

AWS D9.1M/D9.1:2012
An American National Standard

Sheet Metal Welding Code



AWS D9.1M/D9.1:2012
An American National Standard

Approved by the
American National Standards Institute
July 20, 2012

Sheet Metal

Welding Code

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Prepared by the
American Welding Society (AWS) D9 Committee on Welding, Brazing, and Soldering of Sheet Metal

Under the Direction of the
AWS Technical Activities Committee

Approved by the
AWS Board of Directors

Abstract

This code covers the arc and braze welding requirements for nonstructural sheet metal fabrications using the commonly welded metals available in sheet form. Requirements and limitations governing procedure and performance qualification are presented, and workmanship and inspection standards are supplied. The informative annexes provide useful information on materials and processes.



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This standard is subject to revision at any time by the AWS D9 Committee on Welding, Brazing, and Soldering of Sheet Metal. It must be reviewed every five years, and if not revised, it must be either reaffirmed or withdrawn. Comments (recommendations, additions, or deletions) and any pertinent data that may be of use in improving this standard are required and should be addressed to AWS Headquarters. Such comments will receive careful consideration by the AWS D9 Committee on Welding, Brazing, and Soldering of Sheet Metal and the author of the comments will be informed of the Committee's response to the comments. Guests are invited to attend all meetings of the AWS D9 Committee on Welding, Brazing, and Soldering of Sheet Metal to express their comments verbally. Procedures for appeal of an adverse decision concerning all such comments are provided in the Rules of Operation of the Technical Activities Committee. A copy of these Rules can be obtained from the American Welding Society, 8669 Doral Blvd., Doral, FL 33166.

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Foreword

This foreword is not part of AWS D9.1M/D9.1:2012, *Sheet Metal Welding Code*, but is included for informational purposes only.

This code was developed to provide standardized requirements for the qualification, production, and acceptance of welding or braze welding of nonstructural sheet metal components. Preparation of this document is in response to the many requests received from the sheet metal and construction industries.

The AWS Committee on Welding, Brazing, and Soldering of Sheet Metal was organized in May 1978 and has published five previous versions of D9.1.

The first, D9.1-80, *Specification for Welding of Sheet Metal*, was limited to the more common welding processes. The second, D9.1-84, bore the same title, but was augmented to provide coverage of braze welding.

D9.1-90, *Sheet Metal Welding Code*, was written to refine and clarify several areas of the standard and to upgrade it to the status of a code in order to enhance its use and to promote a minimum quality level for those who invoke it.

The 2000 edition, D9.1M/D9.1:2000, *Sheet Metal Welding Code*, provides for maintenance of the document and updates to keep abreast of practices being encountered in sheet metal welding and joining processes since the last revision.

The 2006 edition D9.1M/D9.1:2006, *Sheet Metal Welding Code*, also provides for maintenance of the document and presents up to date practices in sheet metal welding and joining processes since the 2000 revision.

The 2012 edition D9.1M/D9.1:2012, *Sheet Metal Welding Code*, provides for maintenance of the document and incorporates many of the comments received during the balloting process for the 2006 edition.

Underlined text in clauses, tables, or figures indicates an editorial or technical change from the 2006 edition. A vertical line in the margin also indicates a revision from 2006 edition.

As new applications are developed and more experience is gathered, it is anticipated that changes in this standard will be required. Comments and suggestions for the improvement of this standard are welcome. They should be sent to the Secretary, AWS D9 Committee on the Welding, Brazing, and Soldering of Sheet Metal, American Welding Society, 8669 Doral Blvd., Doral, FL 33166.

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Sheet Metal Welding Code

1. General Requirements

1.1 Scope. This code provides qualification, workmanship, and inspection requirements for both arc welding (Part A) and braze welding (Part B), as they apply to the fabrication, manufacture, and erection of nonstructural sheet metal components and systems.

1.1.1 This code was developed to provide standardized requirements for the qualification, production, and acceptance of welding or braze welding of nonstructural sheet metal components.

1.1.2 General applications of this code are in the following industrial areas:

- (1) Heating, ventilating, and air conditioning systems
- (2) Food processing equipment
- (3) Architectural sheet metal and similar applications
- (4) Other nonstructural sheet metal applications

This code covers sheet metal thicknesses up to and including 6.07 mm [0.239 in]. Also covered are the attachment of accessories and components of the system, and joining or attachment of any member, regardless of thickness, whose sole purpose is stiffening, supporting, or reinforcing the sheet metal.

