L	308L	308L	308L	308L	308L
301											308	308L	308L	308	NCW	NCW	308	308L	308	308	308L	308	308	308	308
301L												308L	308L	308L	NCW	NCW	308L	308L	308L	308L	308L	308L	308L	308L	308L
301LN													308L	308L	NCW	NCW	308L	308L	308L	308L	308L	308L	308L	308L	308L
302														308	NCW	NCW	308L	308L	308	308	308L	308	308	308	308
303															NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW
303Se																NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW
304																	308	308L	308	308	308L	308	308	308	308
304L																		308L	308L	308L	308L	308L	308L	308L	308L
304H																			308H	308	308L	308	308	308	308
304N																				308	308L	308l	308	308	308
304LN																					308L	308L	308L	308L	308L
305																						308	308	308	308
306																							NM	309L	309L
308																								308	308
309																									309

NCW = Not Considered Weldable NM = No Matching Filler Metal WA = Weld Autogenously NA = Not Addressed by this Table

(Continued)

Table F.1 (Continued)
Suggested Filler Metals for Various Combinations of Stainless Steel and Other Ferrous Base Metals

	Base Metal																								
Base Metal	309S	309H	309Cb	309HCb	310	310S	310H	310Cb	310HCb	310MoLN	314	316	316L	316H	316Ti	316Cb	316N	316LN	317	317L	317LM	317LMN	317LN	320	321
309S	309	309	309	309	309L	309L	309L	309L	309L	309L	309L	316	316L	316	309	309	309	316L	309	309	309	309	309	2209	308
309H		309	309	309	309L	309L	309L	309L	309L	309L	309L	316	316L	316	309	309	309	316L	309	309	309	309	309	2209	308
309Cb			309Cb	309Cb	309L	309L	309L	309L	309L	309L	309L	316	316L	316	318	318	318	316L	309	309	309	309	309	2209	347
309HCb				309Cb	309L	309L	309L	309L	309L	309L	309L	316	316L	316	318	318	318	316L	309	309	309	309	309	2209	347
310					310	310	310	310	310	310	310	309L	309L	309L	309L	309L	309L	309L	309	309	309	309	309	310	309
310S						310	310	310	310	310	310	309L	309L	309L	309L	309L	309L	309L	309	309	309	309	309	310	309
310H							310	310	310	310	310	309L	309L	309L	309L	309L	309L	309L	309	309	309	309	309	310	309
310Cb								310Cb	310Cb	310	310	309L	309L	309L	309L	309L	309L	309L	309	309	309	309	309	310	309
310HCb									310Cb	310	310	309L	309L	309L	309L	309L	309L	309L	309	309	309	309	309	310	309
310MoLN										385	310	316L	316L	316	316	316	316	316L	317L	317L	385	385	385	385	309L
314											310	309L	309L	309L	309L	309L	309L	309L	309	309	309	309	309	310	309
316												316	316L	316	316	316	316	316L	316	316L	316L	316L	316L	2209	347
316L													316L	316	316L	316L	316L	316L	316L	316L	316L	316L	316L	2209	347
316H														316	316	316	316	316	316	316	316	316	316	2209	347
316Ti															318	318	316	316	316	316	316	316	316	2209	347
316Cb																318	316	316	316	316	316	316	316	2209	347
316N																	316	316	316	316	316	316	316	2209	347
316LN																		317L	317L	317L	317L	317L	317L	2209	347
317																			317	317L	317L	317L	317L	2209	347
317L																				317L	317L	317L	317L	2209	347
317LM																					385	385	385	385	347
317LMN																						385	317L	385	347
317LN																							317L	385	347
320																								320LR	2209
321																									347

NCW = Not Considered Weldable NM = No Matching Filler Metal WA = Weld Autogenously NA = Not Addressed by this Table

(Continued)

Table F.1 (Continued)
Suggested Filler Metals for Various Combinations of Stainless Steel and Other Ferrous Base Metals

	Base Metal																								
Base Metal	321H	329	330	334	347	347H	348	348H	403	405	409	410	410S	410NiMo	414	416	416Se	420	420F	420FSe	429	430	431	434	436
321H	347	347	310	310	347	347	347	347	308	308	308	308	308	308	308	308	NCW	308	NCW	NCW	308	308	308	308	308
329		2593	312	312	347	347	347	347	308	308	308	308	308	308	308	308	NCW	308	NCW	NCW	308	308	308	308	308
330			330	310	310	310	310	310	310	310	310	310	310	310	310	310	NCW	310	NCW	NCW	310	310	310	310	310
334				310	310	310	310	310	310	310	310	310	310	310	310	310	NCW	310	NCW	NCW	310	310	310	310	310
347					347	347	347	347	308	308	308	308	308	308	308	308	NCW	308	NCW	NCW	308	308	308	308	308
347H						347	347	347	308	308	308	308	308	308	308	308	NCW	308	NCW	NCW	308	308	308	308	308
348							347	347	308	308	308	308	308	308	308	308	NCW	308	NCW	NCW	308	308	308	308	308
348H								347	308	308	308	308	308	308	308	308	NCW	308	NCW	NCW	308	308	308	308	308
403									410	409	409	410	410	410NiMo	410NiMo	410NiMo	NCW	410NiMo	NCW	NCW	410NiMo	410NiMo	410NiMo	410NiMo	410NiMo
405										409	409	409	409	410NiMo	410NiMo	410NiMo	NCW	410NiMo	NCW	NCW	410NiMo	410NiMo	410NiMo	410NiMo	410NiMo
409											409	409	409	410NiMo	410NiMo	410NiMo	NCW	410NiMo	NCW	NCW	410NiMo	410NiMo	410NiMo	410NiMo	410NiMo
410												410	410	410NiMo	410NiMo	410NiMo	NCW	410NiMo	NCW	NCW	410NiMo	410NiMo	410NiMo	410NiMo	410NiMo
410S													410	410NiMo	410NiMo	410NiMo	NCW	410NiMo	NCW	NCW	410NiMo	410NiMo	410NiMo	410NiMo	410NiMo
410NiMo														410NiMo	410NiMo	410NiMo	NCW	410NiMo	NCW	NCW	410NiMo	410NiMo	410NiMo	410NiMo	410NiMo
414															410NiMo	410NiMo	NCW	410NiMo	NCW	NCW	410NiMo	410NiMo	410NiMo	410NiMo	410NiMo
416																410NiMo	NCW	410NiMo	NCW	NCW	410NiMo	410NiMo	410NiMo	410NiMo	410NiMo
416Se																	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW
420																		410NiMo	NCW	NCW	410NiMo	410NiMo	410NiMo	410NiMo	410NiMo
420F																			NCW	NCW	NCW	NCW	NCW	NCW	NCW
420FSe																				NCW	NCW	NCW	NCW	NCW	NCW
429																					430	430	430	430	430
430																						430	430	430	430
431																							NM	430	430
434																								444	444
436																									444

NCW = Not Considered Weldable NM = No Matching Filler Metal WA = Weld Autogenously NA = Not Addressed by this Table

(Continued)

Table F.1 (Continued)
Suggested Filler Metals for Various Combinations of Stainless Steel and Other Ferrous Base Metals

	Base Metal																								
Base Metal	439	440A	440B	440C	440F	444	446	630	631	632	633	634	635	660	662	904L	1925 hMo	2205	2304	2507	A286	AL-6XN	CA-6N	CA-6NM	CA-15
439	444	310	310	310	NCW	430	430	308	308	308	308	308	308	430	430	309L	2209	2209	2209	2209	2209	2209	308	308	308
440A		NM	310	310	NCW	430	430	630	630	630	630	630	630	310	310	310	310	2209	2209	2209	310	310	410NiMo	410NiMo	410NiMo
440B			NM	310	NCW	430	430	630	630	630	630	630	630	310	310	310	310	2209	2209	2209	310	310	410NiMo	410NiMo	410NiMo
440C				NM	NCW	430	430	630	630	630	630	630	630	310	310	310	310	2209	2209	2209	310	310	410NiMo	410NiMo	410NiMo
440F					NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW
444						444	444	316L	316L	316L	316L	316L	316L	2209	2209	2209	2209	2209	2209	2209	2209	2209	410NiMo	410NiMo	410NiMo
446							310	308	308	308	308	308	308	310	310	310	310	2209	2209	2593	310	310	308	308	308
630								630	630	630	630	630	630	NiCrMo-3	NiCrMo-3	310	NiCrMo-3	2209	2209	2209	310	NiCrMo-3	410NiMo	410NiMo	410NiMo
631									630	630	630	630	630	NiCrMo-3	NiCrMo-3	310	NiCrMo-3	2209	2209	2209	310	NiCrMo-3	410NiMo	410NiMo	410NiMo
632										630	630	630	630	NiCrMo-3	NiCrMo-3	310	NiCrMo-3	2209	2209	2209	310	NiCrMo-3	410NiMo	410NiMo	410NiMo
633											630	630	630	NiCrMo-3	NiCrMo-3	310	NiCrMo-3	2209	2209	2209	310	NiCrMo-3	410NiMo	410NiMo	410NiMo
634												630	630	NiCrMo-3	NiCrMo-3	310	NiCrMo-3	2209	2209	2209	310	NiCrMo-3	410NiMo	410NiMo	410NiMo
635													630	NiCrMo-3	NiCrMo-3	310	NiCrMo-3	2209	2209	2209	310	NiCrMo-3	410NiMo	410NiMo	410NiMo
660														NiCrMo-3	NiCrMo-3	385	NiCrMo-3	2209	2209	2209	NiCrMo-3	NiCrMo-3	NiCrMo-3	NiCrMo-3	NiCrMo-3
662															NiCrMo-3	385	NiCrMo-3	2209	2209	2209	NiCrMo-3	NiCrMo-3	NiCrMo-3	NiCrMo-3	NiCrMo-3
904L																385	NiCrMo-3	2209	2209	385	NiCrMo-3	NiCrMo-3	309L	309L	309L
1925 hMo																	NiCrMo-3	2209	2209	2593	NiCrMo-3	NiCrMo-3	310	310	310
2205																		2209	2209	2209	2209	2209	2209	2209	2209
2304																			2209	2209	2209	2209	2209	2209	2209
2507																				2593	2593	2593	2593	2593	2593
A286																					NiCrMo-3	NiCrMo-3	310	310	310
AL-6XN																						NiCrMo-3	310	310	310
CA-6N																							410NiMo	410NiMo	410NiMo
CA-6NM																								410NiMo	410NiMo
CA-15																									410

NCW = Not Considered Weldable   NM = No Matching Filler Metal   WA = Weld Autogenously   NA = Not Addressed by this Table

(Continued)

Table F.1 (Continued)
Suggested Filler Metals for Various Combinations of Stainless Steel and Other Ferrous Base Metals

	Base Metal																								
Base Metal	CA-15M	CA-28MWV	CA-40	CA-40F	CB-6	CB-30	CC-50	CD3MCuN	CD3MN	CD3MWCuN	CD4MCu	CD4MCuN	CD6MN	CE3MN	CE8MN	CE-30	CF-3	CF-3M	CF-3MN	CF-8	CF-8C	CF-8M	CF-10SMnN	CF-16F	CF-16Fa
CA-15M	410NiMo	410NiMo	410NiMo	NCW	410NiMo	410NiMo	410NiMo	312	2209	2593	2593	2593	2593	2593	2593	312	308L	316L	316L	308	308	308	308	NCW	NCW
CA-28MWV		CrMoWV12[a]	420	NCW	410NiMo	410NiMo	410NiMo	2593	2209	2593	2593	2593	2593	2593	2593	312	312	312	312	312	310	310	310	NCW	NCW
CA-40			420	NCW	410NiMo	410NiMo	410NiMo	410NiMo	2209	2593	2593	2593	2593	2593	2593	312	312	312	312	312	312	312	312	NCW	NCW
CA-40F				NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW
CB-6					308	308	308	308	2209	2209	2209	2209	2209	2209	2209	312	308L	316L	316L	308	308	308	308	NCW	NCW
CB-30						308	308	308	2209	2209	2209	2209	2209	2209	2209	312	308L	316L	316L	308	308	308	308	NCW	NCW
CC-50							312	2593	2209	2593	2593	2593	2593	2593	2593	312	308L	316L	316L	308	308	308	309	NCW	NCW
CD3MCuN								2593	2209	2593	2593	2593	2593	2593	2593	312	308L	316L	317L	308	308	308	309	NCW	NCW
CD3MN									2209	2209	2209	2209	2209	2209	2209	312	308L	316L	317L	308	308	308	309	NCW	NCW
CD3MWCuN										2593	2593	2593	2593	2593	2593	312	308L	316L	317L	308	308	308	309	NCW	NCW
CD4MCu											2593	2593	2593	2593	2593	312	308L	316L	317L	308	308	308	309	NCW	NCW
CD4MCuN												2593	2593	2593	2593	312	308L	316L	317L	308	308	308	309	NCW	NCW
CD6MN													2593	2593	2593	312	308L	316L	317L	308	308	308	309	NCW	NCW
CE3MN														2593	2593	312	308L	316L	317L	308	308	308	309	NCW	NCW
CE8MN															2593	312	308L	316L	317L	308	308	308	309	NCW	NCW
CE-30																312	308L	316L	316L	308	308	308	309	NCW	NCW
CF-3																	308L	308L	308L	308	308	308	309	NCW	NCW
CF-3M																		316L	316L	308	308	308	309	NCW	NCW
CF-3MN																			317L	308	308	308	309	NCW	NCW
CF-8																				308	308	308	309	NCW	NCW
CF-8C																					347	308	309	NCW	NCW
CF-8M																						316	309	NCW	NCW
CF-10SMnN																							309	NCW	NCW
CF-16F																								NCW	NCW
CF-16Fa																									NCW

[a]EN 1599 or ISO 3580.

NCW = Not Considered Weldable NM = No Matching Filler Metal WA = Weld Autogenously NA = Not Addressed by this Table

(Continued)

Table F.1 (Continued)
Suggested Filler Metals for Various Combinations of Stainless Steel and Other Ferrous Base Metals

Base Metal	CF-20	CG-3M	CG-6MMN	CG-8M	CG-12	CH-10	CH-20	CK-3MCuN	CK-20	CK-35MN	CN-3M	CN-3MN	CN-7M	CN-7MS	Nitronic 30	Nitronic 32	Nitronic 33	Nitronic 40	Nitronic 50	Nitronic 60	Carbon Steel, <0.3% C	Carbon Steel, >0.3% C	Cr-Mo Creep Resisting Steel	Low Alloy Steel, <0.3% C	Low Alloy Steel, >0.3% C
CF-20	308	308	308	308	308	308	308	308	308	308	308	308	310	310	308	308	308	308	308	308	309	312	NiCr-3	309	312
CG-3M		317L	317L	317	309	309	309	317L	317L	317L	317L	317L	310	310	308	308	308	308	317L	308	309	312	NiCr-3	309	312
CG-6MMN			309LMo[b]	317	309	309	309	385	309LMo[b]	385	385	385	310	310	308	308	308	308	209	209	309	312	NiCr-3	309	312
CG-8M				317	309	309	309	317	317	317L	317L	317L	310	310	308	308	308	308	317	308	309	312	NiCr-3	309	312
CG-12					309	309	309	309	309	309	309	309	310	310	308	308	308	308	309	308	309	312	NiCr-3	309	312
CH-10						309	309	309L	309	309	309	309	310	310	308	308	308	308	309	308	309	312	NiCr-3	309	312
CH-20							310	309L	310	309	309	309	310	310	309	309	309	308	309	309	309	312	NiCr-3	309	312
CK-3MCuN								NiCrMo-3	310	NiCrMo-3	385	385	385	385	308	308	308	308	317L	308L	309	312	NiCr-3	309	312
CK-20									310	310	385	385	310	310	308	308	308	308	310	308	309	312	NiCr-3	309	312
CK-35MN										NiCrMo-3	NiCrMo-3	NiCrMo-3	NiCrMo-3	NiCrMo-3	308	308	308	308	317L	308L	309	312	NiCr-3	309	312
CN-3M											385	385	385	385	308	308	308	308	317L	308L	309	312	NiCr-3	309	312
CN-3MN												385	385	385	308	308	308	308	317L	308L	309	312	NiCr-3	309	312
CN-7M													320LR	320LR	2209	2209	2209	2209	2209	2209	312	312	NiCr-3	312	312
CN-7MS														320LR	2209	2209	2209	2209	2209	2209	312	312	NiCr-3	312	312
Nitronic 30															209	209	209	209	209	209	309	312	NiCr-3	309	312
Nitronic 32																209	209	209	209	209	309	312	NiCr-3	309	312
Nitronic 33																	209	209	209	209	309	312	NiCr-3	309	312
Nitronic 40																		209	209	209	309	312	NiCr-3	309	312
Nitronic 50																			209	209	309	312	NiCr-3	309	312
Nitronic 60																				218	309	312	NiCr-3	309	312
Carbon Steel, < 0.3% C																					NA	NA	NA	NA	NA
Carbon Steel, > 0.3% C																						NA	NA	NA	NA
Cr-Mo Creep Resisting Steel																							NA	NA	NA
Low Alloy Steel, < 0.3% C																								NA	NA
Low Alloy Steel, > 0.3% C																									NA

[b]Sometimes identified as 309MoL.

NCW = Not Considered Weldable NM = No Matching Filler Metal WA = Weld Autogenously NA = Not Addressed by this Table

(Continued)

Table F.1 (Continued)
Suggested Filler Metals for Various Combinations of Stainless Steel and Other Ferrous Base Metals

	Base Metal																								
Base Metal	309S	309H	309Cb	309HCb	310	310S	310H	310Cb	310HCb	310MoLN	314	316	316L	316H	316Ti	316Cb	316N	316LN	317	317L	317LM	317LMN	317LN	320	321
17-4PH	308	308	308	308	309L	309L	309L	309L	309L	309L	309L	308	308L	308	308	308	308	308L	308	308	308	308	308	2209	308
17-7PH	308	308	308	308	309L	309L	309L	309L	309L	309L	309L	308	308L	308	308	308	308	308L	308	308	308	308	308	2209	308
25-6MO	309L	309L	309L	309L	310	310	310	310	310	385	310	316L	316L	316L	316L	316L	317L	317L	385	385	NiCrMo-3	NiCrMo-3	385	NiCrMo-3	309L
26-1	308L	308L	308L	308L	309L	309L	309L	309L	309L	309L	309L	316L	316L	316L	316L	316L	316L	316L	317L	317L	NiCrMo-3	NiCrMo-3	385	385	308L
29-4	308L	308L	308L	308L	309L	309L	309L	309L	309L	309L	309L	316L	316L	316L	316L	316L	316L	316L	317L	317L	NiCrMo-3	NiCrMo-3	385	385	308L
29-4-2	308L	308L	308L	308L	309L	309L	309L	309L	309L	309L	309L	316L	316L	316L	316L	316L	316L	316L	317L	317L	NiCrMo-3	NiCrMo-3	385	385	308L
201	308	308	308	308	309L	309L	309L	309L	309L	309L	309L	308L	308L	308	308	308	308	308L	308	308	308	308	308	2209	308
202	308	308	308	308	309L	309L	309L	309L	309L	309L	309L	308L	308L	308	308	308	308	308L	308	308	308	308	308	2209	308
254SMo	308L	308L	308L	308L	310	310	310	310	310	310	310	316L	316L	316L	316L	316L	316L	316L	317L	317L	385	385	385	385	308L
255	308L	308L	308L	308L	309L	309L	309L	309L	309L	309L	309L	316L	316L	316L	316	316	316	316L	317L	317L	2593	2593	2593	2593	308L
301	308	308	308	308	309L	309L	309L	309L	309L	309L	309L	308	308L	308	308	308	308	308L	308	308	308	308	308	2209	308
301L	308L	308L	308L	308L	309L	309L	309L	309L	309L	309L	309L	308L	308L	308	308L	308L	308L	308L	308L	308L	308L	308L	308L	2209	308L
301LN	308L	308L	308L	308L	309L	309L	309L	309L	309L	309L	309L	308L	308L	308	308L	308L	308L	308L	308L	308L	308L	308L	308L	2209	308L
302	308	308	308	308	309L	309L	309L	309L	309L	309L	309L	308	308L	308	308	308	308	308L	308	308	308	308	308	2209	308
303	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW
303Se	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW
304	308	308	308	308	309L	309L	309L	309L	309L	309L	309L	308	308L	308	308	308	308	308L	308	308	308	308	308	2209	308
304L	308L	308L	308L	308L	309L	309L	309L	309L	309L	309L	309L	308L	308L	308	308L	308L	308L	308L	308L	308L	308L	308L	308L	2209	308L
304H	308	308	308	308	309L	309L	309L	309L	309L	309L	310	308	308	308H	308H	308H	308H	308	308	308	308	308	308	2209	347
304N	308	308	308	308	309L	309L	309L	309L	309L	309L	309L	308	308L	308	308	308	308	308L	308	308	308	308	308	2209	308
304LN	308L	308L	308L	308L	309L	309L	309L	309L	309L	309L	309L	308L	308L	308L	308L	308L	308L	308L	308L	308L	308L	308L	308L	2209	308L
305	308	308	308	308	309L	309L	309L	309L	309L	309L	309L	308	308L	308	308	308	308	308L	308	308	308	308	308	2209	308
306	309L	309L	309L	309L	309L	309L	309L	309L	309L	309L	310	309L	309L	309L	309L	309L	309L	309L	309L	309L	309L	309L	309L	2209	309L
308	308	308	308	308	309L	309L	309L	309L	309L	309L	309L	308	308L	308	308	308	308	308L	308	308	308	308	308	2209	308
309	309	309	309	309	309L	309L	309L	309L	309L	309L	309L	316	316L	316	309	309	309	316L	309	309	309	309	309	2209	308

NCW = Not Considered Weldable   NM = No Matching Filler Metal   WA = Weld Autogenously   NA = Not Addressed by this Table

(Continued)

Table F.1 (Continued)
Suggested Filler Metals for Various Combinations of Stainless Steel and Other Ferrous Base Metals

Base Metal	Base Metal: 321H	329	330	334	347	347H	348	348H	403	405	409	410	410S	410NiMo	414	416	416Se	420	420F	420FSe	429	430	431	434	436
17-4PH	308	308	312	312	308	308	308	308	410NiMo	308	308	410NiMo	410NiMo	410NiMo	410NiMo	410NiMo	NCW	410NiMo	NCW	NCW	430	430	630	630	630
17-7PH	308	308	312	312	308	308	308	308	410NiMo	308	308	410NiMo	410NiMo	410NiMo	410NiMo	410NiMo	NCW	410NiMo	NCW	NCW	430	430	630	630	630
25-6MO	309L	2593	310	310	309L	309L	309L	309L	309L	309L	309L	310	310	310	310	310	NCW	310	NCW	NCW	310	430	310	310	2209
26-1	308L	2593	2209	2209	316L	316L	316L	316L	316L	316L	316L	316L	316L	316L	316L	316L	NCW	316L	NCW	NCW	316L	316L	316L	316L	316L
29-4	308L	2593	2209	2209	316L	316L	316L	316L	316L	316L	316L	316L	316L	316L	316L	316L	NCW	316L	NCW	NCW	316L	316L	316L	316L	316L
29-4-2	308L	2593	2209	2209	316L	316L	316L	316L	316L	316L	316L	316L	316L	316L	316L	316L	NCW	316L	NCW	NCW	316L	316L	316L	316L	316L
201	308	308	312	312	308	308	308	308	308	308	308	308	308	308	308	308	NCW	308	NCW	NCW	308	308	308	308	308
202	308	308	312	312	308	308	308	308	308	308	308	308	308	308	308	308	NCW	308	NCW	NCW	308	308	308	308	308
254SMo	347	2593	312	312	347	347	347	347	310	316L	316L	316L	316L	316L	316L	316L	NCW	316L	NCW	NCW	316L	316L	316L	316L	316L
255	347	2593	2593	2593	347	347	347	347	2593	316L	316L	2593	2593	2593	2593	2593	NCW	316L	NCW	NCW	316L	316L	2593	316L	316L
301	308	308	312	312	308	308	308	308	308	308	308	308	308	308	308	308	NCW	308	NCW	NCW	308	308	308	308	308
301L	308L	308L	312	312	308L	308L	308L	308L	308L	308L	308L	308L	308L	308L	308L	308L	NCW	308L	NCW	NCW	308L	308L	308L	308L	308L
301LN	308L	308L	312	312	308L	308L	308L	308L	308L	308L	308L	308L	308L	308L	308L	308L	NCW	308L	NCW	NCW	308L	308L	308L	308L	308L
302	308	308	312	312	308	308	308	308	308	308	308	308	308	308	308	308	NCW	308	NCW	NCW	308	308	308	308	308
303	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW
303Se	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW
304	308	308	312	312	308	308	308	308	308	308	308	308	308	308	308	308	NCW	308	NCW	NCW	308	308	308	308	308
304L	308L	308L	312	312	308L	308L	308L	308L	308L	308L	308L	308L	308L	308L	308L	308L	NCW	308L	NCW	NCW	308L	308L	308L	308L	308L
304H	347	308	310	310	347	347	347	347	308	308	308	308	308	308	308	308	NCW	308	NCW	NCW	308	308	308	308	308
304N	308	308	312	312	308	308	308	308	308	308	308	308	308	308	308	308	NCW	308	NCW	NCW	308	308	308	308	308
304LN	308L	308L	312	312	308L	308L	308L	308L	308L	308L	308L	308L	308L	308L	308L	308L	NCW	308L	NCW	NCW	308L	308L	308L	308L	308L
305	308	308	312	312	347	347	347	347	308	308	308	308	308	308	308	308	NCW	308	NCW	NCW	308	308	308	308	308
306	309L	309L	310	310	310	310	310	310	310	309L	309L	309L	309L	309L	309L	309L	NCW	309L	NCW	NCW	309L	309L	309L	309L	309L
308	308	308	312	312	347	347	347	347	308	308	308	308	308	308	308	308	NCW	308	NCW	NCW	308	308	308	308	308
309	308	309	312	312	347	347	347	347	308	308	308	308	308	308	308	308	NCW	308	NCW	NCW	308	308	308	308	308

NCW = Not Considered Weldable NM = No Matching Filler Metal WA = Weld Autogenously NA = Not Addressed by this Table

(Continued)

Table F.1 (Continued)
Suggested Filler Metals for Various Combinations of Stainless Steel and Other Ferrous Base Metals

Base Metal	Base Metal																								
	439	440A	440B	440C	440F	444	446	630	631	632	633	634	635	660	662	904L	1925 hMo	2205	2304	2507	A286	AL-6XN	CA-6N	CA-6NM	CA-15
17-4PH	630	630	630	630	NCW	316L	308	630	630	630	630	630	630	NiCrMo-3	NiCrMo-3	308	308	2209	2209	2593	NiCrMo-3	308	410NiMo	410NiMo	410NiMo
17-7PH	630	630	630	630	NCW	316L	308	630	630	630	630	630	630	NiCrMo-3	NiCrMo-3	308	308	2209	2209	2593	NiCrMo-3	308	410NiMo	410NiMo	410NiMo
25-6MO	2209	310	310	310	NCW	2209	310	NiCrMo-3	NiCrMo-3	NiCrMo-3	NiCrMo-3	NiCrMo-3	NiCrMo-3	NiCrMo-3	NiCrMo-3	NiCrMo-3	NiCrMo-3	2209	2209	2593	NiCrMo-3	NiCrMo-3	310	310	310
26-1	316L	316L	316L	316L	NCW	316L	316L	316L	316L	316L	316L	316L	316L	2209	2209	NiCrMo-3	NiCrMo-3	2209	2209	2593	2209	NiCrMo-3	2209	2209	2209
29-4	316L	316L	316L	316L	NCW	316L	316L	316L	316L	316L	316L	316L	316L	2209	2209	NiCrMo-3	NiCrMo-3	2209	2209	2593	2209	NiCrMo-3	2209	2209	2209
29-4-2	316L	316L	316L	316L	NCW	316L	316L	316L	316L	316L	316L	316L	316L	2209	2209	NiCrMo-3	NiCrMo-3	2209	2209	2593	2209	NiCrMo-3	2209	2209	2209
201	308	308	308	308	NCW	316L	308	308	308	308	308	308	308	312	312	309L	309L	308L	308L	308L	312	309L	308	308	308
202	308	308	308	308	NCW	316L	308	308	308	308	308	308	308	312	312	309L	309L	308L	308L	308L	312	309L	308	308	308
254SMo	316L	316L	316L	316L	NCW	2209	316L	316L	316L	316L	316L	316L	316L	2209	2209	385	NiCrMo-3	2209	2209	NiCrMo-3	2209	NiCrMo-3	316L	316L	316L
255	316L	2593	2593	2593	NCW	2593	2593	2593	2593	2593	2593	2593	2593	2593	2593	2593	2593	2209	2209	2593	2593	2593	2593	2593	2593
301	308	308	308	308	NCW	316L	308	308	308	308	308	308	308	312	312	309L	309L	308L	308L	308L	312	309L	308	308	308
301L	308L	308L	308L	308L	NCW	316L	308L	308L	308L	308L	308L	308L	308L	312	312	309L	309L	308L	308L	308L	312	309L	308L	308L	308L
301LN	308L	308L	308L	308L	NCW	316L	308L	308L	308L	308L	308L	308L	308L	312	312	309L	309L	308L	308L	308L	312	309L	308L	308L	308L
302	308	308	308	308	NCW	316L	308	308	308	308	308	308	308	312	312	309L	309L	308L	308L	308L	312	309L	308	308	308
303	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW
303Se	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW
304	308	308	308	308	NCW	316L	308	308	308	308	308	308	308	312	312	309L	309L	308L	308L	308L	312	309L	308	308	308
304L	308L	308L	308L	308L	NCW	316L	308L	308L	308L	308L	308L	308L	308L	312	312	309L	309L	308L	308L	308L	312	309L	308L	308L	308L
304H	308	308	308	308	NCW	316L	308	308	308	308	308	308	308	312	312	309L	309L	308L	308L	308L	312	309L	308	308	308
304N	308	308	308	308	NCW	316L	308	308	308	308	308	308	308	312	312	309L	309L	308L	308L	308L	312	309L	308	308	308
304LN	308L	308L	308L	308L	NCW	316L	308L	308L	308L	308L	308L	308L	308L	312	312	309L	309L	308L	308L	308L	312	309L	308L	308L	308L
305	308	308	308	308	NCW	316L	308	308	308	308	308	308	308	312	312	309L	309L	308L	308L	308L	312	309L	308	308	308
306	309L	309L	309L	309L	NCW	2209	310	310	310	310	310	310	310	2209	2209	385	385	2209	2209	2209	2209	385	308L	308L	308L
308	308	308	308	308	NCW	316L	308	308	308	308	308	308	308	312	312	309L	309L	308L	308L	308L	312	309L	308	308	308
309	308	308	308	308	NCW	309L	309	309	309	309	309	309	309	312	312	309L	309L	309L	309L	309L	312	309L	308	308	308

NCW = Not Considered Weldable NM = No Matching Filler Metal WA = Weld Autogenously NA = Not Addressed by this Table

(Continued)

Table F.1 (Continued)
Suggested Filler Metals for Various Combinations of Stainless Steel and Other Ferrous Base Metals

	Base Metal																								
Base Metal	CA-15M	CA-28MWV	CA-40	CA-40F	CB-6	CB-30	CC-50	CD3MCuN	CD3MN	CD3MWCuN	CD4MCu	CD4MCuN	CD6MN	CE3MN	CE8MN	CE-30	CF-3	CF-3M	CF-3MN	CF-8	CF-8C	CF-8M	CF-10SMnN	CF-16F	CF-16Fa
17-4PH	410NiMo	630	630	NCW	630	630	630	2593	2209	2593	2593	2593	2593	2593	2593	312	308L	316L	316L	308	308	308	309	NCW	NCW
17-7PH	410NiMo	630	630	NCW	630	630	630	2593	2209	2593	2593	2593	2593	2593	2593	312	308L	316L	316L	308	308	308	309	NCW	NCW
25-6MO	310	310	310	NCW	310	310	310	2593	2209	2593	2593	2593	2593	2593	2593	312	308L	316L	385	308	308	308	309	NCW	NCW
26-1	2209	2209	2209	NCW	2209	2209	312	2593	2209	2593	2593	2593	2593	2593	2593	312	308L	316L	317L	308	308	308	309	NCW	NCW
29-4	2209	2209	2209	NCW	2209	2209	312	2593	2209	2593	2593	2593	2593	2593	2593	312	308L	316L	317L	308	308	308	309	NCW	NCW
29-4-2	2209	2209	2209	NCW	2209	2209	312	2593	2209	2593	2593	2593	2593	2593	2593	312	308L	316L	317L	308	308	308	309	NCW	NCW
201	308	309	309	NCW	308	308	308	308	308	308	308	308	308	308	308	308	308L	316L	316L	308	308	308	308	NCW	NCW
202	308	309	309	NCW	308	308	308	308	308	308	308	308	308	308	308	308	308L	316L	316L	308	308	308	308	NCW	NCW
254SMo	316L	309L	309L	NCW	309L	309L	2209	NiCrMo-3	2209	2593	2593	2593	2593	2593	2593	312	308L	316L	317L	308	308	316	309	NCW	NCW
255	2593	2593	2593	NCW	2593	2593	2593	2593	2209	2593	2593	2593	2593	2593	2593	312	308L	316L	317L	308	308	316	309	NCW	NCW
301	308	309	309	NCW	308	308	308	308	308	308	308	308	308	308	308	308	308L	316L	316L	308	308	308	308	NCW	NCW
301L	308L	309	309	NCW	308L	308L	308L	308L	308L	308L	308L	308L	308L	308L	308L	308L	308L	316L	316L	308	308	308	308	NCW	NCW
301LN	308L	309	309	NCW	308L	308L	308L	308L	308L	308L	308L	308L	308L	308L	308L	308L	308L	316L	316L	308	308	308	308	NCW	NCW
302	308	309	309	NCW	308	308	308	308	308	308	308	308	308	308	308	308	308L	316L	316L	308	308	308	308	NCW	NCW
303	NCW	NCW	NCW	NCW	NCW.	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW
303Se	NCW	NCW	NCW	NCW	NCW.	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW
304	308	309	309	NCW	308	308	308	308	308	308	308	308	308	308	308	308	308L	316L	316L	308	308	308	308	NCW	NCW
304L	308L	309	309	NCW	308L	308L	308L	308L	308L	308L	308L	308L	308L	308L	308L	308L	308L	316L	316L	308	308	308	308	NCW	NCW
304H	308	NiCr-3	NiCr-3	NCW	308	308	308	308	308	308	308	308	308	308	308	308	308L	316L	316L	308	308	308	308	NCW	NCW
304N	308	309	309	NCW	308	308	308	308	308	308	308	308	308	308	308	308	308L	316L	316L	308	308	308	308	NCW	NCW
304LN	308L	309	309	NCW	308L	308L	308L	308L	308L	308L	308L	308L	308L	308L	308L	308L	308L	316L	316L	308	308	308	308	NCW	NCW
305	308	309	309	NCW	308	308	308	308	308	308	308	308	308	308	308	308	308L	316L	316L	308	308	308	308	NCW	NCW
306	308L	NiCr-3	NiCr-3	NCW	308	308	308	308	2209	2593	2593	2593	2593	2593	2593	312	308L	316L	316L	308	308	316	308	NCW	NCW
308	308	309	309	NCW	308	308	308	308	308	308	308	308	308	308	308	308	308L	316L	316L	308	308	308	308	NCW	NCW
309	308	309	309	NCW	308	308	309	309	309	309	309	309	309	309	309	309	308L	316L	316L	308	308	316	308	NCW	NCW

NCW = Not Considered Weldable NM = No Matching Filler Metal WA = Weld Autogenously NA = Not Addressed by this Table

(Continued)

Table F.1 (Continued)
Suggested Filler Metals for Various Combinations of Stainless Steel and Other Ferrous Base Metals

	Base Metal																								
Base Metal	CF-20	CG-3M	CG-6MMN	CG-8M	CG-12	CH-10	CH-20	CK-3MCuN	CK-20	CK-35MN	CN-3M	CN-3MN	CN-7M	CN-7MS	Nitronic 30	Nitronic 32	Nitronic 33	Nitronic 40	Nitronic 50	Nitronic 60	Carbon Steel, <0.3% C	Carbon Steel, >0.3% C	Cr-Mo Creep Resisting Steel	Low Alloy Steel, <0.3% C	Low Alloy Steel, >0.3% C
17-4PH	308	308	308	308	308	308	308	308	308	308	308	308	2209	2209	209	209	209	209	209	209	309	310	NiCr-3	309	310
17-7PH	308	308	308	308	308	308	308	308	308	308	308	308	2209	2209	209	209	209	209	209	209	309	310	NiCr-3	309	310
25-6MO	308	317L	385	317L	309	309	309	NiCrMo-3	310	NiCrMo-3	NiCrMo-3	NiCrMo-3	NiCrMo-3	NiCrMo-3	308L	308L	308L	308L	209	308L	309	312	NiCr-3	309	312
26-1	308	317L	2593	317L	309	309	309	NiCrMo-3	310	NiCrMo-3	NiCrMo-3	NiCrMo-3	385	385	308L	308L	308L	308L	2209	308L	309	2209	NiCr-3	309	2209
29-4	308	317L	2593	317L	309	309	309	NiCrMo-3	310	NiCrMo-3	NiCrMo-3	NiCrMo-3	385	385	308L	308L	308L	308L	2209	308L	309	2209	NiCr-3	309	2209
29-4-2	308	317L	2593	317L	309	309	309	NiCrMo-3	310	NiCrMo-3	NiCrMo-3	NiCrMo-3	385	385	308L	308L	308L	308L	2209	308L	309	2209	NiCr-3	309	2209
201	308	308	308	308	308	308	308	308	308	309L	309L	309L	2209	2209	209	209	209	209	209	308	309	312	NiCr-3	309	312
202	308	308	308	308	308	308	308	308	308	309L	309L	309L	2209	2209	209	209	209	209	209	308	309	312	NiCr-3	309	312
254SMo	308	385	385	385	309	309	309	NiCrMo-3	310	NiCrMo-3	385	385	385	385	308L	308L	308L	308L	209	308L	309	2209	NiCr-3	309	2209
255	308	317L	2593	317L	309	309	309	2593	2593	2593	2593	2593	2593	2593	2593	2593	2593	2593	2593	2593	309	2593	NiCr-3	309	2593
301	308	308	308	308	308	308	308	308	308	309L	309L	309L	2209	2209	308	308	308	308	308	308	309	312	NiCr-3	309	312
301L	308	308L	308L	308L	308	308	308	308L	308L	309L	309L	309L	2209	2209	308L	308L	308L	308L	308L	308L	309	312	NiCr-3	309	312
301LN	308	308L	308L	308L	308	308	308	308L	308L	309L	309L	309L‘	2209	2209	308L	308L	308L	308L	308L	308L	309	312	NiCr-3	309	312
302	308	308	308	308	308	308	308	308	308	309L	309L	309L	2209	2209	308	308	308	308	308	308	309	312	NiCr-3	309	312
303	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW
303Se	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW
304	308	308	308	308	308	308	308	308	308	309L	309L	309L	2209	2209	308	308	308	308	308	308	309	312	NiCr-3	309	312
304L	308	308L	308L	308L	308	308	308	308L	308L	309L	309L	309L	2209	2209	308L	308L	308L	308L	308L	308L	309	312	NiCr-3	309	312
304H	308	308	308	308	308	308	308	308	308	309L	309L	309L	2209	2209	308	308	308	308	308	308	309	312	NiCr-3	309	312
304N	308	308	308	308	308	308	308	308	308	309L	309L	309L	2209	2209	308	308	308	308	308	308	309	312	NiCr-3	309	312
304LN	308	308L	308L	308L	308	308	308	308L	308L	309L	309L	309L	2209	2209	308L	308L	308L	308L	308L	308L	309	312	NiCr-3	309	312
305	308	308	308	308	308	308	308	308	308	309L	309L	309L	2209	2209	308	308	308	308	308	308	309	312	NiCr-3	309	312
306	308	317L	385	317L	309	309	309	309	309	385	385	385	2209	2209	308	308	308	308	209	308	309	312	NiCr-3	309	312
308	308	308	308	308	308	308	308	308	308	309L	309L	309L	2209	2209	308	308	308	308	308	308	309	312	NiCr-3	309	312
309	308	309	309	309	309	309	309	309	309	309L	309L	309L	2209	2209	308	308	308	308	309	308	309	312	NiCr-3	309	312

NCW = Not Considered Weldable   NM = No Matching Filler Metal   WA = Weld Autogenously   NA = Not Addressed by this Table

(Continued)

Table F.1 (Continued)
Suggested Filler Metals for Various Combinations of Stainless Steel and Other Ferrous Base Metals

	Base Metal																								
Base Metal	321H	329	330	334	347	347H	348	348H	403	405	409	410	410S	410NiMo	414	416	416Se	420	420F	420FSe	429	430	431	434	436
309S	308	309	312	312	347	347	347	347	308	308	308	308	308	308	308	308	NCW	308	NCW	NCW	308	308	308	308	308
309H	308	309	312	312	347	347	347	347	308	308	308	308	308	308	308	308	NCW	308	NCW	NCW	308	308	308	308	308
309Cb	347	309	312	312	347	347	347	347	308	308	308	308	308	308	308	308	NCW	308	NCW	NCW	308	308	308	308	308
309HCb	347	309	312	312	347	347	347	347	308	308	308	308	308	308	308	308	NCW	308	NCW	NCW	308	308	308	308	308
310	309	2593	310	310	310	310	310	310	310	309	309	309	309	309	309	309	NCW	309	NCW	NCW	309	309	309	309	309
310S	309	2593	310	310	310	310	310	310	310	309	309	309	309	309	309	309	NCW	309	NCW	NCW	309	309	309	309	309
310H	309	2593	310	310	310	310	310	310	310	309	309	309	309	309	309	309	NCW	309	NCW	NCW	309	309	309	309	309
310Cb	309	2593	310	310	310	310	310	310	310	309	309	309	309	309	309	309	NCW	309	NCW	NCW	309	309	309	309	309
310HCb	309	2593	310	310	310	310	310	310	310	309	309	309	309	309	309	309	NCW	309	NCW	NCW	309	309	309	309	309
310MoLN	309L	2593	310	310	309L	309L	309L	309L	310	310	310	310	310	310	310	310	NCW	310	NCW	NCW	310	310	310	310	310
314	309	2593	310	310	310	310	310	310	310	310	310	310	310	310	310	310	NCW	310	NCW	NCW	310	310	310	310	310
316	347	316	2209	2209	316	316	316	316	308	308	308	308	308	308	308	308	NCW	308	NCW	NCW	308	308	308	308	308
316L	347	316L	2209	2209	316L	316L	316L	316L	308	308L	308L	308L	308L	308L	308L	308L	NCW	308L	NCW	NCW	308L	308L	308L	308L	308L
316H	347	316	310	310	316	316	316	316	308	308	308	308	308	308	308	308	NCW	308	NCW	NCW	308	308	308	308	308
316Ti	347	2593	2209	2209	316	316	316	316	308	308	308	308	308	308	308	308	NCW	308	NCW	NCW	308	308	308	308	308
316Cb	347	2593	2209	2209	316	316	316	316	308	308	308	308	308	308	308	308	NCW	308	NCW	NCW	308	308	308	308	308
316N	347	316	2209	2209	316	316	316	316	308	308	308	308	308	308	308	308	NCW	308	NCW	NCW	308	308	308	308	308
316LN	347	316LN	2209	2209	316L	316L	316L	316L	308	308L	308L	308L	308L	308L	308L	308L	NCW	308L	NCW	NCW	308L	308L	308L	308L	308L
317	347	317L	2209	2209	316	316	316	316	308	308	308	308	308	308	308	308	NCW	308	NCW	NCW	308	308	308	308	308
317L	347	317L	2209	2209	316L	316L	316L	316L	308	308L	308L	308L	308L	308L	308L	308L	NCW	308L	NCW	NCW	308L	308L	308L	308L	308L
317LM	347	2593	2209	2209	316L	316L	316L	316L	308	308L	308L	308L	308L	308L	308L	308L	NCW	308L	NCW	NCW	308L	308L	308L	308L	308L
317LMN	347	2593	2209	2209	316L	316L	316L	316L	308	308L	308L	308L	308L	308L	308L	308L	NCW	308L	NCW	NCW	308L	308L	308L	308L	308L
317LN	347	2593	2209	2209	316L	316L	316L	316L	308	308L	308L	308L	308L	308L	308L	308L	NCW	308L	NCW	NCW	308L	308L	308L	308L	308L
320	2209	2593	310	310	310	310	310	310	310	2209	2209	2209	2209	2209	2209	2209	NCW	2209	NCW	NCW	2209	2209	2209	2209	2209
321	347	347	310	310	347	347	347	347	308	308	308	308	308	308	308	308	NCW	308	NCW	NCW	308	308	308	308	308

NCW = Not Considered Weldable NM = No Matching Filler Metal WA = Weld Autogenously NA = Not Addressed by this Table

(Continued)

Table F.1 (Continued)
Suggested Filler Metals for Various Combinations of Stainless Steel and Other Ferrous Base Metals

	Base Metal																								
Base Metal	439	440A	440B	440C	440F	444	446	630	631	632	633	634	635	660	662	904L	1925 hMo	2205	2304	2507	A286	AL-6XN	CA-6N	CA-6NM	CA-15
309S	308	308	308	308	NCW	309L	309	309	309	309	309	309	309	312	312	309L	309L	309L	309L	309L	312	309L	308	308	308
309H	308	308	308	308	NCW	309L	309	309	309	309	309	309	309	312	312	309L	309L	309L	309L	309L	312	309L	308	308	308
309Cb	308	308	308	308	NCW	309L	309	309	309	309	309	309	309	312	312	309L	309L	309L	309L	309L	312	309L	308	308	308
309HCb	308	308	308	308	NCW	309L	309	309	309	309	309	309	309	312	312	309L	309L	309L	309L	309L	312	309L	308	308	308
310	309	309	309	309	NCW	2209	310	310	310	310	310	310	310	310	310	310	310	2209	310	310	310	310	309	309	309
310S	309	309	309	309	NCW	2209	310	310	310	310	310	310	310	310	310	310	310	2209	310	310	310	310	309	309	309
310H	309	309	309	309	NCW	2209	310	310	310	310	310	310	310	310	310	310	310	2209	310	310	310	310	309	309	309
310Cb	309	309	309	309	NCW	2209	310	310	310	310	310	310	310	310	310	310	310	2209	310	310	310	310	309	309	309
310HCb	309	309	309	309	NCW	2209	310	310	310	310	310	310	310	310	310	310	310	2209	310	310	310	310	309	309	309
310MoLN	310	310	310	310	NCW	2209	310	309L	309L	309L	309L	309L	309L	2209	2209	385	385	2209	385	385	2209	385	309L	309L	309L
314	310	310	310	310	NCW	2209	310	310	310	310	310	310	310	310	310	310	310	2209	2209	2209	310	310	310	310	310
316	308	308	308	308	NCW	316L	316L	308	308	308	308	308	308	2209	2209	316L	316L	316L	316L	316L	2209	316L	309	309	309
316L	308L	308L	308L	308L	NCW	316L	316L	308	308	308	308	308	308	2209	2209	316L	316L	316L	316L	316L	2209	316L	309L	309L	309L
316H	308	308	308	308	NCW	316L	316L	308	308	308	308	308	308	2209	2209	316L	316L	316L	316L	316L	2209	316L	309	309	309
316Ti	308	308	308	308	NCW	316L	316L	308	308	308	308	308	308	2209	2209	316L	316L	316L	316L	316L	2209	316L	309	309	309
316Cb	308	308	308	308	NCW	316L	316L	308	308	308	308	308	308	2209	2209	316L	316L	316L	316L	316L	2209	316L	309	309	309
316N	308	308	308	308	NCW	316L	316L	308	308	308	308	308	308	2209	2209	316L	317L	316L	316L	316L	2209	317L	309	309	309
316LN	308L	308L	308L	308L	NCW	316L	316L	308	308	308	308	308	308	2209	2209	316L	317L	316L	316L	316L	2209	317L	309L	309L	309L
317	308	308	308	308	NCW	2209	309	308	308	308	308	308	308	2209	2209	317L	385	317L	317L	317L	2209	385	309	309	309
317L	308L	308L	308L	308L	NCW	2209	309L	308	308	308	308	308	308	2209	2209	317L	385	317L	317L	317L	2209	385	309L	309L	309L
317LM	308L	308L	308L	308L	NCW	2209	309L	308	308	308	308	308	308	2209	2209	385	NiCrMo-3	2209	2209	385	2209	NiCrMo-3	309L	309L	309L
317LMN	308L	308L	308L	308L	NCW	2209	309L	308	308	308	308	308	308	2209	2209	385	NiCrMo-3	2209	2209	385	2209	NiCrMo-3	309L	309L	309L
317LN	308L	308L	308L	308L	NCW	2209	309L	308	308	308	308	308	308	2209	2209	317L	385	2209	317L	317L	2209	385	309L	309L	309L
320	2209	2209	2209	2209	NCW	2209	310	310	310	310	310	310	310	310	310	385	NiCrMo-3	2209	2209	2593	310	NiCrMo-3	2209	2209	2209
321	308	308	308	308	NCW	316L	347	347	347	347	347	347	347	312	312	309L	309L	308	308L	308L	312	309L	308	308	308