1.1.2.1 Limitations/Exceptions. This code does not apply:

- (1) Where negative pressure or positive pressure exceeds 30 kPa [5 psi], which is approximately 3 m [120 in] of standing water
- (2) Where structural requirements are concerned (including AWS D1.3/D1.3M, *Structural Welding Code—Sheet Steel*)
- (3) Where sheet metal products related to automotive applications are concerned

1.1.3 This code requires values to be specified by the Engineer for subclauses 8.2, 8.4, 13.1, and 13.3.

1.1.4 Symbols used in this code shall be in accordance with the latest edition of AWS A2.4, *Standard Symbols for Welding, Brazing, and Nondestructive Examination*.

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

1.3 Safety. Safety and health issues and concerns are beyond the scope of this standard and therefore are not addressed herein. Safety and health information is available from the following sources:

American Welding Society:

- (1) ANSI Z49.1, *Safety in Welding, Cutting, and Allied Processes*
- (2) AWS Safety and Health Fact Sheets
- (3) Other safety and health information on the AWS website

Material or Equipment Manufacturers:

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

Applicable Regulatory Agencies

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

2. Normative References

The standards listed below contain provisions that through reference in this text constitute mandatory provisions of this AWS standard. For undated references, the latest edition of the referenced standard shall apply. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply.

ANSI Z49.1, *Safety in Welding, Cutting, and Allied Processes*;¹ and
AWS Standards;²

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

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

3. Terms and Definitions

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

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

Engineer. The duly designated person who acts on behalf of the Owner in all matters within the scope of this code.

Contractor. The party responsible for performing the welding under this code. The term is used collectively to mean contractor, fabricator, erector, or manufacturer.

Independent Third Party. An organization or agency qualified to perform inspection and testing required by this code.

Supplemental terms and definitions of significant importance to sheet metal welding are given in Annex B.

Part A *Arc Welding*

4. General Provisions for Arc Welding

4.1 Base Metal

4.1.1 Base metals to be joined under this code include coated and uncoated forms of carbon steel, high strength low-alloy steel, chromium and chromium-nickel stainless steel alloys, aluminum and aluminum alloys, copper and copper alloys, nickel and nickel alloys, and titanium and titanium alloys.

¹ ANSI Z49. 1 is published by the American Welding Society, 8669 Doral Blvd., Doral, FL 33166.

² AWS standards are published by the American Welding Society, 8669 Doral Blvd., Doral, FL 33166.

4.1.2 Rust inhibitive coatings (including weldable primers), galvanized or aluminized coatings, or anti-spatter compounds may remain on the metal to be joined.

4.2 Filler Metal

4.2.1 Filler metals shall be compatible with the base metal designated on the drawings or specified by the Engineer.

4.2.2 Recommended filler metals are listed in Annex A.

4.3 Processes. Joining processes under this code shall include shielded metal arc welding (SMAW), gas metal arc welding (GMAW), flux cored arc welding (FCAW), gas tungsten arc welding (GTAW), plasma arc welding (PAW), and carbon arc welding (CAW). Other processes may be used, provided they are qualified in accordance with the requirements of this code.

5. Arc Welding Procedure Qualification

5.1 Prior Procedure Qualification

5.1.1 The use of welding procedure specifications qualified in accordance with AWS B2.1/B2.M, *Specification for Welding Procedure and Performance Qualification*, shall be accepted for welding to this code. Standard Welding Procedure Specifications (SWPSs) published by AWS shall be accepted as qualified procedures.

5.1.2 The Engineer, exercising proper discretion, may accept evidence of previous qualification of specific procedures to be used on work being performed under this code.

5.2 Required Procedure Qualification Tests

5.2.1 Welding Procedure Specification. The qualification of a Welding Procedure Specification (WPS) shall be the responsibility of the Contractor. Each welding procedure to be used in conjunction with this code shall be prepared as a WPS to be used in fabrication and installation. An independent third party may perform the actual procedure qualification tests and prepare the forms; however, the Contractor shall be responsible for certifying acceptance in accordance with the requirements of this code (see 5.5.1). All required information for the WPS, listed in 5.3, shall be recorded on a form similar to that shown in Annex D.

5.2.2 Typical Joints. Qualification of any groove weld shown in Annex G provides qualification for any groove or fillet weld. Qualification of any fillet weld shown in Annex G provides qualification for any fillet weld. Qualification of a fillet weld does NOT provide qualification for a groove weld.

5.2.3 Preparing Joint Chosen for Testing. The chosen joint type shall be prepared as a longitudinal weld joint between two 75 mm [3 in] by 150 mm [6 in] sheets, assembled using one of the joints types shown in Figure 1 or by using the actual joint to be used. Qualification testing using the butt joint in Figure 1 shall qualify all groove and fillet weld joint types.

5.2.4 Welding the Test Joint. The joint shall be welded using the process specified by the WPS (see 5.2.1).

5.3 Limitations of Procedure Qualification. A qualified welding procedure shall be used only with the allowable ranges of operating variables tested during qualification. These limits of essential variables are described in 5.3.1 through 5.3.10. The variables shall be recorded on a PQR form similar to that shown in Annex E.

5.3.1 Base Metals. A change from one of the following base metal groups to another, or a change to a weld between dissimilar metals, requires separate qualification:

- (1) Carbon steel with 0.30% maximum carbon and 0.50% maximum chromium
- (2) High-strength, low-alloy steels
- (3) Chromium and chromium-nickel stainless steels
- (4) Copper and copper alloys
- (5) Nickel and nickel alloys
- (6) Aluminum and aluminum alloys
- (7) Titanium and titanium alloys