NCW = Not Considered Weldable NM = No Matching Filler Metal WA = Weld Autogenously NA = Not Addressed by this Table

(Continued)

Table F.1 (Continued)
Suggested Filler Metals for Various Combinations of Stainless Steel and Other Ferrous Base Metals

	Base Metal																								
Base Metal	CA-15M	CA-28MWV	CA-40	CA-40F	CB-6	CB-30	CC-50	CD3MCuN	CD3MN	CD3MWCuN	CD4MCu	CD4MCuN	CD6MN	CE3MN	CE8MN	CE-30	CF-3	CF-3M	CF-3MN	CF-8	CF-8C	CF-8M	CF-10SMnN	CF-16F	CF-16Fa
309S	308	309	309	NCW	308	308	309	309	309	309	309	309	309	309	309	309	308L	316L	316L	308	308	316	308	NCW	NCW
309H	308	NiCr-3	NiCr-3	NCW	308	308	309	309	309	309	309	309	309	309	309	309	308L	316L	316L	308	308	316	308	NCW	NCW
309Cb	308	309	309	NCW	308	308	309	309	309	309	309	309	309	309	309	309	308L	316L	316L	308	347	316	308	NCW	NCW
309HCb	308	NiCr-3	NiCr-3	NCW	308	308	309	309	309	309	309	309	309	309	309	309	308L	316L	316L	308	347	316	308	NCW	NCW
310	309	NiCr-3	NiCr-3	NCW	309	309	310	2593	2209	2593	2593	2593	2593	2593	2593	312	308L	316L	316L	308	308	316	309	NCW	NCW
310S	309	NiCr-3	NiCr-3	NCW	309	309	310	2593	2209	2593	2593	2593	2593	2593	2593	312	308L	316L	316L	308	308	316	309	NCW	NCW
310H	309	NiCr-3	NiCr-3	NCW	309	309	310	2593	2209	2593	2593	2593	2593	2593	2593	312	308L	316L	316L	308	308	316	309	NCW	NCW
310Cb	309	NiCr-3	NiCr-3	NCW	309	309	310	2593	2209	2593	2593	2593	2593	2593	2593	312	308L	316L	316L	308	308	316	309	NCW	NCW
310HCb	309	NiCr-3	NiCr-3	NCW	309	309	310	2593	2209	2593	2593	2593	2593	2593	2593	312	308L	316L	316L	308	308	316	309	NCW	NCW
310MoLN	309L	310	310	NCW	309L	309L	310	2593	2209	2593	2593	2593	2593	2593	2593	312	308L	316L	316L	308	308	316	309	NCW	NCW
314	310	NiCr-3	NiCr-3	NCW	310	310	310	2593	2209	2593	2593	2593	2593	2593	2593	312	308	316	317	308	308	316	309	NCW	NCW
316	309	309	309	NCW	308	308	316	316	316	316	316	316	316	316	316	316	308L	316L	316L	308	308	316	309	NCW	NCW
316L	309L	309	309	NCW	308L	308L	316L	316L	316L	316L	316L	316L	316L	316L	316L	316L	308L	316L	316L	308	308	316	309	NCW	NCW
316H	309	NiCr-3	NiCr-3	NCW	308	308	316	316	316	316	316	316	316	316	316	316	308L	316L	316L	308	308	316	309	NCW	NCW
316Ti	309	309	309	NCW	308	308	316	316	316	316	316	316	316	316	316	316	308L	316L	316L	308	347	316	309	NCW	NCW
316Cb	309	309	309	NCW	308	308	316	316	316	316	316	316	316	316	316	316	308L	316L	316L	308	347	316	309	NCW	NCW
316N	309	309	309	NCW	308	308	316	316	316	316	316	316	316	316	316	316	308L	316L	316L	308	308	316	309	NCW	NCW
316LN	309L	309L	309L	NCW	308L	308L	316L	316L	316L	316L	316L	316L	316L	316L	316L	316L	308L	316L	317L	308	308	316	309	NCW	NCW
317	309	309	309	NCW	308	308	317	317	317	317	317	317	317	317	317	312	308L	316L	317L	308	308	316	309	NCW	NCW
317L	309L	309L	309L	NCW	308L	308L	317L	317L	317L	317L	317L	317L	317L	317L	317L	312	308L	316L	317L	308	308	316	309	NCW	NCW
317LM	309L	309L	309L	NCW	308L	308L	385	2593	2209	2593	2593	2593	2593	2593	2593	312	308L	316L	317L	308	308	316	309	NCW	NCW
317LMN	309L	309L	309L	NCW	308L	308L	385	2593	2209	2593	2593	2593	2593	2593	2593	312	308L	316L	317L	308	308	316	309	NCW	NCW
317LN	309L	309L	309L	NCW	308L	308L	317L	317L	2209	2593	2593	2593	2593	2593	2593	312	308L	316L	317L	308	308	316	309	NCW	NCW
320	2209	310	310	NCW	310	310	310	2593	2209	2593	2593	2593	2593	2593	2593	312	310	310	310	310	310	310	310	NCW	NCW
321	308	NiCr-3	NiCr-3	NCW	308	308	308	308	308	308	308	308	308	308	308	308	308L	316L	316L	308	347	308	308	NCW	NCW

NCW = Not Considered Weldable NM = No Matching Filler Metal WA = Weld Autogenously NA = Not Addressed by this Table

(Continued)

Table F.1 (Continued)
Suggested Filler Metals for Various Combinations of Stainless Steel and Other Ferrous Base Metals

Base Metal	CF-20	CG-3M	CG-6MMN	CG-8M	CG-12	CH-10	CH-20	CK-3MCuN	CK-20	CK-35MN	CN-3M	CN-3MN	CN-7M	CN-7MS	Nitronic 30	Nitronic 32	Nitronic 33	Nitronic 40	Nitronic 50	Nitronic 60	Carbon Steel, <0.3% C	Carbon Steel, >0.3% C	Cr-Mo Creep Resisting Steel	Low Alloy Steel, < 0.3% C	Low Alloy Steel, > 0.3% C
309S	308	309	309	309	309	309	309	309	309	309L	309L	309L	2209	2209	308	308	308	308	309	308	309	312	NiCr-3	309	312
309H	308	309	309	309	309	309	309	309	309	309L	309L	309L	2209	2209	308	308	308	308	309	308	309	312	NiCr-3	309	312
309Cb	308	309	309	309	309	309	309	309	309	309L	309L	309L	2209	2209	308	308	308	308	309	308	309	312	NiCr-3	309	312
309HCb	308	309	309	309	309	309	309	309	309	309L	309L	309L	2209	2209	308	308	308	308	309	308	309	312	NiCr-3	309	312
310	308	317L	310	317L	309	309	310	310	310	310	310	310	310	310	308	308	308	308	309	308	309	310	NiCr-3	309	310
310S	308	317L	310	317L	309	309	310	310	310	310	310	310	310	310	308	308	308	308	309	308	309	310	NiCr-3	309	310
310H	308	317L	310	317L	309	309	310	310	310	310	310	310	310	310	308	308	308	308	309	308	309	310	NiCr-3	309	310
310Cb	308	317L	310	317L	309	309	310	310	310	310	310	310	310	310	308	308	308	308	309	308	309	310	NiCr-3	309	310
310HCb	308	317L	310	317L	309	309	310	310	310	310	310	310	310	310	308	308	308	308	309	308	309	310	NiCr-3	309	310
310MoLN	308	317L	385	317L	309	309	310	385	310	385	385	385	385	385	308	308	308	308	209	308	309	310	NiCr-3	309	310
314	308	317L	310	317L	309	309	310	310	310	310	310	310	310	310	309	309	309	309	309	309	309	310	NiCr-3	309	310
316	308	316	316	316	309	309	309	316	316	316L	316L	316L	2209	2209	308	308	308	308	316	308	309	312	NiCr-3	309	312
316L	308	316L	316L	316L	309	309	309	316L	316L	316L	316L	316L	2209	2209	308L	308L	308L	308L	316L	308L	309	312	NiCr-3	309	312
316H	308	316	316	316	309	309	309	316	316	316L	316L	316L	2209	2209	308	308	308	308	316	308	309	312	NiCr-3	309	312
316Ti	308	316	316	316	309	309	309	316	316	316L	316L	316L	2209	2209	308	308	308	308	316	308	309	312	NiCr-3	309	312
316Cb	308	316	316	316	309	309	309	316	316	316L	316L	316L	2209	2209	308	308	308	308	316	308	309	312	NiCr-3	309	312
316N	308	317L	317L	317L	309	309	309	317L	317L	317L	316L	316L	2209	2209	308	308	308	308	317L	308	309	312	NiCr-3	309	312
316LN	308	317L	317L	317L	309	309	309	317L	317L	317L	316L	316L	2209	2209	308L	308L	308L	308L	317L	308L	309	312	NiCr-3	309	312
317	308	317L	317L	317L	309	309	309	317	317	385	317L	317L	2209	2209	308	308	308	308	317	308	309	312	NiCr-3	309	312
317L	308	317L	317L	317L	309	309	309	317L	317L	385	317L	317L	2209	2209	308L	308L	308L	308L	317L	308L	309	312	NiCr-3	309	312
317LM	308	385	385	385	309	309	309	385	310	NiCrMo-3	385	385	385	385	308L	308L	308L	308L	317L	308L	309	312	NiCr-3	309	312
317LMN	308	385	385	385	309	309	309	385	310	NiCrMo-3	385	385	385	385	308L	308L	308L	308L	317L	308L	309	312	NiCr-3	309	312
317LN	308	385	385	385	309	309	309	385	310	385	317L	317L	385	385	308L	308L	308L	308L	317L	308L	309	312	NiCr-3	309	312
320	310	310	310	310	310	310	310	385	310	NiCrMo-3	385	385	320LR	320LR	310	310	310	310	310	310	312	312	NiCr-3	312	312
321	308	308	308	308	308	308	308	308	308	309L	309L	309L	2209	2209	308	308	308	308	308	308	309	312	NiCr-3	309	312

NCW = Not Considered Weldable NM = No Matching Filler Metal WA = Weld Autogenously NA = Not Addressed by this Table

(Continued)

Table F.1 (Continued)
Suggested Filler Metals for Various Combinations of Stainless Steel and Other Ferrous Base Metals

	Base Metal																								
Base Metal	439	440A	440B	440C	440F	444	446	630	631	632	633	634	635	660	662	904L	1925 hMo	2205	2304	2507	A286	AL-6XN	CA-6N	CA-6NM	CA-15
321H	308	308	308	308	NCW	316L	347	347	347	347	347	347	347	312	312	309L	309L	308	308L	308L	312	309L	308	308	308
329	308	308	308	308	NCW	2209	2593	2593	2593	2593	2593	2593	2593	2593	2593	2593	2593	2209	2209	2593	2593	2593	2593	2593	2593
330	310	310	310	310	NCW	2209	310	310	310	310	310	310	310	310	310	310	310	2209	2209	2209	310	310	310	310	310
334	310	310	310	310	NCW	2209	310	310	310	310	310	310	310	310	310	310	310	2209	2209	2209	310	310	310	310	310
347	308	308	308	308	NCW	316L	347	347	347	347	347	347	347	312	312	309L	309L	308	308L	308L	312	309L	308	308	308
347H	308	308	308	308	NCW	316L	347	347	347	347	347	347	347	312	312	309L	309L	308L	308L	308L	312	309L	308	308	308
348	308	308	308	308	NCW	316L	347	347	347	347	347	347	347	312	312	309L	309L	308L	308L	308L	312	309L	308	308	308
348H	308	308	308	308	NCW	316L	347	347	347	347	347	347	347	312	312	309L	309L	308L	308L	308L	312	309L	308	308	308
403	410NiMo	410NiMo	410NiMo	410NiMo	NCW	410NiMo	410NiMo	410NiMo	410NiMo	410NiMo	410NiMo	410NiMo	410NiMo	310	310	309L	309L	2209	2209	2209	310	309L	410NiMo	410NiMo	410
405	410NiMo	410NiMo	410NiMo	410NiMo	NCW	409	409	409	409	409	409	409	409	312	312	309L	309L	308L	308L	398L	312	309L	410NiMo	410NiMo	410NiMo
409	410NiMo	410NiMo	410NiMo	410NiMo	NCW	409	409	409	409	409	409	409	409	312	312	309L	309L	308L	308L	308L	312	309L	410NiMo	410NiMo	410NiMo
410	410NiMo	410NiMo	410NiMo	410NiMo	NCW	410NiMo	410NiMo	410NiMo	410NiMo	410NiMo	410NiMo	410NiMo	410NiMo	310	310	309L	310	2209	2209	2209	310	310	410NiMo	410NiMo	410
410S	410NiMo	410NiMo	410NiMo	410NiMo	NCW	410NiMo	410NiMo	410NiMo	410NiMo	410NiMo	410NiMo	410NiMo	410NiMo	310	310	309L	310	2209	2209	2209	310	310	410NiMo	410NiMo	410
410NiMo	410NiMo	410NiMo	410NiMo	410NiMo	NCW	410NiMo	410NiMo	410NiMo	410NiMo	410NiMo	410NiMo	410NiMo	410NiMo	310	310	309L	310	2209	2209	2209	310	310	410NiMo	410NiMo	410NiMo
414	410NiMo	410NiMo	410NiMo	410NiMo	NCW	410NiMo	410NiMo	410NiMo	410NiMo	410NiMo	410NiMo	410NiMo	410NiMo	310	310	309L	310	2209	2209	2209	310	310	410NiMo	410NiMo	410
416	410NiMo	410NiMo	410NiMo	410NiMo	NCW	410NiMo	410NiMo	630	630	630	630	630	630	310	310	309L	310	2209	2209	2209	310	310	410NiMo	410NiMo	410
416Se	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW
420	410NiMo	410NiMo	410NiMo	410NiMo	NCW	410NiMo	410NiMo	630	630	630	630	630	630	310	310	309L	310	2209	2209	2209	310	310	410NiMo	410NiMo	410
420F	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW
420FSe	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW
429	430	310	310	310	NCW	430	430	308	308	308	308	308	308	310	310	309L	310	2209	4409	2209	310	310	308	308	308
430	430	310	310	310	NCW	430	430	308	308	308	308	308	308	430	430	309L	430	2209	2209	2209	430	430	308	308	308
431	430	310	310	310	NCW	430	430	630	630	630	630	630	630	310	310	309L	310	2209	2209	2209	310	310	410NiMo	410NiMo	410NiMo
434	444	310	310	310	NCW	430	430	308	308	308	308	308	308	310	310	309L	310	2209	2209	2209	310	310	308	308	308
436	444	310	310	310	NCW	430	430	308	308	308	308	308	308	430	430	309L	2209	2209	2209	2209	2209	2209	308	308	308

NCW = Not Considered Weldable NM = No Matching Filler Metal WA = Weld Autogenously NA = Not Addressed by this Table

(Continued)

Table F.1 (Continued)
Suggested Filler Metals for Various Combinations of Stainless Steel and Other Ferrous Base Metals

	Base Metal																								
Base Metal	CA-15M	CA-28MWV	CA-40	CA-40F	CB-6	CB-30	CC-50	CD3MCuN	CD3MN	CD3MWCuN	CD4MCu	CD4MCuN	CD6MN	CE3MN	CE8MN	CE-30	CF-3	CF-3M	CF-3MN	CF-8	CF-8C	CF-8M	CF-10SMnN	CF-16F	CF-16Fa
321H	308	NiCr-3	NiCr-3	NCW	308	308	308	308	308	308	308	308	308	308	308	308	308L	316L	316L	308	347	308	308	NCW	NCW
329	2593	2593	2593	NCW	308	308	2593	2593	2209	2593	2593	2593	2593	2593	2593	312	308L	316L	317L	308	308	308	309	NCW	NCW
330	310	NiCr-3	NiCr-3	NCW	310	310	310	312	2209	2593	2593	2593	2593	2593	2593	312	310	310	310	310	310	310	310	NCW	NCW
334	310	NiCr-3	NiCr-3	NCW	310	310	310	2209	2209	2593	2593	2593	2593	2593	2593	312	308L	316L	317L	308	308	308	309	NCW	NCW
347	308	NiCr-3	NiCr-3	NCW	308	308	308	308	308	308	308	308	308	308	308	308	308L	316L	316L	308	347	308	308	NCW	NCW
347H	308	NiCr-3	NiCr-3	NCW	308	308	308	308	308	308	308	308	308	308	308	308	308L	316L	316L	308	347	308	308	NCW	NCW
348	308	309L	309L	NCW	308	308	308	308	308	308	308	308	308	308	308	308	308L	316L	316L	308	347	308	308	NCW	NCW
348H	308	NiCr-3	NiCr-3	NCW	308	308	308	308	308	308	308	308	308	308	308	308	308L	316L	316L	308	347	308	308	NCW	NCW
403	410NiMo	410NiMo	410NiMo	NCW	410NiMo	410NiMo	410NiMo	2593	2209	2593	2593	2593	2593	2593	2593	312	308L	316L	316L	308	308	308	308	NCW	NCW
405	410NiMo	410NiMo	410NiMo	NCW	410NiMo	410NiMo	308	2209	2209	308	308	308	308	308	308	308	308L	316L	316L	308	308	308	308	NCW	NCW
409	410NiMo	410NiMo	410NiMo	NCW	410NiMo	410NiMo	308	2209	2209	308	308	308	308	308	308	308	308L	316L	316L	308	308	308	308	NCW	NCW
410	410NiMo	410NiMo	410NiMo	NCW	410NiMo	410NiMo	410NiMo	2593	2209	2593	2593	2593	2593	2593	2593	312	308L	316L	316L	308	308	308	308	NCW	NCW
410S	410NiMo	410NiMo	410NiMo	NCW	410NiMo	410NiMo	410NiMo	2593	2209	2593	2593	2593	2593	2593	2593	312	308L	316L	316L	308	308	308	308	NCW	NCW
410NiMo	410NiMo	410NiMo	410NiMo	NCW	410NiMo	410NiMo	410NiMo	2593	2209	2593	2593	2593	2593	2593	2593	312	308L	316L	316L	308	308	308	308	NCW	NCW
414	410NiMo	410NiMo	410NiMo	NCW	410NiMo	410NiMo	410NiMo	2593	2209	2593	2593	2593	2593	2593	2593	312	308L	316L	316L	308	308	308	308	NCW	NCW
416	410NiMo	410NiMo	410NiMo	NCW	410NiMo	410NiMo	410NiMo	2593	2209	2593	2593	2593	2593	2593	2593	312	308L	316L	316L	308	308	308	308	NCW	NCW
416Se	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW
420	410NiMo	410NiMo	410NiMo	NCW	410NiMo	410NiMo	410NiMo	312	2209	2593	2593	2593	2593	2593	2593	312	308L	316L	316L	308	308	308	308	NCW	NCW
420F	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW
420FSe	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW
429	308	309	309	NCW	430	430	430	312	2209	2593	2593	2593	2593	2593	2593	312	308L	316L	316L	308	308	308	308	NCW	NCW
430	308	309	309	NCW	430	430	430	312	2209	2593	2593	2593	2593	2593	2593	312	308L	316L	316L	308	308	308	308	NCW	NCW
431	410NiMo	410NiMo	410NiMo	NCW	630	630	630	2593	2209	2593	2593	2593	2593	2593	2593	312	308L	316L	316L	308	308	308	308	NCW	NCW
434	308	309	309	NCW	308	308	2209	312	2209	2593	2593	2593	2593	2593	2593	312	308L	316L	316L	308	308	308	308	NCW	NCW
436	308	309	309	NCW	308	308	2209	312	2209	2593	2593	2593	2593	2593	2593	312	308L	316L	316L	308	308	308	308	NCW	NCW

NCW = Not Considered Weldable   NM = No Matching Filler Metal   WA = Weld Autogenously   NA = Not Addressed by this Table

(Continued)

Table F.1 (Continued)
Suggested Filler Metals for Various Combinations of Stainless Steel and Other Ferrous Base Metals

	Base Metal																								
Base Metal	CF-20	CG-3M	CG-6MMN	CG-8M	CG-12	CH-10	CH-20	CK-3MCuN	CK-20	CK-35MN	CN-3M	CN-3MN	CN-7M	CN-7MS	Nitronic 30	Nitronic 32	Nitronic 33	Nitronic 40	Nitronic 50	Nitronic 60	Carbon Steel, <0.3% C	Carbon Steel, >0.3% C	Cr-Mo Creep Resisting Steel	Low Alloy Steel, <0.3% C	Low Alloy Steel, >0.3% C
321H	308	308	308	308	308	308	308	308	308	309L	309L	309L	2209	2209	308	308	308	308	308	308	309	312	NiCr-3	309	312
329	308	317L	2593	317L	309	309	309	2593	2593	2593	2593	2593	2593	2593	2593	2593	2593	2593	2593	2593	309	312	NiCr-3	309	312
330	310	310	310	310	310	310	310	385	310	310	310	310	310	310	310	310	310	310	310	310	312	312	NiCr-3	312	312
334	308	308	385	308	308	308	309	385	310	310	310	310	310	310	308	308	308	308	308	308	309	312	NiCr-3	309	312
347	308	308	308	308	308	308	308	308	308	309L	309L	309L	310	310	308	308	308	308	308	308	309	312	NiCr-3	309	312
347H	308	308	308	308	308	308	308	308	308	309L	309L	309L	310	310	308	308	308	308	308	308	309	312	NiCr-3	309	312
348	308	308	308	308	308	308	308	308	308	309L	309L	309L	310	310	308	308	308	308	308	308	309	312	NiCr-3	309	312
348H	308	308	308	308	308	308	308	308	308	309L	309L	309L	310	310	308	308	308	308	308	308	309	312	NiCr-3	309	312
403	308	308	308	308	308	308	308	308	308	309L	309L	309L	310	310	209	209	209	209	209	218	309	310	NiCr-3	309	310
405	308	308	308	308	308	308	308	308	308	309L	309L	309L	2209	2209	308	308	308	308	308	308	309	312	NiCr-3	309	312
409	308	308	308	308	308	308	308	308	308	309L	309L	309L	2209	2209	308	308	308	308	308	308	309	312	NiCr-3	309	312
410	308	308	308	308	308	308	308	308	308	310	309L	309L	2209	2209	209	209	209	209	209	218	309	310	NiCr-3	309	310
410S	308	308	308	308	308	308	308	308	308	310	309L	309L	2209	2209	209	209	209	209	209	218	309	310	NiCr-3	309	310
410NiMo	308	308	308	308	308	308	308	308	308	310	309L	309L	2209	2209	209	209	209	209	209	218	309	310	NiCr-3	309	310
414	308	308	308	308	308	308	308	308	308	310	309L	309L	2209	2209	209	209	209	209	209	218	309	310	NiCr-3	309	310
416	308	308	308	308	308	308	308	308	308	310	309L	309L	2209	2209	209	209	209	209	209	218	309	310	NiCr-3	309	310
416Se	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW
420	308	308	308	308	308	308	308	308	308	310	309L	309L	2209	2209	209	209	209	209	209	218	309	310	NiCr-3	309	310
420F	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW
420FSe	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW
429	308	308	308	308	308	308	308	308	308	310	309L	309L	2209	2209	308	308	308	308	308	308	309	312	NiCr-3	309	312
430	308	308	308	308	308	308	308	308	308	430	309L	309L	2209	2209	308	308	308	308	308	308	309	312	NiCr-3	309	312
431	308	308	308	308	308	308	308	308	308	310	309L	309L	2209	2209	209	209	209	209	209	218	309	310	NiCr-3	309	310
434	308	308	308	308	308	308	308	308	308	310	309L	309L	2209	2209	308	308	308	308	308	308	309	312	NiCr-3	309	312
436	308	308	308	308	308	308	308	308	308	2209	309L	309L	2209	2209	308	308	308	308	308	308	309	312	NiCr-3	309	312

NCW = Not Considered Weldable NM = No Matching Filler Metal WA = Weld Autogenously NA = Not Addressed by this Table

(Continued)

Table F.1 (Continued)
Suggested Filler Metals for Various Combinations of Stainless Steel and Other Ferrous Base Metals

	Base Metal																								
Base Metal	CA-15M	CA-28MWV	CA-40	CA-40F	CB-6	CB-30	CC-50	CD3MCuN	CD3MN	CD3MWCuN	CD4MCu	CD4MCuN	CD6MN	CE3MN	CE8MN	CE-30	CF-3	CF-3M	CF-3MN	CF-8	CF-8C	CF-8M	CF-10SMnN	CF-16F	CF-16Fa
439	308	309	309	NCW	308	308	2209	2209	2209	2593	2593	2593	2593	2593	2593	312	308L	316L	316L	308	308	308	308	NCW	NCW
440A	410NiMo	410NiMo	410NiMo	NCW	630	630	630	312	2209	2593	2593	2593	2593	2593	2593	312	310	310	310	310	310	310	310	NCW	NCW
440B	410NiMo	410NiMo	410NiMo	NCW	630	630	630	312	2209	2593	2593	2593	2593	2593	2593	312	310	310	310	310	310	310	310	NCW	NCW
440C	410NiMo	410NiMo	410NiMo	NCW	630	630	630	312	2209	2593	2593	2593	2593	2593	2593	312	310	310	310	310	310	310	310	NCW	NCW
440F	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW
444	410NiMo	410NiMo	410NiMo	NCW	410NiMo	410NiMo	410NiMo	2209	2209	2593	2593	2593	2593	2593	2593	312	308L	316L	317L	308	308	308	309	NCW	NCW
446	308	310	310	NCW	308	308	308	312	2209	2593	2593	2593	2593	2593	2593	312	308L	316L	316L	308	308	308	309	NCW	NCW
630	410NiMo	410NiMo	410NiMo	NCW	630	630	630	2593	2209	2593	2593	2593	2593	2593	2593	312	308L	316L	316L	308	308	308	308	NCW	NCW
631	410NiMo	410NiMo	410NiMo	NCW	630	630	630	2593	2209	2593	2593	2593	2593	2593	2593	312	308L	316L	316L	308	308	308	308	NCW	NCW
632	410NiMo	410NiMo	410NiMo	NCW	630	630	630	2593	2209	2593	2593	2593	2593	2593	2593	312	308L	316L	316L	308	308	308	308	NCW	NCW
633	410NiMo	410NiMo	410NiMo	NCW	630	630	630	2593	2209	2593	2593	2593	2593	2593	2593	312	308L	316L	316L	308	308	308	308	NCW	NCW
634	410NiMo	410NiMo	410NiMo	NCW	630	630	630	2593	2209	2593	2593	2593	2593	2593	2593	312	308L	316L	316L	308	308	308	308	NCW	NCW
635	410NiMo	410NiMo	410NiMo	NCW	630	630	630	2593	2209	2593	2593	2593	2593	2593	2593	312	308L	316L	316L	308	308	308	308	NCW	NCW
660	NiCrMo-3	NiCrMo-3	NiCrMo-3	NCW	NiCrMo-3	NiCrMo-3	NiCrMo-3	2593	2209	2593	2593	2593	2593	2593	2593	312	310	310	310	310	310	310	310	NCW	NCW
662	NiCrMo-3	NiCrMo-3	NiCrMo-3	NCW	NiCrMo-3	NiCrMo-3	NiCrMo-3	2593	2209	2593	2593	2593	2593	2593	2593	312	310	310	310	310	310	310	310	NCW	NCW
904L	309L	310	310	NCW	309L	309L	385	2593	2209	2593	2593	2593	2593	2593	2593	312	308L	316L	385	308	308	308	309	NCW	NCW
1925 hMo	310	310	310	NCW	310	310	310	2593	2209	2593	2593	2593	2593	2593	2593	312	308L	316L	385	308	308	308	309	NCW	NCW
2205	2209	2209	2209	NCW	2209	2209	2209	2209	2209	2209	2209	2209	2209	2209	2209	312	308L	316L	317L	308	308	308	309	NCW	NCW
2304	2209	2209	2209	NCW	2209	2209	2209	2209	2209	2209	2209	2209	2209	2209	2209	312	308L	316L	317L	308	308	308	309	NCW	NCW
2507	2593	2593	2593	NCW	2593	2593	2593	2593	2209	2593	2593	2593	2593	2593	2593	312	308L	316L	317L	308	308	308	309	NCW	NCW
A286	310	310	310	NCW	310	310	310	312	2209	2593	2593	2593	2593	2593	2593	312	310	310	310	310	310	310	310	NCW	NCW
AL-6XN	310	310	310	NCW	310	310	310	2593	2209	2593	2593	2593	2593	2593	2593	312	308L	316L	385	308	308	308	309	NCW	NCW
CA-6N	410NiMo	410NiMo	410NiMo	NCW	410NiMo	410NiMo	410NiMo	312	2209	2593	2593	2593	2593	2593	2593	312	308L	316L	316L	308	308	308	308	NCW	NCW
CA-6NM	410NiMo	410NiMo	410NiMo	NCW	410NiMo	410NiMo	410NiMo	312	2209	2593	2593	2593	2593	2593	2593	312	308L	316L	316L	308	308	308	308	NCW	NCW
CA-15	410NiMo	410NiMo	410NiMo	NCW	410NiMo	410NiMo	410NiMo	312	2209	2593	2593	2593	2593	2593	2593	312	308L	316L	316L	308	308	308	308	NCW	NCW

NCW = Not Considered Weldable NM = No Matching Filler Metal WA = Weld Autogenously NA = Not Addressed by this Table

(Continued)

Table F.1 (Continued)
Suggested Filler Metals for Various Combinations of Stainless Steel and Other Ferrous Base Metals

	Base Metal																								
Base Metal	CF-20	CG-3M	CG-6MMN	CG-8M	CG-12	CH-10	CH-20	CK-3MCuN	CK-20	CK-35MN	CN-3M	CN-3MN	CN-7M	CN-7MS	Nitronic 30	Nitronic 32	Nitronic 33	Nitronic 40	Nitronic 50	Nitronic 60	Carbon Steel, <0.3% C	Carbon Steel, >0.3% C	Cr-Mo Creep Resisting Steel	Low Alloy Steel, <0.3% C	Low Alloy Steel, >0.3% C
439	308	308	308	308	308	308	308	308	308	2209	309L	309L	2209	2209	308	308	308	308	308	308	309	312	NiCr-3	309	312
440A	310	310	310	310	310	310	310	310	310	310	310	310	2209	2209	310	310	310	310	310	310	310	310	NiCr-3	310	310
440B	310	310	310	310	310	310	310	310	310	310	310	310	2209	2209	310	310	310	310	310	310	310	310	NiCr-3	310	310
440C	310	310	310	310	310	310	310	310	310	310	310	310	2209	2209	310	310	310	310	310	310	310	310	NiCr-3	310	310
440F	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW
444	308	317L	2209	317L	309	309	309	385	309	2209	2209	2209	2209	2209	308L	308L	308L	308L	2209	308L	309	312	NiCr-3	309	312
446	308	308	310	308	309	309	309	309	310	310	310	310	310	310	308	308	308	308	310	308	309	310	NiCr-3	309	310
630	308	308	308	308	308	308	308	308	308	NiCrMo-3	310	310	310	310	209	209	209	209	209	218	309	310	NiCr-3	309	310
631	308	308	308	308	308	308	308	308	308	NiCrMo-3	310	310	310	310	209	209	209	209	209	218	309	310	NiCr-3	309	310
632	308	308	308	308	308	308	308	308	308	NiCrMo-3	310	310	310	310	209	209	209	209	209	218	309	310	NiCr-3	309	310
633	308	308	308	308	308	308	308	308	308	NiCrMo-3	310	310	310	310	209	209	209	209	209	218	309	310	NiCr-3	309	310
634	308	308	308	308	308	308	308	308	308	NiCrMo-3	310	310	310	310	209	209	209	209	209	218	309	310	NiCr-3	309	310
635	308	308	308	308	308	308	308	308	308	NiCrMo-3	310	310	310	310	209	209	209	209	209	218	309	310	NiCr-3	309	310
660	310	310	310	310	310	310	310	310	310	NiCrMo-3	385	385	310	310	209	209	209	209	310	310	312	310	NiCr-3	312	310
662	310	310	310	310	310	310	310	310	310	NiCrMo-3	385	385	310	310	209	209	209	209	310	310	312	310	NiCr-3	312	310
904L	308	317L	385	317L	309	309	309	385	385	NiCrMo-3	385	385	385	385	308	308	308	308	209	308L	309	312	NiCr-3	309	312
1925 hMo	308	317L	385	317L	309	309	309	NiCrMo-3	310	NiCrMo-3	NiCrMo-3	NiCrMo-3	NiCrMo-3	NiCrMo-3	308L	308L	308L	308L	209	308L	309	312	NiCr-3	309	312
2205	308	317L	2209	317L	309	309	309	2209	2209	2209	2209	2209	2209	2209	2209	2209	2209	2209	2209	2209	309	2209	NiCr-3	309	2209
2304	308	317L	2209	317L	309	309	309	2209	2209	2209	2209	2209	2209	2209	2209	2209	2209	2209	2209	2209	309	2209	NiCr-3	309	2209
2507	308	317L	2593	317L	309	309	309	2593	2593	2593	385	385	2593	2593	2593	2593	2593	2593	2593	2593	309	2209	NiCr-3	309	2209
A286	310	310	310	310	310	310	310	310	310	NiCrMo-3	NiCrMo-3	NiCrMo-3	310	310	310	310	310	310	310	310	312	310	NiCr-3	312	310
AL-6XN	308	317L	385	317L	309	309	309	NiCrMo-3	310	NiCrMo-3	NiCrMo-3	NiCrMo-3	NiCrMo-3	NiCrMo-3	308L	308L	308L	308L	209	308L	309	312	NiCr-3	309	312
CA-6N	308	308	308	308	308	308	308	308	308	310	309L	309L	2209	2209	209	209	209	209	209	218	309	310	NiCr-3	309	310
CA-6NM	308	308	308	308	308	308	308	308	308	310	309L	309L	2209	2209	209	209	209	209	209	218	309	310	NiCr-3	309	310
CA-15	308	308	308	308	308	308	308	308	308	310	309L	309L	2209	2209	209	209	209	209	209	218	309	310	NiCr-3	309	310

NCW = Not Considered Weldable NM = No Matching Filler Metal WA = Weld Autogenously NA = Not Addressed by this Table

(Continued)

Table F.1 (Continued)
Suggested Filler Metals for Various Combinations of Stainless Steel and Other Ferrous Base Metals

	Base Metal																								
Base Metal	CF-20	CG-3M	CG-6MMN	CG-8M	CG-12	CH-10	CH-20	CK-3MCuN	CK-20	CK-35MN	CN-3M	CN-3MN	CN-7M	CN-7MS	Nitronic 30	Nitronic 32	Nitronic 33	Nitronic 40	Nitronic 50	Nitronic 60	Carbon Steel, <0.3% C	Carbon Steel, >0.3% C	Cr-Mo Creep Resisting Steel	Low Alloy Steel, <0.3% C	Low Alloy Steel, >0.3% C
CA-15M	308	308	308	308	308	308	308	308	308	310	309L	309L	2209	2209	209	209	209	209	209	218	309	310	NiCr-3	309	310
CA-28MWV	312	312	312	312	312	312	312	312	310	310	310	310	310	310	310	310	310	310	310	310	310	310	NiCr-3	310	310
CA-40	312	312	312	312	312	312	312	312	310	310	310	310	310	310	310	310	310	310	209	310	309	310	NiCr-3	309	310
CA-40F	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW
CB-6	308	308	308	308	308	308	308	308	308	310	309L	309L	310	310	308	308	308	308	308	308	309	312	NiCr-3	309	312
CB-30	308	308	308	308	308	308	308	308	310	310	309L	309L	310	310	308	308	308	308	308	308	309	312	NiCr-3	309	312
CC-50	308	317L	312	317L	309	309	309	312	310	310	385	385	310	310	308	308	308	308	2209	309	309	312	NiCr-3	309	312
CD3MCuN	308	317L	2593	317L	309	309	309	2593	2593	2593	2593	2593	2593	2593	2593	2593	2593	2593	2593	2593	309	2593	NiCr-3	309	2593
CD3MN	308	317L	2209	317L	309	309	309	2209	2209	2209	2209	2209	2209	2209	2209	2209	2209	2209	2209	2209	309	2209	NiCr-3	309	2209
CD3MWCuN	308	317L	2593	317L	309	309	309	2593	2593	2593	2593	2593	2593	2593	2593	2593	2593	2593	2593	2593	309	2593	NiCr-3	309	2593
CD4MCu	308	317L	2593	317L	309	309	309	2593	2593	2593	2593	2593	2593	2593	2593	2593	2593	2593	2593	2593	309	2593	NiCr-3	309	2593
CD4MCuN	308	317L	2593	317L	309	309	309	2593	2593	2593	2593	2593	2593	2593	2593	2593	2593	2593	2593	2593	309	2593	NiCr-3	309	2593
CD6MN	308	317L	2593	317L	309	309	309	2593	2593	2593	2593	2593	2593	2593	2593	2593	2593	2593	2593	2593	309	2593	NiCr-3	309	2593
CE3MN	308	317L	2593	317L	309	309	309	2593	2593	2593	2593	2593	2593	2593	2593	2593	2593	2593	2593	2593	309	2593	NiCr-3	309	2593
CE8MN	308	317L	2593	317L	309	309	309	2593	2593	2593	2593	2593	2593	2593	2593	2593	2593	2593	2593	2593	309	2593	NiCr-3	309	2593
CE-30	308	317L	312	317L	309	309	309	312	312	312	312	312	312	312	312	312	312	312	312	309	309	312	NiCr-3	309	312
CF-3	308	308L	308L	308L	308L	308L	308L	308L	308L	308L	308L	308L	310	310	308L	308L	308L	308L	308L	308L	309	312	NiCr-3	309	312
CF-3M	308	316L	316L	316L	309	309	309	316L	316L	316L	316L	316L	310	310	308L	308L	308L	308L	316L	308L	309	312	NiCr-3	309	312
CF-3MN	308	317L	317L	317L	309	309	309	317L	317L	385	385	385	310	310	308L	308L	308L	308L	317L	308L	309	312	NiCr-3	309	312
CF-8	308	308	308	308	308	308	308	308	308	308	308	308	310	310	308	308	308	308	308	308	309	312	NiCr-3	309	312
CF-8C	308	308	308	308	308	308	308	308	308	308	308	308	310	310	308	308	308	308	308	308	309	312	NiCr-3	309	312
CF-8M	308	316	316	316	309	309	309	316	316	308	308	308	310	310	308	308	308	308	316	308	309	312	NiCr-3	309	312
CF-10SMnN	308	317L	310	317	309	309	310	310	310	310	309	309	310	310	309	309	309	309	209	218	309	312	NiCr-3	309	312
CF-16F	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NiCr-3	NCW	NCW
CF-16Fa	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NCW	NiCr-3	NCW	NCW

NCW = Not Considered Weldable NM = No Matching Filler Metal WA = Weld Autogenously NA = Not Addressed by this Table

(Continued)

Table F.2
Type and Chemical Composition of Stainless Steels and Other Ferrous Base Metals

		Nominal Composition, %													
Filler Metal	Type	C	Mn	P	S	Si	Cr	Ni	Mo	Nb	Cu	N	Al	Ti	Other
17-4PH	Martensitic PH	0.04	0.50	0.02	0.01	0.50	16.25	4.00		0.30	4.00				
17-7PH	Semi-Austenitic PH	0.05	0.50	0.02	0.01	0.50	17.00	7.00					1.00		
25-6MO	Austenitic	0.01	1.00	0.02	0.01	0.30	20.00	25.00	6.50		1.00	0.20			
26-1	Ferritic	0.01	0.20	0.01	0.01	0.02	26.00		1.00						
29-4	Ferritic	0.01	0.20	0.01	0.01	0.10	29.00		4.00						C + N < 0.025
29-4-2	Ferritic	0.01	0.20	0.01	0.01	0.10	29.00	2.25	4.00						C + N < 0.025
201	Austenitic	0.08	6.50	0.03	0.01	0.50	17.00	4.50				0.20			
202	Austenitic	0.08	9.25	0.03	0.01	0.50	18.00	5.00				0.2			
254SMo	Austenitic	0.01	0.50	0.01	0.01	0.40	20.00	18.00	6.25		0.75	0.20			
255	Duplex	0.02	0.75	0.02	0.01	0.50	25.50	5.50	3.40		2.00	0.18			
301	Austenitic	0.08	1.00	0.03	0.01	0.50	17.00	7.00							
301L	Austenitic	0.02	1.00	0.03	0.01	0.50	17.00	7.00				0.1			
301LN	Austenitic	0.02	1.00	0.03	0.01	0.50	17.00	7.00				0.15			
302	Austenitic	0.08	1.00	0.03	0.01	0.40	18.00	9.00							
303	Austenitic—FM	0.08	1.00	0.10	0.20	0.50	18.00	9.00							
303Se	Austenitic—FM	0.08	1.00	0.10	0.13	0.50	18.00	9.00							Se: 0.2
304	Austenitic	0.04	1.00	0.03	0.01	0.40	19.00	9.25							
304L	Austenitic	0.02	1.00	0.03	0.01	0.40	19.00	10.00							
304H	Austenitic	0.07	1.00	0.03	0.01	0.40	19.00	9.25							
304N	Austenitic	0.04	1.00	0.03	0.01	0.40	19.00	9.25				0.13			
304LN	Austenitic	0.02	1.00	0.03	0.01	0.40	19.00	10.00				0.13			
305	Austenitic	0.06	1.00	0.03	0.01	0.40	18.00	11.75							
306	Austenitic	0.01	1.00	0.01	0.01	4.00	17.75	14.75							
308	Austenitic	0.04	1.00	0.03	0.01	0.50	20.00	11.00							
309	Austenitic	0.10	1.00	0.03	0.01	0.50	23.00	13.50							

PH = Precipitation Hardened FM = Free-Matching

(Continued)

Table F.2 (Continued)
Type and Chemical Composition of Stainless Steels and Other Ferrous Base Metals

		Nominal Composition, %													
Filler Metal	Type	C	Mn	P	S	Si	Cr	Ni	Mo	Nb	Cu	N	Al	Ti	Other
309S	Austenitic	0.04	1.00	0.03	0.01	0.40	23.00	13.50							
309H	Austenitic	0.07	1.00	0.03	0.01	0.40	23.00	13.50							
309Cb	Austenitic	0.04	1.00	0.03	0.01	0.40	23.00	14.00		0.60					
309HCb	Austenitic	0.07	1.00	0.03	0.01	0.40	23.00	14.00		0.80					
310	Austenitic	0.15	1.00	0.03	0.01	0.75	25.00	20.50							
310S	Austenitic	0.04	1.00	0.03	0.01	0.75	25.00	20.50							
310H	Austenitic	0.07	1.00	0.03	0.01	0.40	25.00	20.50							
310Cb	Austenitic	0.04	1.00	0.03	0.01	0.75	25.00	20.50		0.60					
310HCb	Austenitic	0.07	1.00	0.03	0.01	0.40	25.00	20.50		0.80					
310MoLN	Austenitic	0.01	1.00	0.02	0.01	0.25	25.00	22.00	2.10			0.12			
314	Austenitic	0.15	1.00	0.03	0.01	2.25	24.50	20.50							
316	Austenitic	0.04	1.00	0.03	0.01	0.40	17.00	12.00	2.20						
316L	Austenitic	0.02	1.00	0.03	0.01	0.40	17.00	12.00	2.20						
316H	Austenitic	0.07	1.00	0.03	0.01	0.40	17.00	12.00	2.20						
316Ti	Austenitic	0.04	1.00	0.03	0.01	0.40	17.00	12.00	2.20					0.50	
316Cb	Austenitic	0.04	1.00	0.03	0.01	0.40	17.00	12.00	2.20					0.60	
316N	Austenitic	0.04	1.00	0.03	0.01	0.40	17.00	12.00	2.20			0.13			
316LN	Austenitic	0.02	1.00	0.03	0.01	0.40	17.00	12.00	2.20			0.13			
317	Austenitic	0.04	1.00	0.03	0.01	0.40	19.00	13.00	3.30						
317L	Austenitic	0.02	1.00	0.03	0.01	0.40	19.00	13.00	3.30						
317LM	Austenitic	0.02	1.00	0.03	0.01	0.40	19.00	15.50	4.50						
317LMN	Austenitic	0.02	1.00	0.03	0.01	0.40	18.50	15.50	4.50			0.15			
317LN	Austenitic	0.02	1.00	0.03	0.01	0.40	19.00	13.00	3.30			0.16			
320	Austenitic	0.04	1.00	0.03	0.01	0.50	20.00	35.00	2.50	0.60	3.50				
321	Austenitic	0.04	1.00	0.03	0.01	0.40	18.00	10.50						0.50	

(Continued)

Table F.2 (Continued)
Type and Chemical Composition of Stainless Steels and Other Ferrous Base Metals

Filler Metal	Type	Nominal Composition, %													
		C	Mn	P	S	Si	Cr	Ni	Mo	Nb	Cu	N	Al	Ti	Other
321H	Austenitic	0.07	1.00	0.03	0.01	0.40	18.00	10.50						0.50	
329	Duplex	0.04	0.50	0.03	0.01	0.40	25.50	4.00	1.50						
330	Austenitic	0.05	1.00	0.02	0.01	1.20	18.50	35.50							
334	Austenitic	0.04	0.50	0.02	0.01	0.50	19.00	20.00					0.40	0.40	
347	Austenitic	0.04	1.00	0.03	0.01	0.40	18.00	11.00		0.60					
347H	Austenitic	0.07	1.00	0.03	0.01	0.40	18.00	11.00		0.80					
348	Austenitic	0.04	1.00	0.03	0.01	0.40	18.00	11.00		0.60					Ta < 0.10
348H	Austenitic	0.07	1.00	0.03	0.01	0.40	18.00	11.00		0.80					Ta < 0.10
403	Martensitic	0.08	0.50	0.03	0.01	0.25	12.25								
405	Ferritic	0.04	0.50	0.03	0.01	0.50	13.00						0.20		
409	Ferritic	0.02	0.50	0.03	0.01	0.50	11.10							0.40	
410	Martensitic	0.11	0.50	0.03	0.01	0.50	12.50								
410S	Martensitic	0.04	0.50	0.03	0.01	0.50	12.50								
410NiMo	Martensitic	0.03	0.75	0.02	0.01	0.30	12.75	4.50	0.75						
414	Martensitic	0.08	0.50	0.03	0.01	0.50	12.50	2.00							
416	Martensitic	0.08	0.60	0.03	0.20	0.50	13.00								
416Se	Martensitic	0.08	0.60	0.03	0.03	0.50	13.00								Se: 0.2
420	Martensitic	0.20	0.50	0.03	0.01	0.50	13.00								
420F	Martensitic	0.35	0.60	0.03	0.20	0.50	13.00								
420FSe	Martensitic	0.30	0.60	0.03	0.03	0.50	13.00								Se: 0.2
429	Ferritic	0.06	0.50	0.03	0.01	0.50	15.00								
430	Ferritic	0.06	0.50	0.03	0.01	0.50	17.00								
431	Martensitic	0.10	0.50	0.03	0.01	0.50	16.00	2.00							
434	Ferritic	0.06	0.50	0.03	0.01	0.50	17.00	1.00							
436	Ferritic	0.06	0.50	0.03	0.01	0.50	17.00	1.00		0.50					

(Continued)

Table F.2 (Continued)
Type and Chemical Composition of Stainless Steels and Other Ferrous Base Metals

Filler Metal	Type	Nominal Composition, %													
		C	Mn	P	S	Si	Cr	Ni	Mo	Nb	Cu	N	Al	Ti	Other
439	Ferritic	0.03	0.50	0.03	0.01	0.50	18.00							0.60	
440A	Martensitic	0.70	0.50	0.03	0.01	0.50	17.00								
440B	Martensitic	0.85	0.50	0.03	0.01	0.50	17.00								
440C	Martensitic	1.10	0.50	0.03	0.01	0.50	17.00								
440F	Martensitic	1.10	0.50	0.03	0.01	0.50	17.00								
444	Ferritic	0.01	0.50	0.03	0.01	0.50	18.50		2.10	0.20				0.30	
446	Ferritic	0.10	0.75	0.03	0.01	0.50	25.00								
630	Martensitic PH	0.04	0.50	0.02	0.01	0.50	16.25	4.00		0.30	4.00				
631	Semi-Austenitic PH	0.05	0.50	0.02	0.01	0.50	17.00	7.00					1.00		
632	Semi-Austenitic PH	0.05	0.50	0.03	0.01	0.50	15.00	7.00	2.50				1.00		
633	Martensitic PH	0.09	1.00	0.03	0.01	0.25	16.50	4.50	2.90			0.1			
634	Martensitic PH	0.12	1.00	0.03	0.01	0.25	16.50	4.50	2.90			0.10			
635	Semi-Austenitic PH	0.04	0.50	0.03	0.01	0.50	16.75	6.75					0.20	0.80	
660	Austenitic PH	0.04	1.00	0.03	0.01	0.50	14.75	25.50	1.25				0.20	2.10	V: 0.30; B: 0.005
662	Austenitic PH	0.04	0.75	0.03	0.01	0.50	13.50	26.00	3.00				0.20	1.80	B: 0.005
904L	Austenitic	0.01	1.00	0.03	0.01	0.50	21.00	25.50	4.50		1.50				
1925 hMo	Austenitic	0.01	1.00	0.02	0.01	0.30	20.00	25.00	6.50		1.00	0.20			
2205	Duplex	0.02	1.00	0.02	0.01	0.50	22.50	5.50	3.25			0.17			
2304	Duplex	0.02	1.25	0.03	0.01	0.50	23.00	4.25	0.30			0.12			
2507	Duplex	0.02	0.60	0.02	0.01	0.40	25.00	7.00	4.00			0.28			
A286	Austenitic PH	0.04	0.75	0.03	0.01	0.50	13.50	26.00	3.00				0.20	1.80	B: 0.005
AL-6XN	Austenitic	0.02	1.00	0.03	0.01	0.50	21.00	24.50	6.50			0.22			
CA-6N	Martensitic	0.04	0.25	0.01	0.01	0.50	11.50	7.00							
CA-6NM	Martensitic	0.04	0.50	0.02	0.01	12.75	4.00	0.70							
CA-15	Martensitic	0.10	0.50	0.03	0.01	0.75	12.75								

PH = Precipitation Hardened FM = Free-Matching

(Continued)

Table F.2 (Continued)
Type and Chemical Composition of Stainless Steels and Other Ferrous Base Metals

Filler Metal	Type	Nominal Composition, %													
		C	Mn	P	S	Si	Cr	Ni	Mo	Nb	Cu	N	Al	Ti	Other
CA-15M	Martensitic	0.10	0.50	0.03	0.01	0.30	12.75		0.60						
CA-28MWV	Martensitic	0.24	0.75	0.02	0.01	0.50	11.75	0.75	1.10						W: 1.1; V: 0.25
CA-40	Martensitic	0.30	0.50	0.03	0.01	0.75	12.75								
CA-40F	Martensitic	0.30	0.50	0.03	0.30	0.75	12.75								
CB-6	M + F	0.04	0.50	0.03	0.01	0.50	16.50	4.50							
CB-30	M + F	0.20	0.50	0.03	0.01	0.75	19.50								
CC-50	M + F	0.30	0.50	0.03	0.01	0.75	28.00								
CD3MCuN	Duplex	0.02	0.60	0.02	0.01	0.55	25.30	6.10	3.35		1.65	0.28			
CD3MN	Duplex	0.02	0.75	0.03	0.01	0.50	22.25	5.50	3.00			0.20			
CD3MWCuN	Duplex	0.02	0.50	0.02	0.02	0.50	25.00	7.50	3.50		0.75	0.25			W: 0.75
CD4MCu	Duplex	0.03	0.50	0.03	0.01	0.50	25.50	5.20	2.00		3.00				
CD4MCuN	Duplex	0.03	0.50	0.03	0.01	0.50	25.50	5.20	2.00		3.00	0.18			
CD6MN	Duplex	0.04	0.50	0.03	0.01	0.50	25.50	5.00	2.10			0.20			
CE3MN	Duplex	0.02	0.75	0.03	0.01	0.50	25.00	7.00	4.50			0.2			
CE8MN	Duplex	0.04	0.50	0.03	0.01	0.75	24.00	9.50	3.75			0.20			
CE-30	Duplex	0.15	0.75	0.03	0.01	1.00	28.00	9.50							
CF-3	Austenitic	0.02	0.75	0.03	0.01	1.00	19.00	10.00							
CF-3M	Austenitic	0.02	0.75	0.03	0.01	0.75	19.00	11.00	2.50						
CF-3MN	Austenitic	0.02	0.75	0.03	0.01	0.75	19.50	11.00	2.50			0.15			
CF-8	Austenitic	0.04	0.75	0.03	0.01	1.00	19.50	9.50							
CF-8C	Austenitic	0.04	0.75	0.03	0.01	1.00	19.50	10.50		0.60					
CF-8M	Austenitic	0.04	0.75	0.03	0.01	1.00	19.50	10.50	2.50						
CF-10SMnN	Austenitic	0.05	8.00	0.04	0.01	4.00	17.00	8.50				0.13			
CF-16F	Austenitic	0.08	0.75	0.09	0.02	1.00	19.50	10.50							Se: 0.28
CF-16Fa	Austenitic	0.08	0.75	0.03	0.30	1.00	19.50	10.50	0.60						

PH = Precipitation Hardened FM = Free-Matching

(Continued)

Table F.2 (Continued)
Type and Chemical Composition of Stainless Steels and Other Ferrous Base Metals

	Nominal Composition, %														
Filler Metal	Type	C	Mn	P	S	Si	Cr	Ni	Mo	Nb	Cu	N	Al	Ti	Other
CF-20	Austenitic	0.10	0.75	0.03	0.01	1.00	19.50	9.50							
CG-3M	Austenitic	0.02	0.75	0.03	0.01	0.75	19.50	11.00	3.50						
CG-6MMN	Austenitic	0.04	5.00	0.03	0.01	0.50	22.00	12.50	2.25	0.20		0.3			V: 0.20
CG-8M	Austenitic	0.04	0.75	0.03	0.01	0.75	19.50	11.00	3.50						
CG-12	Austenitic	0.06	0.75	0.03	0.01	1.00	21.50	11.50							
CH-10	Austenitic	0.05	0.75	0.03	0.01	1.00	24.00	13.50							
CH-20	Austenitic	0.10	0.75	0.03	0.01	1.00	24.00	13.50							
CK-3MCuN	Austenitic	0.02	0.60	0.03	0.01	0.50	20.00	18.50	6.50		0.75	0.21			
CK-20	Austenitic	0.10	1.00	0.03	0.01	1.00	25.00	20.50							
CK-35MN	Austenitic	0.02	1.00	0.02	0.01	0.50	23.00	21.00	6.40			0.26			
CN-3M	Austenitic	0.02	1.00	0.02	0.01	0.50	21.00	25.00	5.00						
CN-3MN	Austenitic	0.02	1.00	0.03	0.01	0.50	21.00	24.50	6.50			0.22			
CN-7M	Austenitic	0.04	0.75	0.03	0.01	0.75	20.50	29.00	2.50		3.50				
CN-7MS	Austenitic	0.04	0.50	0.03	0.01	3.00	19.00	23.50	2.75		1.75				
Nitronic 30	Austenitic	0.02	8.00	0.03	0.01	0.50	16.00	2.25				0.23			
Nitronic 32	Austenitic	0.08	18.00	0.03	0.01	0.50	18.00		1.00		1.00	0.50			
Nitronic 33	Austenitic	0.04	13.00	0.03	0.01	0.40	18.00	3.00				0.3			
Nitronic 40	Austenitic	0.04	9.00	0.04	0.01	0.50	20.00	6.50				0.28			
Nitronic 50	Austenitic	0.04	5.00	0.03	0.01	0.40	22.00	12.50	2.25	0.20		0.3			V: 0.20
Nitronic 60	Austenitic	0.05	8.00	0.04	0.01	4.00	17.00	8.50				0.13			

Annex G (Informative)

List of Reference Documents

This annex is not part of AWS D1.6/D1.6M:2007, *Structural Welding Code—Stainless Steel*,
but is included for informational purposes only.

The following documents are referenced in AWS D1.6/D1.6M:2007.

1. AWS A2.4, *Symbols for Welding, Brazing and Nondestructive Examination*.
2. AWS A3.0, *Standard Welding Terms and Definitions Including Terms for Adhesive Bonding, Brazing, Soldering, Thermal Cutting, and Thermal Spraying*.
3. ANSI Z49.1, *Safety in Welding, Cutting, and Allied Processes*.
4. American Society of Mechanical Engineers (ASME), Boiler and Pressure Vessel Code, Section II, Part D.
5. AWS B2.1, *Standard for Welding Procedure and Performance Qualification*.
6. AWS A4.2, *Standard Procedures for Calculating Magnetic Instruments to Measure the Delta Ferrite Content of Austenitic and Duplex Austenitic-Ferritic Stainless Steel Weld Metal*.
7. AWS A5.4, *Specification for Stainless Steel Welding Electrodes for Shielded Metal Arc Welding*.
8. AWS A5.9, *Specification for Bare Stainless Steel Welding Electrodes and Rods*.
9. AWS A5.22, *Specification for Stainless Steel Electrodes for Flux Cored Arc Welding and Stainless Steel Flux Cored Rods for Gas Tungsten Arc Welding*.
10. ASME Boiler and Pressure Vessel Code, Section IX.
11. AWS A5.12, *Specification for Tungsten and Tungsten Alloy Electrodes for Arc Welding and Cutting*.
12. AWS B4.0, *Standard Methods for Mechanical Testing of Welds*.
13. AWS QC1, *Standard for AWS Certification of Welding Inspectors*.
14. Canadian Standards Association (CSA) W178.2, *Certification of Welding Inspectors*.
15. American Society for Nondestructive Testing (ASNT) *Recommended Practice SNT-TC-1A*.
16. AWS B1.0, *Guide for Nondestructive Examination of Welds*.
17. ASTM E 165, *Test Method for Liquid Penetrant Examination*.
18. ASTM E 709, *Guide for Magnetic Particle Examination*.
19. ASTM E 94, *Guide for Radiographic Testing*.
20. ASTM E 142, *Method for Controlling Quality of Radiographic Testing*.
21. ASTM E 747, *Practice for Design, Manufacture and Material Grouping of Wire Image Quality Indicators (IQI) for Radiology*.
22. ASTM E 1032, *Method for Radiographic Examination of Weldments*.
23. ANSI/ASME B46.1, *Surface Texture (Surface Roughness, Waviness, and Lay)*.

24. ASTM A 493, *Specification for Stainless and Heat-Resisting Steel Wire and Wire Rods for Cold Heading and Cold Forging*.

25. ASTM A 370, *Test Methods and Definitions of Mechanical Testing of Steel Products*.

26. API Standard 1104, *Welding of Pipelines and Related Facilities*.

27. American Conference of Governmental Industry Hygienists (ACGIH), *Threshold Limit Values for Chemical Substances and Physical Agents in the Workroom Environment*.

28. American National Standards Institute. ANSI Z87.1, *Practice for Occupational and Educational Eye and Face Protection*.

29. American National Standards Institute. ANSI Z41.1, *Personal Protection—Protective Footwear*.

30. American Welding Society. *Fumes and Gases in the Welding Environment*.

31. AWS F6.1, *Method for Sound Level Measurement of Manual Arc Welding and Cutting Processes*.

32. AWS F4.1, *Recommended Safe Practices for the Preparation for Welding and Cutting Containers and Piping*.

33. AWS. *Safe Practices.* (Reprint from Welding Handbook, Volume 1, Eighth Edition).

34. National Fire Protection Association. NFPA Standard 51B, *Fire Prevention in Use of Cutting and Welding Processes*.

35. National Fire Protection Association, National Electrical Code NFPA No. 70. Quincy, Massachusetts: National Fire Protection Association.

36. Occupational Safety and Health Administration. *Code of Federal Regulations,* Title 29 Subtitle B, Chapter XVII, Part 1910.

37. American Institute of Steel Construction (AISC), *Specification for Standard Steel Buildings and Plastic Design*.

38. AISC *Load and Resistance Factor Design Specification for Structural Steel Buildings*.

39. American Society of Testing and Materials (ASTM) A 167, *Specification for Stainless and Heat-Resisting Chromium-Nickel Steel Plate, Sheet and Strip*.

40. ASTM A 213, *Specification for Seamless Ferritic and Austenitic Alloy-Steel Boiler, Superheater and Heat Exchanger Tubes*.

41. ASTM A 240, *Specification for Heat-Resisting Chromium and Chromium-Nickel Stainless Steel Plate, Sheet and Strip for Pressure Vessels*.

42. ASTM A 249, *Specification for Welded Austenitic Steel Boiler, Superheater, Heat-Exchanger and Condenser Tubes*.

43. ASTM A 312, *Specification for Seamless and Welded Austenitic Stainless Steel Pipes*.

445.ASTM A 351, *Specification for Castings, Austenitic, Austenitic-Ferritic (Duplex), for Pressure-Containing Parts*.

45. ASTM A 376, *Specification for Seamless Austenitic Steel Pipe for High-Temperature Central Station Service*.

46. ASTM A 403, *Specification for Wrought Austenitic Stainless Steel Piping Fittings*.

47. ASTM A 409, *Specification for Welded Large Diameter Austenitic Steel Pipe for Corrosive or High-Temperature Service*.

48. ASTM A 430, (Discontinued 1995), *Specification for Austenitic Steel Forged and Bored Pipe for High-Temperature Service (replaced by ASTM A 312)*.

49. ASTM A 451, *Specification for Centrifugally Cast Austenitic Steel Pipe for High-Temperature Service*.

50. ASTM A 452 (Discontinued 1995), *Specification for Centrifugally Cast Austenitic Steel Cold-Wrought Pipe for High-Temperature Service*.

51. ASTM A 473, *Specification for Stainless and Heat-Resisting Steel Forgings*.

52. ASTM A 479, *Specification for Stainless and Heat-Resisting Steel Bars and Shapes for Use in Boilers and Other Pressure Vessels*.

53. ASTM A 511, *Specification for Seamless Stainless Steel Mechanical Tubing*.

54. ASTM A 554, *Specification for Welded Stainless Steel Mechanical Tubing*.

55. ASTM A 666, *Specification for Annealed or Cold-Worked Austenitic Stainless Steel, Sheet, Slip, Plate and Flat-Bar*.

56. ASTM A 743, *Specification for Castings, Iron-Chromium, Iron-Chromium-Nickel Corrosion Resistant, for General Application*.

57. ASTM A 744, *Specification for Castings, Iron-Chromium-Nickel, Corrosion Resistant, for Severe Service*.

58. ASTM A 774, *Specification for As-Welded Wrought Austenitic Stainless Steel Fittings for General Corrosive Service at Low and Moderate Temperatures*.

59. ASTM A 778, *Specification for Welded, Unannealed Austenitic Stainless Steel Tubular Products*.

60. ASTM A 813, *Specification for Single-or Double-Welded Austenitic Stainless Steel Pipe*.

61. ASTM A 814, *Specification for Cold-Worked Welded Austenitic Stainless Steel Pipe*.

62. ASTM A 831, *Specification for Austenitic and Martensitic Stainless Steel Bars, Billets and Forgings for Liquid Metal Cooled Reactor Core Components*.

63. ASTM A 851, *Specification for High-Frequency Induction Welded, Unannealed, Austenitic Steel Condenser Tubes*.

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Annex H (Informative)

Recommended Inspection Practice

This annex is not part of AWS D1.6/D1.6M:2007, *Structural Welding Code—Stainless Steel*, but is included for informational purposes only.

H1. General

This code contains weld quality standards that may be overly restrictive or too liberal for the intended use of the product and/or the types of stainless steel being used. Corrosive service conditions have not been considered in the development of this code. The Engineer should make whatever modifications are needed to accommodate corrosive service; that information should be added to the contract documents.

The use of fracture mechanics analysis and fitness-for-purpose criteria is an alternative method of determining acceptance standards. (For additional information see *API Standard 1104, Welding of Pipelines and Related Facilities, Appendix A*.)

H2. Inspection Guidelines

Inspection guidelines are contained in Tables H.1 and H.2.

When less than 100% inspection is to be performed it should be done by partial inspection of a specified lot of welds or should be done by spot inspection of a specified lot of welds or should be done by spot inspection of a specified length of a weld as described below. Lots should be established on the basis of welder or welding operator, WPS, or other conditions and time periods which are acceptable to the Engineer. Unless specified otherwise by the Engineer, a lot should consist of ten welds made in succession by each welder or welding operator.

A3. Partial Sampling

Partial sampling should be used for inspection of a specified number of percent of welds which are contained in a lot of welds. Each weld of the lot to be examined should be selected by random choice and should be examined 100%. Unless specified otherwise by the Engineer, 1 weld of each 10 weld lots (10%) should be examined. When partial sampling inspection of a lot reveals no rejectable discontinuities, the entire lot of welds should be considered acceptable. When partial sampling inspection of a lot of welds reveals rejectable discontinuities, the entire lot of welds should be considered rejectable and all remaining welds of that lot should be examined.

H4. Spot Sampling

Spot sampling should be used for inspection of a specified length of weld in each weld to be examined. Welds to be examined by the spot sampling method should have been made by the same welder and welding procedure. The welds to be examined should be agreed upon between the fabrication/erection inspector, and the verification inspector or Engineer. Unless specified otherwise by the Engineer, each spot should cover at least 6 in. [150 mm] of the weld length. The location of each spot should be of the weld length. The location of each spot should be randomly selected by the inspector. When spot sampling inspection reveals no rejectable discontinuities, the entire length of weld represented by the spot sample should be considered acceptable. When spot sampling inspection reveals rejectable discontinuities, the entire length of weld represented by the spot sample should be considered rejectable and the remainder of the weld should be examined. In addition to examining the entire weld in question, a minimum of 2 other welds made by the same welder and welding procedure should also be given spot sampling inspection. If either or both of the 2 new welds are found to be rejectable, all welds are given spot sampling inspection.

H5. Inspection Sequence

Final visual inspection should be performed after all required cleaning and preparations. All welds should be visually acceptable prior to performing any other subsequent final NDT.

Testing of welds in all materials may begin immediately after the completed welds have cooled to ambient temperature unless otherwise specified by the Engineer.

H6. Nondestructive Testing

H6.1 General. This annex covers visual inspection and penetrant inspection. See Clause 6, Part B of this code for radiographic testing. See Part C of this code for ultrasonic testing.

H6.2 Visual Testing (VT). VT should consist of, as a minimum, the suggested frequency of Table H.2 and should be performed using application gages, standards and visual aides as necessary.

H6.2.1 Porosity should not exceed the following:

(1) All weld classes of CJP groove welds in butt joints transverse to the direction of computed tensile stress—None permitted.

(2) Weld Classes 0, 1, and 3—the sum of diameters of piping porosity 1/32 in. [1 mm] and greater in diameter should not exceed 3/8 in. [10 mm] in any 1 in. [25 mm] of weld or 3/4 in. [20 mm] in any 12 in. [300 mm] length of weld.

(3) Weld Classes 2, 4, and 5—maximum of one indication in any 4 in. [100 mm] of weld and maximum diameter should not exceed 3/32 in. [2.5 mm].

H6.2.2 Fillet Weld Size Underrun—1/16 in. [2 mm] maximum for 20% of weld length maximum.

(1) No underrun permitted at the ends of web to flange fillet welds of girders for weld class 2.

(2) For weld classes 0 and 1, underrun is permitted at the ends of web to flange fillet welds for a length equal to twice the width of the flange.

H6.2.3 Undercut limitations are described in Table H.3.

H6.3 Penetrant Testing (PT). PT guidelines may be in accordance with this informative annex, unless specified otherwise in the contract documents. PT should be performed in accordance with a written procedure which meets the requirements of ASTM E 165 and is acceptable to the engineer. Inspection requirements should be in accordance with Table H.2. Acceptance standards for welds and adjacent base metal heat-affected zones should be as follows:

(1) No linear indications permitted;

(2) Rounded indications:

(a) CJP groove welds with transverse tensile stress and welds to be used in immersion service—no indications permitted;

(b) All other statically loaded groove and fillet welds and cyclically loaded fillet welds—the sum of diameters of indications 1/32 in. [1 mm] and greater in diameter should not exceed 3/8 in. [10 mm] in any 1 in. [25 mm] of weld or 3/4 in. [20 mm] in any 12 in. [300 mm] length of weld;

(c) All other cyclically loaded groove welds—maximum of one indication in any 4 in. [100 mm] of weld and maximum diameter should not exceed 3/32 in. [2.5 mm].

Table H.1
Weld Classification (see H2)

Weld Class
0—Non-load carrying welds.
1—Statically loaded fillet welds, tubular fillet welds, and cyclically loaded stiffener to web fillet welds.
2—Cyclically loaded fillet welds, except stiffener to web fillet welds.
3—Statically loaded groove welds and tubular groove welds (except welds subject to fatigue control).
4—Cyclically loaded groove welds subject to compressive stress.
5—Cyclically loaded groove welds subject to tensile or shear stress and tubular groove welds subject to fatigue control.

Table H.2
Nondestructive Testing/Examination Methods[a] (see H2)

Method	Application	Suggested Frequency
VT	Completed weld for compliance	
	Class 0	10%
	Class 1–5	100%
	NDT Reports, Radiographs	100%
PT	NDT—Class 0	0% (Note b)
	NDT—Class 1	5%
	NDT—Class 2	10%
	NDT—Class 3,4	25%
	NDT—Class 5	100%
RT/UT	NDT—Class 0, 1, 2	0%
	NDT—Class 3, 4	10%
	NDT—Class 50%	25%

[a] The frequency should be determined based on the function of component, the actual loads on the welds, service temperatures, corrosive environments and the consequences of failure.
[b] Non-load carrying seal welds may require NDT.

Table H.3
Recommended Undercut Criteria (see H6.2.3)

Weld Class[a]	Base Metal Thickness,[b] in. [mm]	Maximum Depth, in. [mm]	Undercut Maximum Length, in. [mm]
0, 1	< 1 [25]	1/32 [1]	Unlimited
	≥ 1 [25]	1/16 [2]	2 in 12 [50 in 300]
2, 3	All	1/16 [2]	Unlimited
4	All	1/32 [1]	Unlimited
5	All	0.01 [0.25]	Unlimited
		None Permitted	None Permitted

[a] See Table H.1 for weld classes.
[b] Nominal thickness of base metal in which the undercut occurs.

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Annex I (Informative)

Nonprequalified Stainless Steels—Guidelines for WPS Qualification and Use

This annex is not part of AWS D1.6/D1.6M:2007, *Structural Welding Code—Stainless Steel*, but is included for informational purposes only.

I1. General

Prequalification, in Clause 3 of this code, is extended to those nominally austenitic stainless steel base metals which normally produce a small amount of delta ferrite when they are fused without filler metal, and for which there are suitable AWS classifications of nominally austenitic stainless steel filler metals that match the base metal strength and normally also provide a small amount of delta ferrite in the weld metal. The prequalified base metals are listed in Table 3.2 and the corresponding filler metals are listed in Table 3.3.

Nonprequalified stainless steels, therefore, include:

(1) martensitic stainless steels

(2) ferritic stainless steels

(3) austenitic stainless steels which normally do not provide ferrite when fused without filler metal

(4) austenitic stainless steels whose strength cannot be matched by any AWS classification of nominally austenitic stainless steel filler metal which normally provides a small amount of delta ferrite in the weld metal

(5) duplex ferritic-austenitic stainless steels

(6) precipitation hardening stainless steels

Selection of a nonprequalified stainless steel of one of the above general types might be made by the Engineer out of need for high strength or hardness, high toughness at very low temperatures, creep resistance, resistance to special corrodents, and other such concerns. Then a PQR and resulting WPS may be developed according to Clause 4 of this code. In developing the PQR and WPS, the fabricator may draw upon prior experience, base metal and filler metal manufacturers' expertise, handbook data, and the like. The following are general guidelines for welding the several types of nonprequalified stainless steels which may also be useful to the fabricator. However, no warranty should be construed as accompanying these guidelines.

I2. Nonprequalified Austenitic Stainless Steels

I2.1 A number of nominally austenitic stainless steels cannot be expected to provide delta ferrite in their welds, even if welded with filler metals that normally provide some ferrite. These stainless steels include Types 310, 320, 330, 904L, 254SMo, AL6XN, and many more. Such steels have some tendency to produce hot cracks in their fusion zones and in their high temperature heat-affected zones. They are usually welded with matching or near-matching filler metals. While this tendency towards hot cracking cannot be totally eliminated, it can be held in check by the following:

(1) Purchasing base metal and filler metal that are low in residual elements, especially sulfur and phosphorus. The lower the sum of these two impurities, the better, within the limits of commercial availability.

(2) Using low heat input procedures that produce shallow penetration and convex beads—submerged arc and spray transfer GMAW are best avoided.

(3) Maintaining low preheat and interpass temperature—250°F [120°C] maximum has been used successfully.

(4) Skip welding to avoid heat buildup in one area.

(5) Pausing at the end of each bead to fill the crater while down-sloping the welding current.

(6) Designing the weldment and the welding sequence to minimize restraint on the solidifying weld metal.

I2.2 Some austenitic stainless steels can be provided in conditions of cold work, which raise the tensile and yield strength to levels which cannot be matched by any nominally austenitic stainless steel filler metal in the as-welded condition.[1] Furthermore, the heat of welding partially anneals the heat-affected zone, reducing its strength. When these base metals are chosen, there are two possible approaches:

(1) Design the weldment taking into account the properties of the undermatching weld metal and of the heat-affected zone. Minimum design properties for the joint area should be those of the filler metal used or of the annealed base metal, whichever is less. Conservative design values may also be based on the SEI/ASCE-8, *Specification for the Design of Cold-Formed Stainless Steel Structural Members*. Higher design properties may be established by testing.

(2) Cold work the weld metal and heat-affected zone to increase joint strength. Roll planishing the weld area has been successfully used to this effect in thin sections. The parameters of cold working should be a part of the welding procedure specifications for joints to which this process is applied. Design properties of cold worked joints, which are higher than minimum values as per (1), shall be established by testing.

In both cases (1) and (2) described above, the tests and acceptance criteria for the increased design properties shall be specified in the contract documents.

I3. Martensitic Stainless Steel

Martensitic stainless steels are susceptible to cold cracking, in which diffusible hydrogen can play a contributing role. Procedures which have proven successful in welding martensitic stainless steels without cracking include:

(1) Maintenance of high preheat and interpass temperature—400°F may be necessary for Type 410, and 600°F may be necessary for Type 420 stainless steel.

(2) Use of very low hydrogen filler metals, fluxes, shielding gas, etc.

(3) Use of high heat input welding procedures to slow weld cooling.

(4) Use of insulation and/or supplemental heating to slow the cooling of the weldment.

(5) Application of postweld heat treatment as soon as the weld cools sufficiently that martensite transformation is nearly complete (typically this temperature is about 200°F [90°C]). Then the PWHT temperature must be chosen to temper martensite and remove hydrogen without re-austenitizing the metal; isothermal transformation diagrams for the base metal and weld metal should be consulted concerning the temperature at which austenite will start to form for a particular base metal and filler metal.

I4. Ferritic Stainless Steels

Ferritic stainless steels are susceptible to embrittlement from grain growth during welding, and from precipation of intermetallic compounds during postweld heat treatment or service at temperatures from as low as 600°F [315°C] to as high as 1700°F [930°C]. Due to the grain growth phenomenon, ferritic stainless steels are normally provided only in thin sections. Procedures which have proven successful in joining stainless steels without serious embrittlement include:

(1) Use of low heat input single-pass welding procedures.

(2) Skip welding to avoid heat buildup in one area.

(3) Certain ferritic stainless steels which contain considerable carbon, such as Type 430, may benefit from a short-time PWHT which permits carbon to diffuse out of the ferrite to small martensite islands which are softened by the same PWHT—the provider of the base metal should be consulted for exact recommendations for such PWHT.

(4) Where such use does not cause adverse corrosion effects, use of an austenitic filler metal which includes some ferrite, instead of a ferritic filler metal, may provide a more forgiving weldment.

[1] Refer to ASTM A 666, *Standard Specification for Annealed or Cold-Worked Austenitic Stainless Steel Sheet, Strip, Plate, and Flat Bar*.

I5. Duplex Ferritic-Austenitic Stainless Steels

Modern duplex stainless steels, deliberately alloyed with considerable nitrogen (typically 0.15% or more), are relatively easy to weld when the filler metal is essentially matching except for being overalloyed with nickel (typically 9% nickel is present in most duplex stainless steel filler metals). However, certain conditions are best avoided.

(1) Welds with high dilution can result in very high ferrite in the weld metal, and the weld may then have poor ductility, poor toughness, and poor corrosion resistance. Resistance welds should be avoided. GTAW should include much filler metal—open roots are recommended to force the welder to add sufficient filler metal. SAW conditions should be chosen to produce no more than 40% dilution.

(2) Very cold and very hot welds should be avoided. Very cold welds (less than 15 kilojoules per inch [0.6 kilojoules per mm]) can result in excessive weld and HAZ ferrite contents, and inferior properties. Very hot welds (in excess of about 60 kilojoules per inch [2.4 kilojoules per mm]) can result in precipitation of intermetallic compounds in the ferrite, causing poor weldment properties.

I6. Precipitation Hardening Stainless Steel

Each precipitation hardening stainless steel has its own special welding characteristics. Some, such as Type 630 (a.k.a. 17-4PH) are relatively easy to weld without hot cracks. Others, such as A-286, are very difficult to weld without hot cracks. Welding invariably overages part of the HAZ, and may leave the weld metal with a need for aging. Balance of the properties across the weldment is a very complex problem, unless the entire weldment can be solution heat treated and aged after welding, which is almost never possible. There are no good general rules which can be offered. The manufacturer of the precipation hardening base metal should be consulted for welding recommendations.

I.7 Welding Stainless Steel to Structural Carbon Steel or Low Alloy Steel

I7.1 General Principles. In most cases, stainless steel filler metal is used for these joints. When stainless steel filler metal is used for stainless steel to structural steel or low alloy steel joints, the primary issue is normally avoiding solidification cracks. There are two principles involved in developing a qualified welding procedure for a joint of stainless steel to a structural steel or low alloy steel. First, in order to make the welding operation simple to execute, it is desirable, if possible, to select an austenitic stainless steel welding filler metal that will provide solidification with ferrite as the first phase to freeze. This generally occurs with at least 3 FN in the weld metal, particularly in the root pass. The WRC-1992 Diagram, with extended axes, is useful in making predictions about weld metal solidification mode and Ferrite Number. Second, if the situation dictates that ferrite is not possible in the weld metal, then welding procedures that produce markedly convex weld beads and over-filling of craters are to be recommended.

It should also be recognized that there is a thin martensitic transition zone whenever austenitic stainless steel filler metal is applied on structural steel or low alloy steel. This transition zone can experience cold cracking due to the action of diffusible hydrogen. Although austenitic stainless steel filler metals act as barriers to hydrogen diffusion, they are not perfect barriers. Accordingly it is helpful to use low hydrogen practices for handling and storage of stainless steel filler metals for this purpose. In particular, covered electrodes should be stored in sealed containers until ready for use, and once the container is opened, remaining electrodes should be stored at 250°F [120°C] or higher to avoid moisture pickup. In the same vein, fluxes for submerged arc welding and flux cored wires should be protected from moisture pickup. Solid wires normally present no issues in this respect.

I7.2 Austenitic Stainless Steel to Structural Steel or Low Alloy Steel. By far, 309 or 309L is the most commonly applied filler metal for such joints when the stainless steel is one of the common ones, such as 304(L), 309(L), 316(L), or 347 that would be expected to produce a small amount of ferrite in an autogenous fusion zone. Figure I.1 illustrates the analysis leading to a prediction of ferrite in the root pass of a joint between 304 and carbon steel made with ER309LSi filler metal, using the WRC-1992 Diagram with the axes extended to zero and including the martensite boundary for 1% Mn compositions. A tie-line is first drawn between the composition of each of the two base metals, A 36 steel and 304 in this example. Assuming equal contribution to the dilution from each of these two base metals, the “synthetic” base metal providing the dilution into the root pass is found at the midpoint of this tie-line. Then a second tie-line is drawn from this “synthetic” base metal to the composition of the filler metal. If the expected dilution is 30%, the predicted root pass is found at a point 30% of the distance from the filler metal composition to the “synthetic” base metal composition. From Figure I.1, the predicted ferrite content of the root pass in this example is about 5 FN, and it lies in the range of compositions labeled “FA” on the Diagram, indicating the most crack resistant form of solidification, primary ferrite. Figure I.1 also includes a prediction for 40% dilution, about 2 FN and still in the range of compositions having primary ferrite solidification. Furthermore, with either 30% dilution or 40% dilution, the root pass composition is safely above and to the right of the martensite boundary, which means that no martensite will be found in the bulk of the root pass, and the root pass will therefore be ductile. Similar analysis can be done with any other combination of stainless steel with structural steel or low alloy steel.

With a properly designed 309 or 309L filler metal, solidification as primary ferrite generally occurs in such a root pass, unless excessive dilution takes place. In particular, submerged arc welding and root passes with gas tungsten arc welding are most at risk for excessive dilution. In the case of submerged arc welding, DCEN polarity, with current (wire feed speed) towards the low end of the recommended range for the given electrode diameter, are helpful towards limiting dilution so that at least 3 FN is obtained. With GTAW, an open root joint that requires plenty of filler metal is most helpful towards preventing excessive dilution. Manufacturers of covered electrodes and flux cored wires generally supply high ferrite 309 or 309L filler metals as standard, and these precautions are generally sufficient for SMAW and FCAW. However, GMAW, GTAW, and SAW use solid wires, in which not all suppliers aim for high ferrite content, because steel mills do not like to provide high ferrite 309 or 309L. Filler metal with at least 10 FN in the all-weld metal is safer. In cases where higher nickel stainless steel, such as 310, 320, 330, 904L and the like are to be welded to structural steel or low alloy steel, a filler metal still higher in ferrite content, such as 309LMo, 2209, or 312, may be necessary in order to obtain at least 3 FN in the weld metal, or to obtain primary ferrite solidification.

I7.3 Martensitic Stainless Steel to Structural Steel or Low Alloy Steel. If postweld heat treatment is planned, then a 12% Cr martensitic stainless steel such as 410 or 410NiMo can be welded to structural steel or low alloy steel with mild steel filler metal and proper preheat. However, if PWHT is not in the plan, then the austenitic filler metals of at least 10 FN become best choices, beginning with 309L. For higher alloy martensitic stainless steel, or for higher carbon martensitic stainless steel such as 420, then only high ferrite austenitic stainless steel filler metals such as 309L, 309LMo, 2209 or 312 are appropriate to obtaining at least 3 FN in the deposit, or primary ferrite solidification.

I7.4 Ferritic Stainless Steel to Structural Steel or Low Alloy Steel. The 12% Cr ferritic stainless steels such as 405 and 409 can be welded to structural steel or low alloy steel with mild steel filler metal. Higher alloy ferritic stainless steels are best welded to structural steel or low alloy steel with 309L filler metal. Higher alloy filler metals than 309L are generally unnecessary for such joints, though they can be used.

I7.5 Duplex Stainless Steel to Structural Steel or Low Alloy Steel. Again, 309L is generally the best choice for filler metal, although there is no harm, other than filler metal cost, in using filler metals of still higher ferrite content such as 2209 duplex stainless steel filler metal.

I7.6 Precipitation Hardening Stainless Steel to Structural Steel or Low Alloy Steel. For the martensitic PH stainless steels such as 17-4PH, and for the semi-austenitic PH stainless steels such as 17-7PH, 309L is again generally the best choice for most applications because it will produce at least 3 FN in the root pass, except under conditions of excessive dilution. However, the austenitic PH stainless steels, such as A-286, have high nickel content and therefore generally require a filler metal with higher ferrite content than 309L. At least 309LMo, and possibly 2209 or 312, may be necessary to avoid solidification cracking.

I7.7 Postweld Heat Treatment of Stainless Steel Welds to Structural Steel or Low Alloy Steel. PWHT of stainless steel to structural steel or low alloy steel joints involves possibilities for metallurgical reactions that are not of concern in PWHT of welds between structural steels or low alloy steels. The difference in alloy content between the high chromium stainless steel and the lower chromium structural steel or low alloy steel provides a driving force for carbon migration. This tends to produce a carbon depleted zone in the low chromium steel at the interface between the stainless steel filler metal and the low chromium base metal. This carbon depleted zone will be weaker than any other part of the weldment. The severity of strength loss depends upon the time and temperature used for PWHT, with longer times and higher temperatures generally making a thicker and more severely weakened zone. The engineer should take this into account.

PWHT tempers martensite in the thin transition zone from the stainless steel to the ferritic steel, improving its toughness. However, PWHT also causes some carbide precipitation in the austenite beside this transition zone, which raises the martensite start temperature of that austenite. Subsequent cooling from the PWHT temperature will likely induce new martensite to form where this austenite was. As a result, PWHT of such joints does not eliminate hard martensitic zones. The engineer should take this into account.

The ferrite that forms in the weld metal, when a 309L or other high ferrite filler metal is used for the joint, tends to transform to sigma phase during PWHT of the weldment. Again, longer times and higher temperatures tend to foster this undesirable transformation. The engineer should take this possibility into consideration in designing a weldment of this type.

The effect of PWHT on residual stress caused by differences in coefficients of thermal expansion, and on carbon diffusion cane be mitigated by buttering prior to PWHT and by the use of nickel based filler metal.

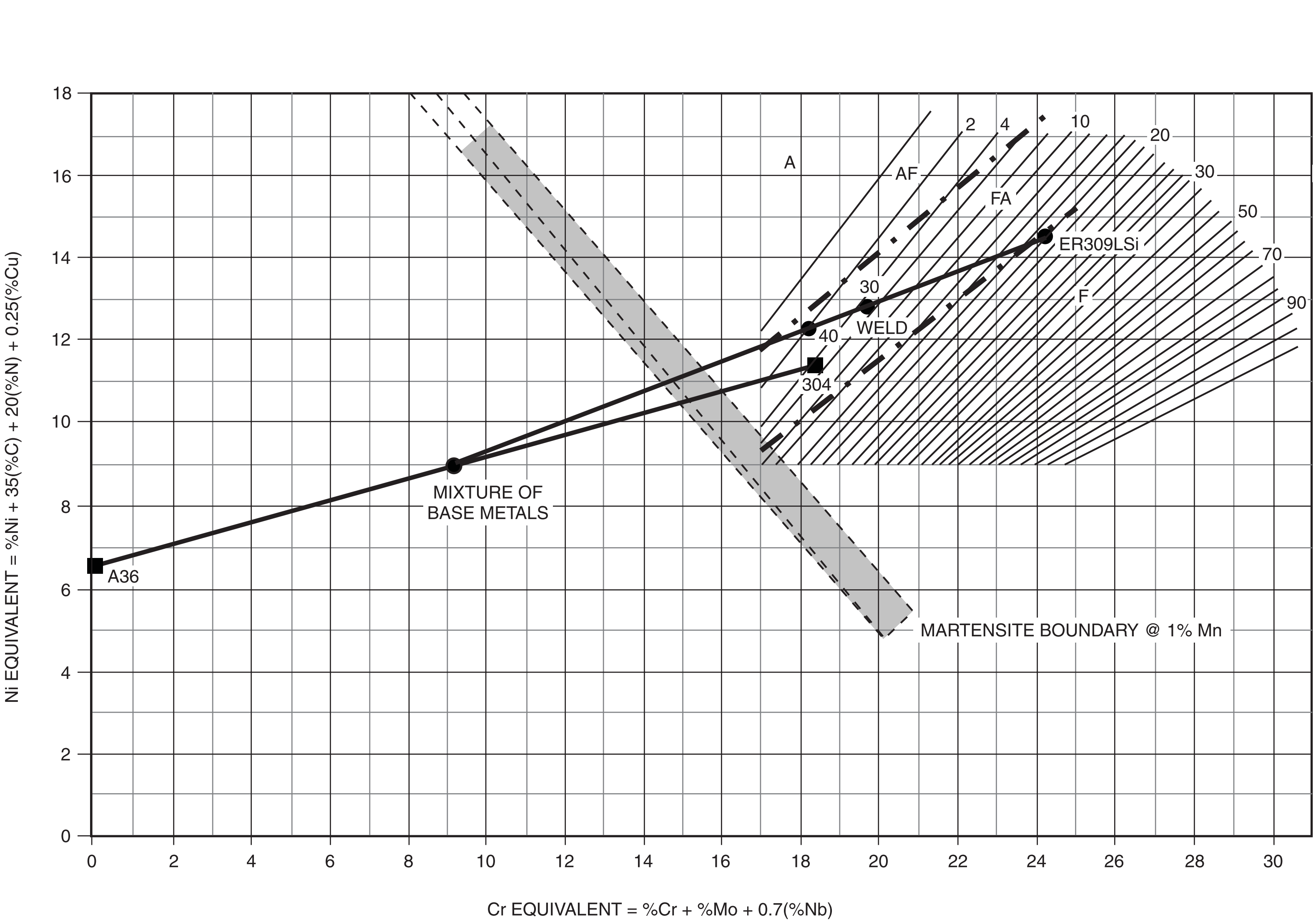

Figure I.1—WRC-1992 Diagram Showing Root Pass Welding of 304 Stainless to A 36 Steel using ER309LSi Filler Metal

Annex J (Informative)

Safe Practices

This annex is not part of AWS D1.6/D1.6M:2007, *Structural Welding Code—Stainless Steel*, but is included for informational purposes only.

This annex covers many of the basic elements of safety general to arc welding processes. It includes many, but not all, of the safety aspects related to structural welding. The hazards that may be encountered and the practices that will minimize personal injury and property damage are reviewed here.

J1. Electrical Hazards

Electric shock can kill. However, it can be avoided. Live electrical parts should not be touched. Read and understand the manufacturer's instructions and recommended safe practices. Faulty installation, improper grounding, and incorrect operation and maintenance of electrical equipment are all sources of danger.

All electrical equipment and the workpiece should be grounded. A separate connection is required to ground the workpiece. The work lead should not be mistaken for a ground connection.

To prevent shock, the work area, equipment, and clothing should be kept dry at all times. Dry gloves and rubber soled shoes should be worn. The welder should stand on a dry board or insulated platform.

Cables and connectors should be kept in good condition. Worn, damaged, or bare cables should not be used. In case of electric shock, the power should be turned off immediately. If the rescuer must resort to pulling the victim from the live contact, nonconducting materials should be used. A physician should be called and CPR continued until breathing has been restored, or until a physician has arrived (see References 7, 8, and 10).

J2. Fumes and Gases

Many welding, cutting, and allied processes produce fumes and gases which may be harmful to one's health. Fumes and solid particles originate from welding consumables, the base metal, and any coatings present on the base metal. Gases are produced during the welding process or may be produced by the effects of process radiation on the surrounding environment. Everyone associated with the welding operation should acquaint themselves with the effects of these fumes and gases.

The possible effects of over-exposure to fumes and gases range from irritation of eyes, skin, and respiratory system to more severe complications. Effects may occur immediately or at some later time. Fumes can cause symptoms such as nausea, headaches, dizziness, and metal fume fever.

Sufficient ventilation, exhaust at the arc, or both, should be used to keep fumes and gases from breathing zones and the general work area.

For more detailed information on fumes and gases produced by the various welding processes, see References 1, 4, and 11.

J3. Noise

Excessive noise is a known health hazard. Exposure to excessive noise can cause a loss of hearing. This loss of hearing can be either full or partial, and temporary or permanent. Excessive noise adversely affects hearing capability. In addition, there is evidence that excessive noise affects other bodily functions and behavior.

Personal protective devices such as ear muffs or ear plugs may be employed. Generally, these devices are only accepted when engineering controls are not fully effective (see References 1, 5, and 11).

J4. Burn Protection

Molten metal, sparks, slag, and hot work surfaces are produced by welding, cutting, and allied processes. These can cause burns if precautionary measures are not used.

Workers should wear protective clothing made of fire-resistant material. Pant cuffs or clothing with open pockets or other places on clothing that can catch and retain molten metal or sparks should not be worn. High-top shoes or leather leggings and fire-resistant gloves should be worn. Pant legs should be worn over the outside of high-top boots. Helmets or hand shields that provide protection for the face, neck, and ears, should be worn, as well as a head covering to protect the head.

Clothing should be kept free of grease and oil. Combustible materials should not be carried in pockets. If any combustible substance is spilled on clothing, it should be replaced with clean fire resistant clothing before working with open arcs or flame.

Appropriate eye protection should be used at all times. Goggles or equivalent also should be worn to give added eye protection.

Insulated gloves should be worn at all times when in contact with hot items or handling electrical equipment.

For more detailed information on personal protection References 2, 3, 8, and 11 should be consulted.

J5. Fire Prevention

Molten metal, sparks, slag, and hot work surfaces are produced by welding, cutting, and allied processes. These can cause fire or explosion if precautionary measures are not used.

Explosions have occurred where welding or cutting has been performed in spaces containing flammable gases, vapors, liquid, or dust. All combustible material should be removed from the work area. Where possible, move the work to a location well away from combustible materials. If neither action is possible, combustibles should be protected with a cover of fire resistant material. All combustible materials should be removed or safely protected within a radius of 35 ft [11 m] around the work area.

Welding or cutting should not be done in atmospheres containing dangerously reactive or flammable gases, vapors, liquid, or dust. Heat should not be applied to a container that has held an unknown substance or a combustible material whose contents when heated can produce flammable or explosive vapors. Adequate ventilation should be provided in work areas to prevent accumulation of flammable gases, vapors or dusts. Containers should be cleaned and purged before applying heat.

For more detailed information on fire hazards from welding and cutting operations, see References 6, 8, 9, and 11.

J6. Radiation

Welding, cutting, and allied operations may produce radiant energy (radiation) harmful to health. Everyone should acquaint themselves with the effects of this radiant energy.

Radiant energy may be ionizing (such as X-rays) or nonionizing (such as ultraviolet, visible light, or infrared). Radiation can produce a variety of effects such as skin burns and eye damage, if excessive exposure occurs.

Some processes such as resistance welding and cold pressure welding ordinarily produce negligible quantities of radiant energy. However, most arc welding and cutting processes (except submerged arc when used properly), laser welding and torch welding, cutting, brazing, or soldering can produce quantities of nonionizing radiation such that precautionary measures are necessary.

Protection from possible harmful radiation effects include the following:

(1) Welding arcs should not be viewed except through welding filter plates, (see Reference 2). Transparent welding curtains are not intended as welding filter plates, but rather, are intended to protect passersby from incidental exposure.

(2) Exposed skin should be protected with adequate gloves and clothing as specified (see Reference 8).

(3) The casual passerby to welding operations should be protected by the use of screens, curtains, or adequate distance from aisles, walkways, etc.

(4) Safety glasses with ultraviolet protective side shields have been shown to provide some beneficial protection from ultraviolet radiation produced by welding arcs.

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Annex K (Informative)

Guidelines for the Preparation of Technical Inquiries

This annex is not part of AWS D1.6/D1.6M:2007, *Structural Welding Code—Stainless Steel*, but is included for informational purposes only.

K1. Introduction

The American Welding Society (AWS) Board of Directors has adopted a policy whereby all official interpretations of AWS standards are handled in a formal manner. Under this policy, all interpretations are made by the committee that is responsible for the standard. Official communication concerning an interpretation is directed through the AWS staff member who works with that committee. The policy requires that all requests for an interpretation be submitted in writing. Such requests will be handled as expeditiously as possible, but due to the complexity of the work and the procedures that must be followed, some interpretations may require considerable time.

K2. Procedure

All inquiries shall be directed to:

Managing Director
Technical Services Division
American Welding Society
550 N.W. LeJeune Road
Miami, FL 33126

All inquiries shall contain the name, address, and affiliation of the inquirer, and they shall provide enough information for the committee to understand the point of concern in the inquiry. When the point is not clearly defined, the inquiry will be returned for clarification. For efficient handling, all inquiries should be typewritten and in the format specified below.

K2.1 Scope. Each inquiry shall address one single provision of the standard unless the point of the inquiry involves two or more interrelated provisions. The provision(s) shall be identified in the scope of the inquiry along with the edition of the standard that contains the provision(s) the inquirer is addressing.

K2.2 Purpose of the Inquiry. The purpose of the inquiry shall be stated in this portion of the inquiry. The purpose can be to obtain an interpretation of a standard's requirement or to request the revision of a particular provision in the standard.

K2.3 Content of the Inquiry. The inquiry should be concise, yet complete, to enable the committee to understand the point of the inquiry. Sketches should be used whenever appropriate, and all paragraphs, figures, and tables (or annex) that bear on the inquiry shall be cited. If the point of the inquiry is to obtain a revision of the standard, the inquiry shall provide technical justification for that revision.

K2.4 Proposed Reply. The inquirer should, as a proposed reply, state an interpretation of the provision that is the point of the inquiry or provide the wording for a proposed revision, if this is what the inquirer seeks.

K3. Interpretation of Provisions of the Standard

Interpretations of provisions of the standard are made by the relevant AWS technical committee. The secretary of the committee refers all inquiries to the chair of the particular subcommittee that has jurisdiction over the portion of the standard addressed by the inquiry. The subcommittee reviews the inquiry and the proposed reply to determine what the response to the inquiry should be. Following the subcommittee's development of the response, the inquiry and the response are presented to the entire committee for review and approval. Upon approval by the committee, the interpretation is an official interpretation of the Society, and the secretary transmits the response to the inquirer and to the *Welding Journal* for publication.

K4. Publication of Interpretations

All official interpretations will appear in the *Welding Journal* and will be posted on the AWS web site.

K5. Telephone Inquiries

Telephone inquiries to AWS Headquarters concerning AWS standards should be limited to questions of a general nature or to matters directly related to the use of the standard. The *AWS Board Policy Manual* requires that all AWS staff members respond to a telephone request for an official interpretation of any AWS standard with the information that such an interpretation can be obtained only through a written request. Headquarters staff cannot provide consulting services. However, the staff can refer a caller to any of those consultants whose names are on file at AWS Headquarters.

K6. AWS Technical Committees

The activities of AWS technical committees regarding interpretations are limited strictly to the interpretation of provisions of standards prepared by the committees or to consideration of revisions to existing provisions on the basis of new data or technology. Neither AWS staff nor the committees are in a position to offer interpretive or consulting services on (1) specific engineering problems, (2) requirements of standards applied to fabrications outside the scope of the document, or (3) points not specifically covered by the standard. In such cases, the inquirer should seek assistance from a competent engineer experienced in the particular field of interest.

Annex L (Informative)

Terms and Definitions

This annex is not part of AWS D1.6/D1.6M:2007, *Structural Welding Code—Stainless Steel*, but is included for informational purposes only.

The terms and definitions in this glossary are defined by the AWS Structural Welding Committee as they relate to this code. Terms and definitions which apply only to ultrasonic testing or radiographic testing are designated by (UT) or (RT) following the term. Other definitions can be found in the latest edition of AWS A3.0, *Standard Welding Terms and Definitions*.

A

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

attenuation (UT). The loss in acoustic energy which occurs between any two points of travel. This loss may be due to absorption, reflection, etc. In this code, using the shear wave pulse-echo method of testing, the loss is determined by calibration to Figure 6.15 with the material to be tested. Alternatively, an adjustable decrease in signal strength created within the UT instrument.

D

decibel (dB) (UT). The logarithmic expression of a ratio of two amplitudes or intensities of acoustic energy. $dB = 10 \log_{10}(P_1/P_2)$, where P_1 and P_2 are two considered levels of energy.

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

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

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

***dihedral angle.** See **local dihedral angle**.

E

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

F

fatigue. Fatigue is a process by which a crack grows in a component subjected to fluctuating load, resulting in failure or damage of the component. The crack may initiate under fluctuating load or be pre-existing.

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

G

geometric unsharpness. The fuzziness or lack of definition in a radiographic image resulting from the source size, object-to-film distance, and source-to-object distance. Geometric unsharpness may be expressed mathematically as:

$U_g = F\,(L_i - L_o)L_o$

Where U_g is the geometric unsharpness, F is the size of the focal spot or gamma radiation, L_i is the source-to-film distance, and L_o is the source-to-object distance.

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

I

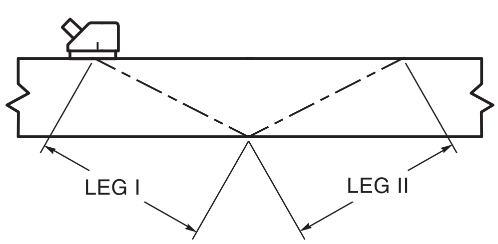
***image quality indicator (IQI).** A device whose image in a radiograph is used to determine radiographic quality level. It is not intended for use in judging the size nor for establishing acceptance limits of discontinuities.

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

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

L

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



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

N

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

P

pipe. Tubular-shaped product of circular cross section. See **tubular**.

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

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

postweld heat treatment. Any heat treatment after welding.

preheat. The application of heat to the base metal immediately before welding.

R

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

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

rejectable discontinuity. See **defect**.

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

S

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

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

T

tubular. Tubular products is a generic term for a family of hollow section products of various cross-sectional configuration. The term ***pipe*** denotes cylindrical products to differentiate from square and rectangular hollow section products. However, a tube or tubing can also be cylindrical. User should note the AISC designation of tubular sections:

TSD × t	for circular tubes (pipe)
TSa × b × t	for square and rectangular tubes (referred to collectively as box sections in this code)

where:

TS = the group symbol
t = nominal wall thickness
D = nominal outside diameter
a = nominal major width
b = nominal minor width

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

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

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Annex M (Informative)

Sample Welding Forms

This annex is not part of AWS D1.6/D1.6M:2007, *Structural Welding Code—Stainless Steel*, but is included for informational purposes only.

This annex contains three forms that the Structural Welding Committee has approved for the recording of WPS qualification, welder qualification, welding operator qualification, and tack welder qualification data required by this code.

It is suggested that the qualification information required by this code be recorded on these forms or similar forms which have been prepared by the user. Variations of these forms to suit the user's needs are permissible.

M1. Commentary on the Use of WPS Forms M-1 (Front) and M-1 (Back)

The Form M-1 may be used to record information for either a WPS or a PQR. The user should indicate their selected application in the appropriate boxes or the user may choose to blank out the inappropriate headings.

The WPSs and PQRs are to be signed by the authorized representative of the Manufacturer or Contractor.

For joint details on the WPS, a sketch or a reference to the applicable prequalified joint detail may be used (e.g., B-U4a).

M2. Prequalified

The WPS may be prequalified in accordance with all of the provisions of Clause 3 in which case only the one-page document, Form M-1 is required.

M3. Qualified by Testing

The WPS may be qualified by testing in accordance with the provisions of Clause 4. In this case, a supporting PQR is required in addition to the WPS. For the PQR, Form M-1 can again be used with an appropriate heading change. Also, the Form M-2 may be used to record the test results and the certifying statement.

For the WPS, state the permitted ranges qualified by testing or state the appropriate tolerances on essential variable (e.g., 250 amps ± 10%).

For the PQR, the actual joint details and the values of essential variables used in the testing should be recorded. A copy of the Mill Test Report for the material tested should be attached. Also, Testing Laboratory Data Reports may also be included as backup information.

The inclusion of items not required by the code is optional; however, they may be of use in setting up equipment, or understanding test results.

WELDING PROCEDURE SPECIFICATION (WPS) Yes ☐
PREQUALIFIED ___________ QUALIFIED BY TESTING ___________
or PROCEDURE QUALIFICATION RECORDS (PQR) Yes ☐

Identification # ______________________
Revision _______ Date __________ By ___________
Authorized by ________________ Date __________
Type—Manual ☐ Semi-Automatic ☐
Machine ☐ Automatic ☐

Company Name ______________________
Welding Process(es) ______________________
Supporting PQR No.(s) ______________________

JOINT DESIGN USED
Type:
Single ☐ Double Weld ☐
Backing: Yes ☐ No ☐
Backing Material:
Root Opening ______ Root Face Dimension ________
Groove Angle: ___________ Radius (J–U) _________
Back Gouging: Yes ☐ No ☐ Method _______

BASE METALS
Material Spec. ______________________
Type or Grade ______________________
Thickness: Groove ___________ Fillet __________
Diameter (Pipe) ______________________

FILLER METALS
AWS Specification ______________________
AWS Classification ______________________

SHIELDING
Flux ________________ Gas ____________
Composition __________
Electrode-Flux (Class) _____ Flow Rate ___________
________________ Gas Cup Size _________

PREHEAT
Preheat Temp., Min. ______________________
Interpass Temp., Min. ___________ Max. _________

POSITION
Position of Groove: _____________ Fillet: __________
Vertical Progression: Up ☐ Down ☐

ELECTRICAL CHARACTERISTICS
Transfer Mode (GMAW) Short-Circuiting ☐
Globular ☐ Spray ☐
Current: AC ☐ DCEP ☐ DCEN ☐ Pulsed ☐
Other ______________________
Tungsten Electrode (GTAW)
Size: _____________
Type: _____________

TECHNIQUE
Stringer or Weave Bead: ________________
Multi-pass or Single Pass (per side) ______________
Number of Electrodes ________________
Electrode Spacing Longitudinal ___________
Lateral ______________
Angle ______________

Contact Tube to Work Distance ________________
Peening ______________________
Interpass Cleaning: ______________________

POSTWELD HEAT TREATMENT
Temp. ______________________
Time ______________________

WELDING PROCEDURE

Pass or Weld Layer(s)	Process	Filler Metals		Current		Volts	Travel Speed	Joint Details
		Class	Diam.	Type & Polarity	Amps or Wire Feed Speed			

Form M-1

Procedure Qualification Record (PQR) # __________
Test Results

TENSILE TEST

Specimen No.	Width	Thickness	Area	Ultimate tensile load, lbs [N]	Ultimate unit stress, psi [MPa]	Character of failure and location

GUIDED BEND TEST

Specimen No.	Type of bend	Result	Remarks

VISUAL INSPECTION
Appearance____________________________________
Undercut ______________________________________
Piping porosity __________________________________
Convexity______________________________________
Test date ______________________________________
Witnessed by___________________________________

Radiographic-ultrasonic examination
RT report no.: ___________ Result_______________
UT report no.: ___________ Result_______________

FILLET WELD TEST RESULTS

Minimum size multiple pass
Macroetch
1. _______ 3. ________
2. _______

Maximum size single pass
Macroetch
1._________ 3._________
2._________

Other Tests

All-weld-metal tension test

Tensile strength, psi [MPa] _____________________
Yield point/strength, psi [MPa] __________________
Elongation in 2 in., % __________________________
Laboratory test no. _____________________

Welder's name ______________________________ Clock no. _____________ Stamp no.____________

Tests conducted by ____ Laboratory

Test number _______________________________

Per ______________________________________

We, the undersigned, certify that the statements in this record are correct and that the test welds were prepared, welded, and tested in accordance with the requirements of Clause 4 of AWS D1.6, (__________) *Structural Welding Code—Stainless Steel*.
(year)

Signed ___________________________________
Manufacturer or Contractor

By_______________________________________

Title _____________________________________

Date _____________________________________

Form M-2

WELDER OR WELDING OPERATOR QUALIFICATION TEST RECORD

Type of Welder ____
Name ____ Identification No.____________________
Welding Procedure Specification No. _________________ Rev ___________________ Date ___________________

Variables	Record Actual Values Used in Qualification	Qualification Range
Process/Type (4.8.1)		
Electrode (single or multiple)		
Current/Polarity		
Position (4.8.4 or 4.9.4)		
Weld Progression (4.8.6)		
Backing (YES or NO) (4.8.7)		
Material/Spec.	to	
Base Metal		
Thickness: (Plate)		
Groove		
Fillet		
Thickness: (Pipe/tube)		
Groove		
Fillet		
Diameter: (Pipe)		
Groove		
Fillet		
Filler Metal (4.8.2)		
Spec. No.		
Class		
F-No.		
Gas/Flux Type (4.8.3)		
Other		

VISUAL INSPECTION (4.10.1.1)
Acceptable YES or NO _____

Guided Bend Test Results (4.10.2.3)

Type	Result	Type	Result

Fillet Test Results (4.10.5)

Appearance ______________________________ Fillet Size ______________________________
Fracture Test Root Penetration ___________________ Macroetch ______________________________
(Describe the location, nature, and size of any crack or tearing of the specimen.)

Inspected by ______________________________ Test Number ______________________________
Organization ______________________________ Date ______________________________

RADIOGRAPHIC TEST RESULTS (4.10.3)

Film Identification Number	Results	Remarks	Film Identification Number	Results	Remarks

Interpreted by ______________________________ Test Number ______________________________
Organization ______________________________ Date ______________________________

We, the undersigned, certify that the statements in this record are correct and that the test welds were prepared, welded, and tested in accordance with the requirements of Clause 4 of AWS D1.6, (__________) *Structural Welding Code—Stainless Steel*.
(year)

Manufacturer or Contractor ______________________ Authorized By ______________________________
Form M-3 Date ______________________________

Annex N (Informative)

Etchant Solutions

This annex is not part of AWS D1.6/D1.6M:2007, *Structural Welding Code—Stainless Steel*, but is included for informational purposes only.

N1. Scope

The etchant solutions described in Annex N are recommended for macroetching stainless steel.

Makeup of Formulas for Aqua Regia and Lepito's Etch

	Aqua Regia[1,3]	Lepito's Etch[2,3]
Nitric Acid Concentrated—HNO_3	1 part	3 ml
Hydrochloric Acid Concentrated—HCl	2 parts	10 ml
Ammonium Sulfate—(NH_4) (SO_4)	…	1.5 g
Ferric Chloride—$FeC1_3$	…	2.5 g
Water	…	7.5 ml

Notes:

(1) Warm the parts for faster action.

(2) Mix solution as follows:

(a) Dissolve $(NH_4)_2$ (SO_4)

(b) Dissolve powdered $FeCl_3$ in warm HCl.

(c) Mix (a) and (b) above and add HNO_3.

(3) Etching is accomplished by either swabbing or immersing the specimen.

N2. Recommended Etchants for Stainless Steel

These materials may also be macroetched with the etchants for stainless steel.

N2.1 Material	**Formula**
Nickel	Nitric Acid or Lepito's Etch
Low Carbon Nickel	Nitric Acid or Lepito's Etch
Nickel-Copper (400)	Nitric Acid or Lepito's Etch
Nickel-Chromium-Iron (600 and 800)	Aqua Regia or Lepito's Etch

N3. Safety Procedures

N3.1 General. All chemicals used as etchants are potentially dangerous. All persons using any of the etchants listed in N2 should be thoroughly familiar with all of the chemicals involved and the proper procedure for handling and mixing these chemicals.

N3.2 Handling and Mixing Acids. Caution must be used in mixing all chemicals, especially strong acids. In all cases, various chemicals should be added slowly INTO the water or solvent while stirring.

N3.3 Basic Recommendations for Handling of Etching Chemicals

N3.3.1 Always use protective garb (gloves, apron, protective glasses or face shield, etc.) when pouring, mixing, or etching.

N3.3.2 Use proper devices (glass or plastic) for weighing, mixing, containing, or storage of solutions.

N3.3.3 Wipe up or flush all spills.

N3.3.4 Dispose of any solutions not properly identified. Do NOT use unidentified solutions; when in doubt, dispose of the unidentified solutions in an environmentally acceptable manner.

N3.3.5 Store and handle chemicals according to manufacturer's recommendations and observe any printed cautions on chemical containers.

N3.3.6 If not sure about the proper use of a chemical, contact your Safety Department.

Annex O (Informative)

Ultrasonic Unit Certification

This annex is not part of AWS D1.6/D1.6M:2007, *Structural Welding Code—Stainless Steel*, but is included for informational purposes only.

Ultrasonic unit
Model ____________ Serial no. ____________
Search unit
Size ____________ Type ____________
Frequency ________ MHz

Date ______________________________
By ______________________________
ASNT Level ______________________________

TABULATION CHART					
No.	a dB Reading	b % Scale	c Corrected Reading	d dB Error	e Collective dB Error
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					
11					
12					
13					
14					
15					
16					
17					
18					
19					
20					
21					
22					
23					
24					
25					
26					

Find the average % screen values from column b disregarding the first three and last three tabulations. Use this percentage as $\%_2$ in calculating the Corrected Reading c.

The dB Error d is established by subtracting the Corrected Reading from the dB Reading a. Beginning with the tabulated dB Error d nearest to 0.0, collectively add the dB Error d values up and down placing the subtotals in column e (Collective dB Errors).

Moving vertically up and down from the Average % line, find the largest vertical span in which the top and bottom Collective dB Error figures remain at or below 2 dB. Count the number of vertical spaces of movement, subtract one, and multiply the remainder by six. This dB value is the acceptable range of the unit.

In order to establish the acceptable range graphically, Form 2 should be used in conjunction with Form 1 as follows:

(1) Apply the collective dB Error "e" values vertically on the horizontal offset coinciding with the dB reading values "a."

(2) Establish a curve line passing through this series of points.

(3) Apply a 2 dB high horizontal window over this curve positioned vertically so that the longest section is completely encompassed within the 2 dB Error height.

(4) This window length represents the acceptable dB range of the unit.

$DB_2 = 20 \times \log(\%2 + 1) + dB_1$

$\%_2$ (Average) ________ %

Total qualified range ________ dB to ________ dB = ________ dB Total error ________ dB

FORM O-1 Total qualified range ________ dB to ________ dB = ________ dB Total error ________ dB

Form O-1—Ultrasonic Unit Certification [see 6.15.11(6)]

Ultrasonic unit
Model UT77 Serial no. 00006

Search unit
Size 1" diam. Type BT
Frequency 2.25 MHz

Date 10-23-90
By I. C. BLIPS
ASNT Level II

TABULATION CHART

No.	a dB Reading	b % Scale	c Corrected Reading	d dB Error	e Collective dB Error
1	6	69	7.1	−1.1	−2.3
2	12	75	12.4	−0.4	−1.2
3	18	75	18.3	−0.3	−0.8
4	24	77	24.1	−0.1	−0.5
5	30	77	30.1	−0.1	−0.4
6	36	77	36.1	−0.1	−0.3
7	42	77	42.1	−0.1	−0.2
8	48	78	48.0	−0.0	−0.1
9	54	77	54.1	−0.1	−0.1
Average 78% — 10	60	78	60.0	0.0	0.0
11	66	79	65.9	+0.1	+0.1
12	72	80	71.8	+0.2	+0.3
13	78	81	77.7	+0.3	+0.6
14	84	86	83.1	+0.9	+1.5
15					
16					
17					
18					
19					
20					
21					
22					
23					
24					
25					
26					

Find the average % screen values from column b disregarding the first three and last three tabulations. Use this percentage as $\%_2$ in calculating the Corrected Reading c.

The dB Error d is established by subtracting the Corrected Reading from the dB Reading a. Beginning with the tabulated dB Error d nearest to 0.0, collectively add the dB Error d values up and down placing the subtotals in column e (Collective dB Errors).

Moving vertically up and down from the Average % line, find the largest vertical span in which the top and bottom Collective dB Error figures remain at or below 2 dB. Count the number of vertical spaces of movement, subtract one, and multiply the remainder by six. This dB value is the acceptable range of the unit.

In order to establish the acceptable range graphically, Form 2 should be used in conjunction with Form 1 as follows:

(1) Apply the collective dB Error "e" values vertically on the horizontal offset coinciding with the dB reading values "a."

(2) Establish a curve line passing through this series of points.

(3) Apply a 2 dB high horizontal window over this curve positioned vertically so that the longest section is completely encompassed within the 2 dB Error height.

(4) This window length represents the acceptable dB range of the unit.

$DB_2 = 20 \times \log(\%2 + 1) + dB_1$

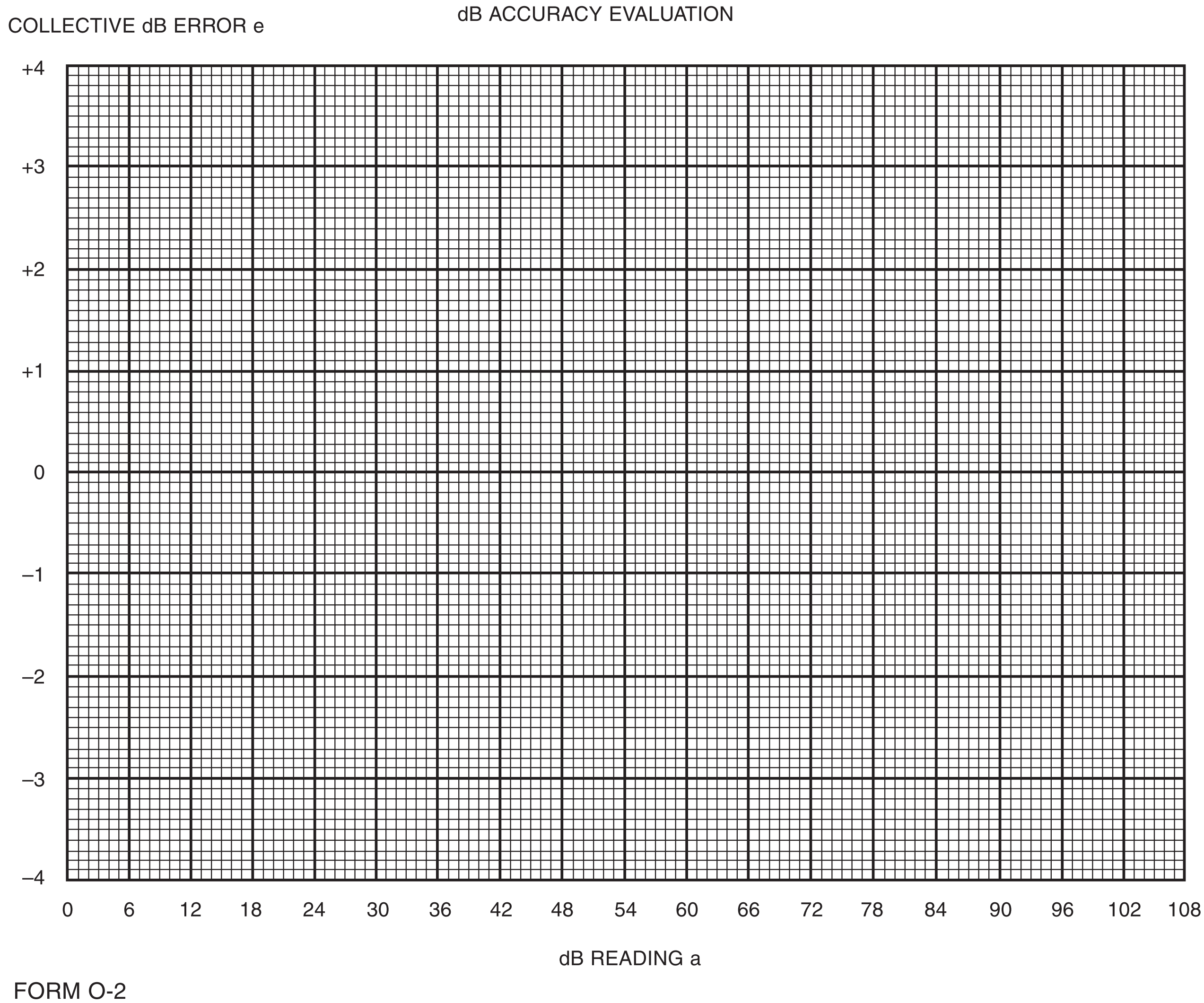
$\%_2$ (Average) 78 %

Total qualified range 12 dB to 78 dB = 66 dB Total error 1.8 dB

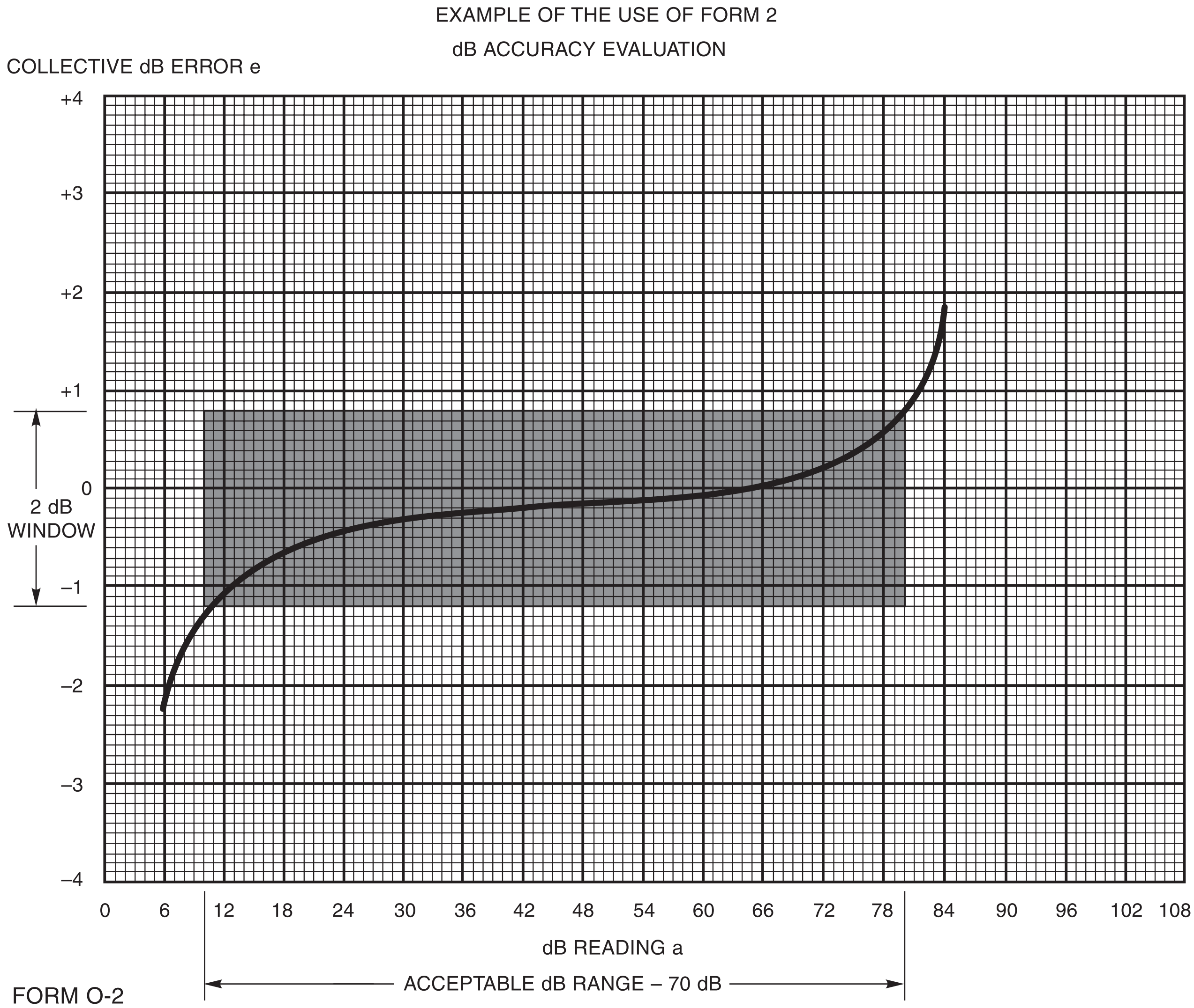
Total qualified range 11 dB to 80 dB = 69 dB Total error 2.0 dB

FORM O-1

Example of the Use of Form O-1—Ultrasonic Unit Certification [see 6.15.11(13)]



Form O-2—dB Accuracy Evaluation [see 6.15.11(15)]



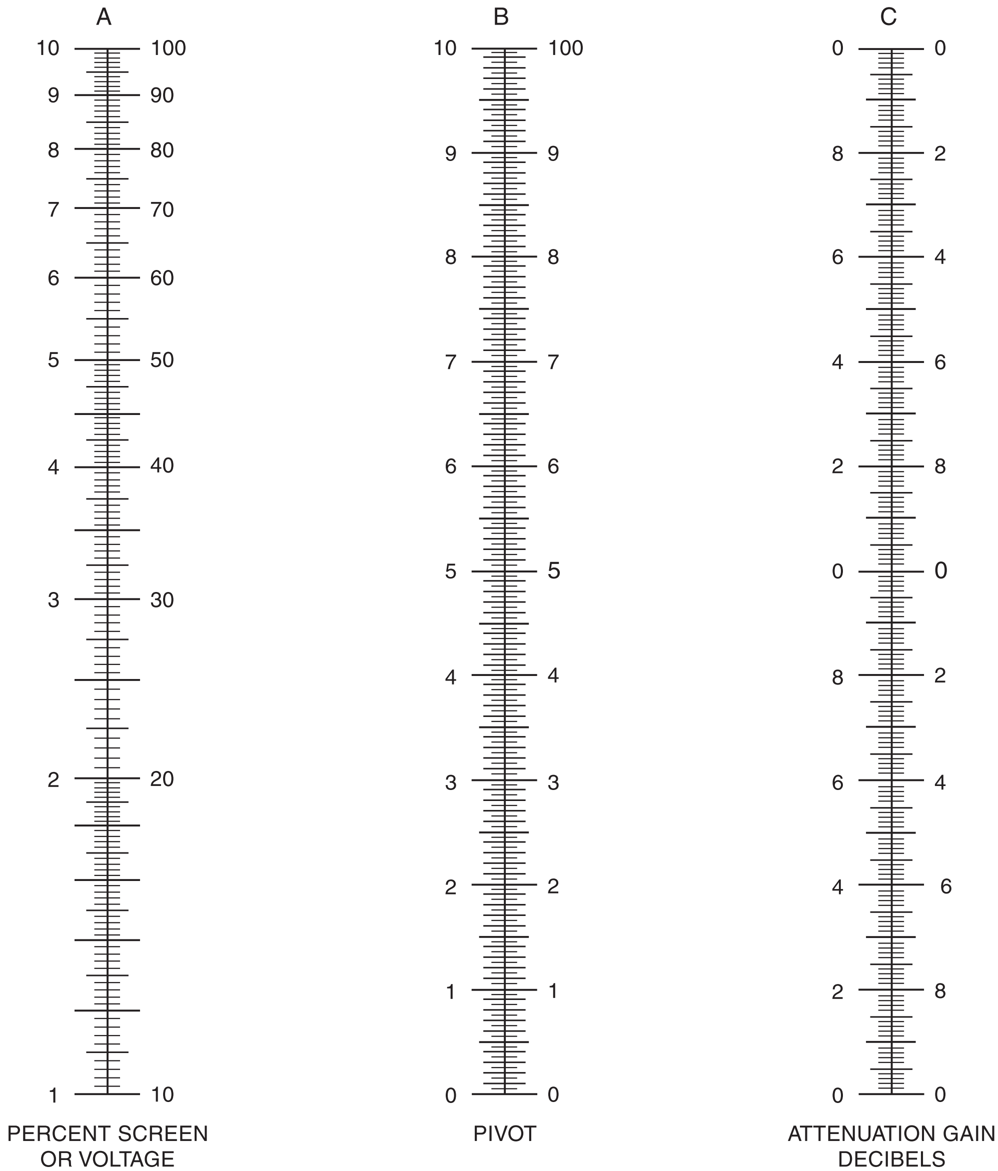
FORM O-2

THE CURVE ON FORM O-2 EXAMPLE IS DERIVED FROM CALCULATIONS FROM FORM 1.
THE CROSS HATCHED ON FIGURE O-2 SHOWS THE AREA OVER WHICH THE EXAMPLE UNIT QUALIFIES TO THIS CODE.

Note: The first line of example of the use of Form O-1 is shown in this example.

Example of the Use of Form O-2—dB Accuracy Evaluation [see 6.15.11(15)]

DECIBEL (ATTENTUATION OR GAIN) VALUES NOMOGRAPH



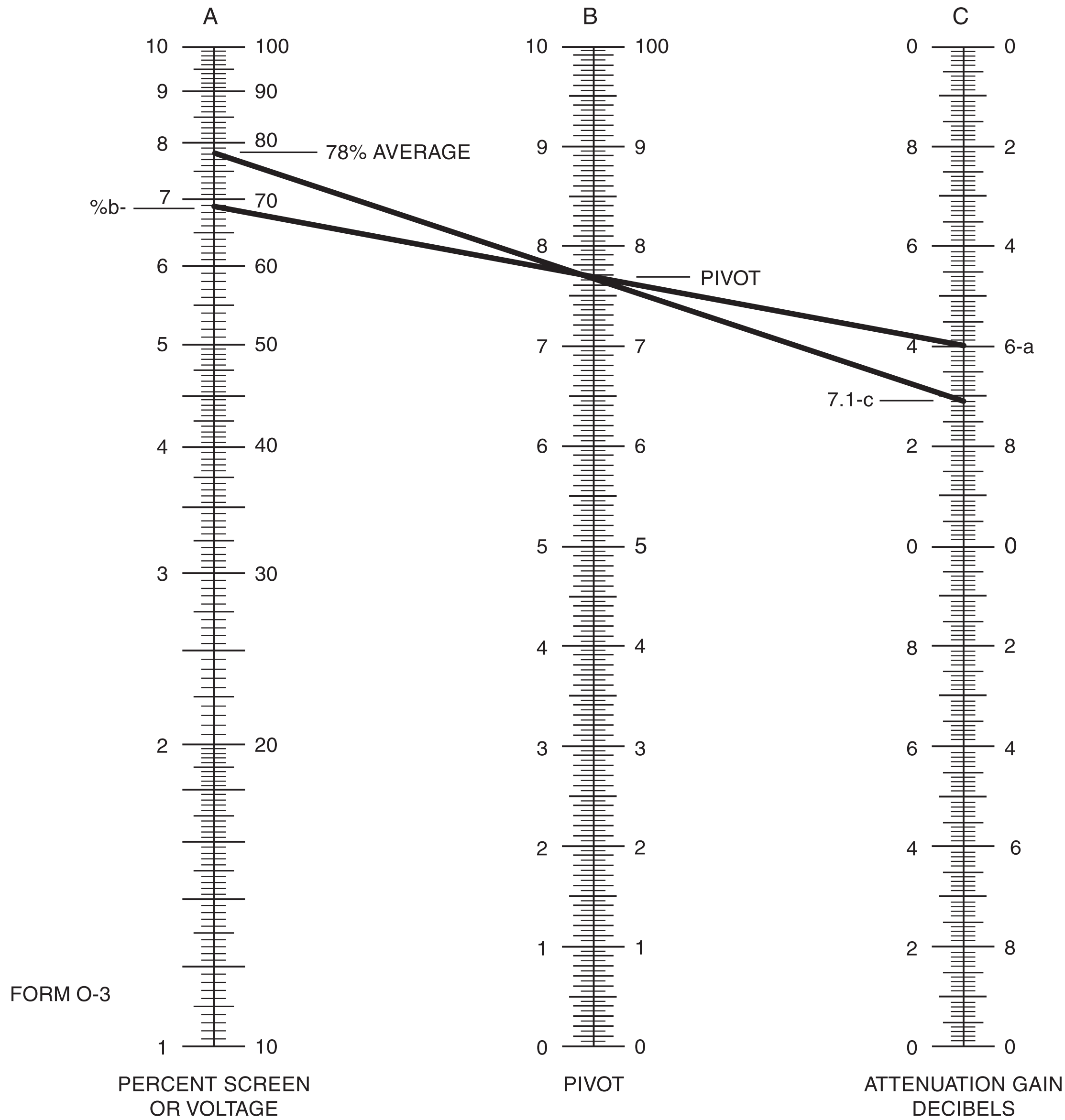
FORM O-3

Form O-3—Decibel (Attenuation or Gain) Values Nomograph [see 6.15.11(16)]

NOTES:
1. THE 6 dB READING AND 69% SCALE ARE DERIVED FROM THE INSTRUMENT READING AND BECOME dB "b_1" AND $\%_1$ "c" RESPECTIVELY.
2. $\%_2$ IS 78 – CONSTANT.
3. dB_2 (WHICH IS CORRECTED dB "d") IS EQUAL TO 20 TIMES X LOG (78/69) + 6 OR 7.1.

THE USE OF THE NOMOGRAPH IN RESOLVING LINE 3 IS AS SHOWN ON THE FOLLOWING EXAMPLE.

DECIBEL (ATTENTUATION OR GAIN) VALUES NOMOGRAPH



THE CURVE ON FORM O-3 EXAMPLE IS DERIVED FROM CALCULATIONS FROM FORM O-2 EXAMPLE. THE CROSS HATCHED AREA ON FORM O-3 EXAMPLE SHOWS THE AREA OVER WHICH THE EXAMPLE UNIT QUALIFIES TO THIS CODE.

Notes: Procedure for using the Nomograph:
1. Extend a straight line between the decibel reading from Column a applied to the C scale and the corresponding percentage from Column b applied to the A scale.
2. Use the point where the straight line from step 1 crosses the pivot line B as a pivot line for a second straight line.
3. Extend a second straight line from the average sign point on scale A, through the pivot point developed in step 2, and onto the dB scale C.
4. This point on the C scale is indicative of the corrected dB for use in Column C.

Example of the Use of Form O-3—Decibel (Attenuation or Gain) Values Nomograph [see 6.15.11(16)]

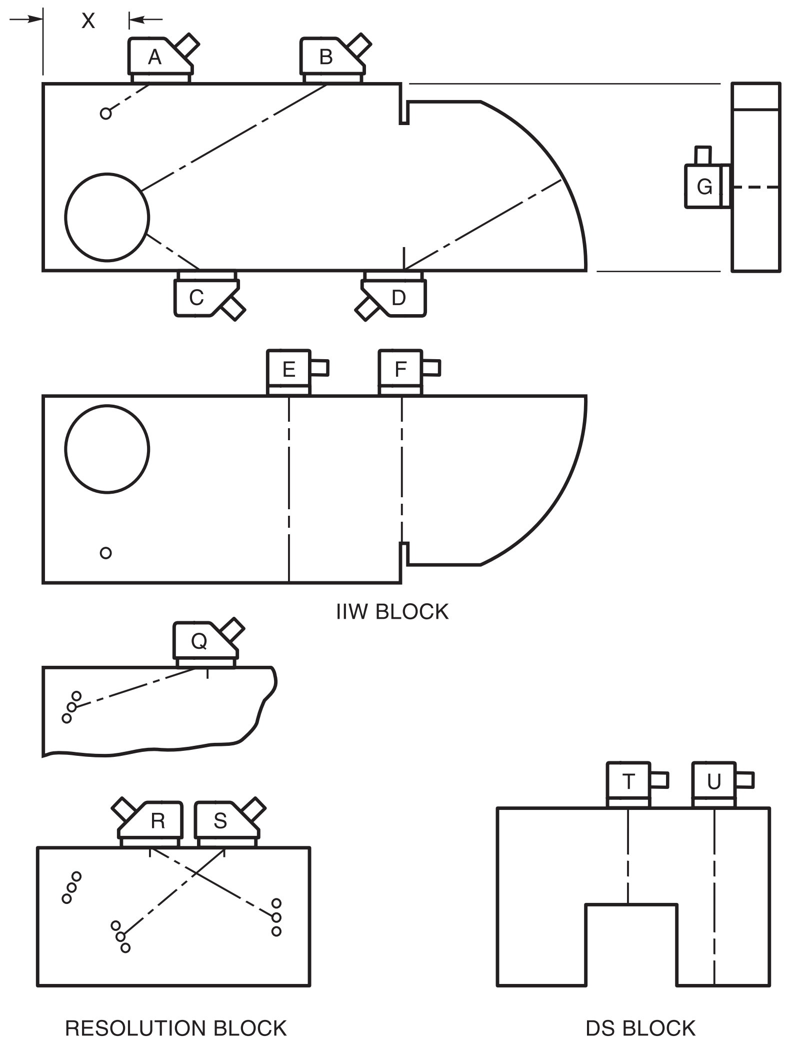


Figure O.1—Transducer Positions (Typical) [see 6.15.11(1)]

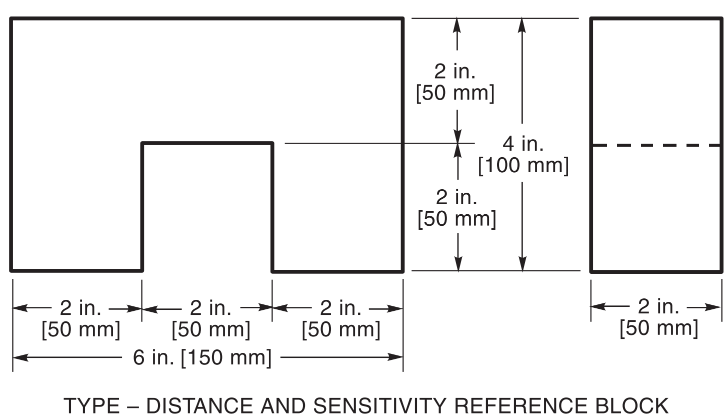


Figure O.2—Qualification Block [see 6.15.11(1)]

Commentary on Structural Welding Code—Stainless Steel

1st Edition

Prepared by the
AWS D1 Committee on Structural Welding

Under the Direction of the
AWS Technical Activities Committee

Approved by the
AWS Board of Directors

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Foreword

This foreword is not a part of the Commentary of AWS D1.6/D1.6M:2007, *Structural Welding Code—Stainless Steel*, but is included for informational purposes only.

This commentary on AWS D1.6/D1.6M:2007 has been prepared to generate better understanding in the application of the code to welding in steel construction. Since the code is written in the form of a specification, it cannot present background material or discuss the Structural Welding Committee's intent; it is the function of this commentary to fill this need. Suggestions for application as well as clarification of code requirements are offered with specific emphasis on new or revised sections that may be less familiar to the user. In this first edition of the D1.6 commentary, the scope is limited to only a few clauses on design. It is anticipated that the commentary will expand as needed in the future to support the code.

The nature of inquiries directed to the American Welding Society and the Structural Welding Committee has indicated that there are some requirements in the code that are either difficult to understand or not sufficiently specific, and others that appear to be overly conservative. It should be recognized that the fundamental premise of the code is to provide general stipulations applicable to any situation and to leave sufficient latitude for the exercise of engineering judgment. Another point to be recognized is that the code represents the collective experience of the committee and while some provisions may seem overly conservative, they have been based on sound engineering practice. The committee, therefore, believes that a commentary is the most suitable means to provide clarification as well as proper interpretation of many of the code requirements.

Obviously, the size of the commentary had to impose some limitations with respect to the extent of coverage. This commentary is not intended to provide a historical background of the development of the code, nor is it intended to provide a detailed resume of the studies and research data reviewed by the committee in formulating the provisions of the code. Generally, the code does not treat such design considerations as loading and the computation of stresses for the purpose of proportioning the load-carrying members of the structure and their connections. Such considerations are assumed to be covered elsewhere, in a general building code, bridge specification, or similar document. As an exception, the code does provide allowable stresses in welds, fatigue provisions for welds in cyclically loaded structures and tubular structures, and strength limitations for tubular connections. These provisions are related to particular properties of welded connections.

The Committee has endeavored to produce a useful document suitable in language, form, and coverage for welding in stainless steel construction. The code provides a means for establishing welding standards for use in design and construction by the Owner or the Owner's designated representative. The code incorporates provisions for regulation of welding that are considered necessary for public safety. The committee recommends that the Owner or Owner's representative be guided by this commentary in application of the code to the welded structure.

The commentary is not intended to supplement code requirements, but only to provide a useful document for interpretation and application of the code; none of its provisions are binding. It is the intention of the Structural Welding Committee to revise the commentary on a regular basis so that commentary on changes to the code can be promptly supplied to the user. In this manner, the commentary will always be current with the edition of the *Structural Welding Code—Stainless Steel* with which it is bound.

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Commentary on Structural Welding Code—Stainless Steel

C-2. Design of Welded Connections

C-2.0 General

The successful application of stainless steels depends on a thorough consideration of their specific properties.

One important aspect is their performance in fires. All stainless steels have superior oxidation resistance to carbon steels. In addition, most stainless steels, except for ferritic stainless steels, retain yield and tensile strength better than carbon steels as temperature is increased.

The coefficient of thermal expansion of austenitic stainless steels is almost 50% greater than that of nonaustenitic steels. This creates supplementary stresses resulting from temperature changes. The distribution of residual stresses in dissimilar joints in the as-welded condition resembles that in similar joints. However, contrarily to the situation relative to similar joints, postweld heat treatment of dissimilar joints may actually introduce residual stresses in the weld zone. In the longitudinal direction, the stress distribution would be as follows: tension in the austenitic steel, compression in the nonaustenitic steel, and shear in the weld. An increase in the temperature of a thermally treated dissimilar joint would actually relieve residual stresses.

C-2.3 Allowable Stresses. Design engineers should be aware of the principles governing the choice of filler metal for a given stainless steel base metal or metals. This choice is based predominantly on the required Ferrite Number as defined in the WRC or similar diagrams. However, filler metals selected in accordance with this criterion may not match the mechanical properties of base metals.

C-2.3.2.7 Allowable Stresses Established by Testing. In some cases, the allowable stress criteria may be overly conservative. Typically, they are based on the properties of annealed base metal and on the properties of weld metal. However, in an actual joint using cold-worked materials, annealing of the base metal is incomplete and localized, and the actual strength of the weld joint may be increased by the presence of high-strength base metal. Appropriate tests may allow for higher allowable stresses.

C-2.3.3 Fatigue Provisions. Existing research data shows that the fatigue strength of joints in stainless steels is similar to that in carbon steels. However, these data do not cover all types of joints and welds, and the number of tests performed is limited. Consequently, this code cannot include fatigue provisions as precise and universal as it is in the case of carbon steels. On the basis of available information, the Engineer may decide to apply fatigue rules for carbon steels. However, certain precautions specific to stainless steels should be taken.

Martensitic steels may develop a high hardness in their heat-affected zones (HAZs). This, in addition to the risk of underbead cracking, may impair the fatigue strength of joints.

Austenitic steels have a thermal conductivity and coefficient of thermal expansion respectively equal to 60% and 150% of those values for carbon steels. This typically leads to residual stresses higher than in welded carbon steels, especially in cases of intense localized heating. The latter may occur in plug or slot welds, in ring welds in small holes, and in cases of high interpass temperatures. As mentioned above, small thicknesses may further contribute to overheating of the base metal and to high residual stresses. As a final result, high residual stresses may decrease the fatigue strength of assemblies.

References for Commentary Clause C-2

1. SEI/ASCE8-02 "Specification for the Design of Cold-Formed Stainless Steel Structural Members"
2. Euro Inox "Design Manual for Structural Stainless Steel," 2nd Edition, 2002

3. Proceedings of the seminar "Stainless Steel in Transport Industry," Helsinki University of Technology, 1998

4. Proceedings of the International Experts Seminar on Stainless Steel in Construction, International Stainless Steel Forum, 2003

Note: Organizations listed below offer information and design aids in both electronic and paper formats:

(1) Australian Stainless Steel Development Association

(2) British Stainless Steel Association

(3) Centro Inox (Italy)

(4) Euro Inox

(5) International Molybdenum Association

(6) International Stainless Steel Forum

(7) Nickel Development Institute

(8) South African Stainless Steel Development Association

(9) Specialty Steel Association of North America

(10) Steel Construction Institute (UK)

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D1.2/D1.2M	*Structural Welding Code—Aluminum*
D1.3/D1.3M	*Structural Welding Code—Sheet Steel*
D1.4/D1.4M	*Structural Welding Code—Reinforcing Steel*
D1.5/D1.5M	*Bridge Welding Code*
D1.6/D1.6M	*Structural Welding Code—Stainless Steel*
D1.8/D1.8M	*Structural Welding Code—Seismic Supplement*
D1.9/D1.9M	*Structural Welding Code—Titanium*

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