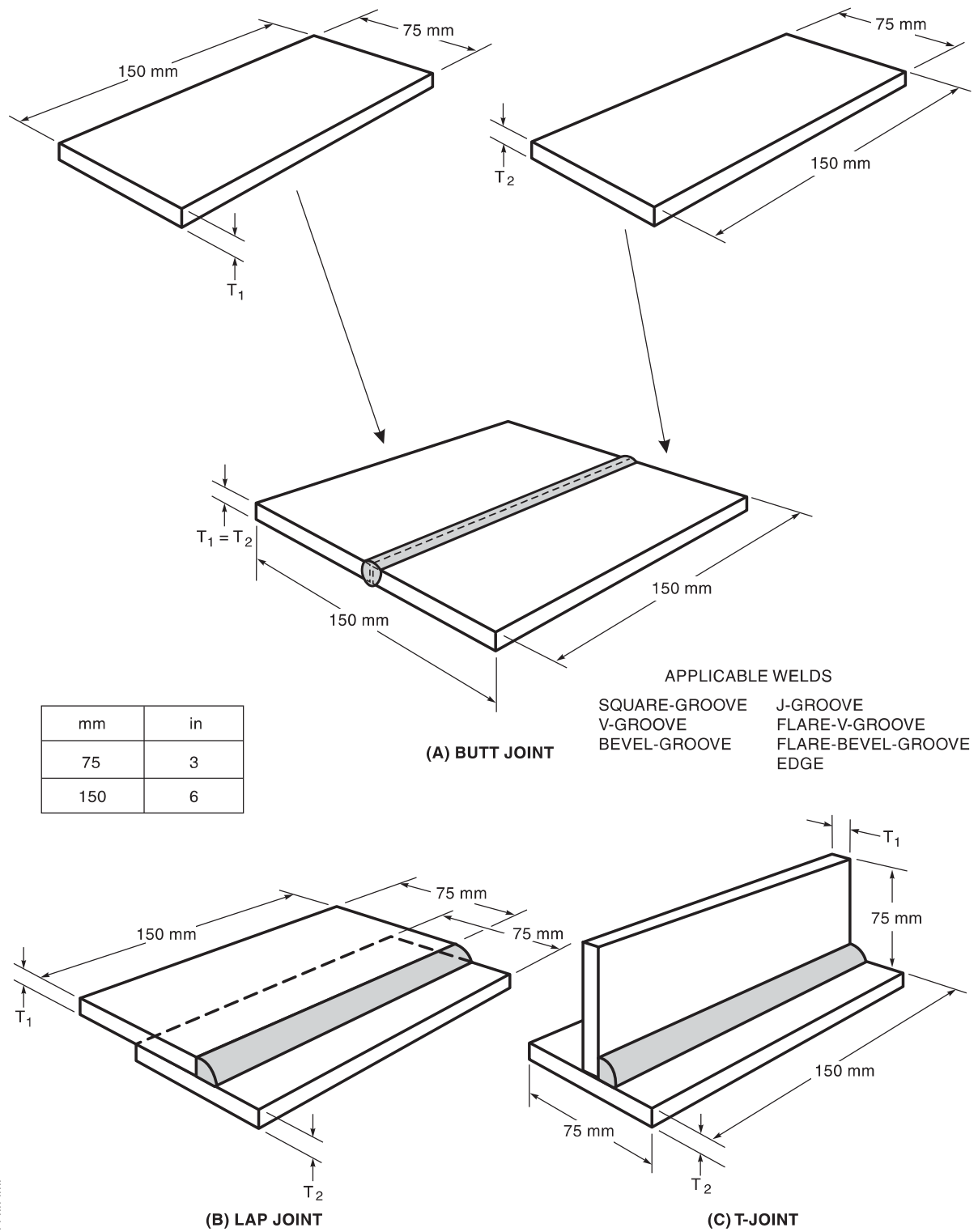


Figure 1—Procedure Qualification Test Assemblies

5.3.2 Coating Material. The addition or change, but not deletion, of coating material on the base metal requires requalification. Anti-spatter compound is not considered a coating material.

5.3.3 Base Metal Thickness

(1) A change in thickness to less than $0.5T$ or to greater than $2T$, where T is the thickness of the thinner base metal qualified, requires requalification.

(2) As an alternate to 5.3.3(1), the following qualification tests may be used to cover the complete range of all sheet metal thicknesses as defined in Annex C.

(a) A qualification weld performed on 18 gage metal shall provide qualification for the procedure for metal 16 gage and thinner (see Annex C for equivalents).

(b) A qualification weld performed on 10 gage metal shall provide qualification for the procedure for metal as thin as 16 gage and thicker, up to 6.07 mm [0.239 in] max. (see Annex C for equivalents).

5.3.4 The omission, but not the addition, of backing material requires requalification. Shielding gas is not considered a backing material.

5.3.5 A change in filler metal “F” number requires requalification (see Annex A, Table A.1).

5.3.6 A change in welding process, or a change in the method of application (manual, semiautomatic, automatic) requires requalification.

5.3.7 A change in the type of welding current from AC to DC, or vice versa, requires requalification. Also, a change in polarity from direct current electrode positive (DCEP) to direct current electrode negative (DCEN), or vice versa, requires requalification.

5.3.8 For the GMAW process, a change in the mode of metal transfer, as indicated below, requires requalification:

(1) Short circuiting transfer to any other mode of metal transfer.

(2) Any mode of metal transfer to short circuiting transfer mode.

5.3.9 Shielding Gas. A change in the minor constituents of the shielding gas mixture of more than $\pm 10\%$ or the deletion of backing gas requires requalification except that, for carbon steel base metals, a change between $100\% \text{ CO}_2$ [AWS A5.32 (ISO 14175)-C1-C] and a mixture of $75\% \text{ Ar} - 25\% \text{ CO}_2$ [AWS A5.32 (ISO 14175)-M21-ArC-25] does not require requalification.

5.3.10 Position Qualification. Except as listed below, changes in the welding position require requalification (see Figure 2 and Figure 3):

(1) Qualification in the 1G or 1F position shall qualify the procedure only in the flat position.

(2) Qualification in the 2G or 2F position shall qualify the procedure in both the flat and horizontal positions.

(3) Qualification in the 3G or 3F position (with downhill progression) shall qualify the procedure in the flat, horizontal, and vertical positions (with downhill progression only)

(4) Qualification in the 3G or 3F position (with uphill progression) shall qualify the procedure in the flat, horizontal, and vertical positions (with either uphill or downhill progression).

(5) Qualification in the 4G or 4F position shall qualify the procedure in the flat, horizontal, vertical (with downhill progression only), and overhead positions.

(6) Qualification in the 3G or 3F position (with uphill progression) and the 4G or 4F positions respectively, shall qualify the procedure in all positions (with either uphill or downhill progression).

5.4 Inspection of Procedure Qualification Test Welds. Inspection of all test welds shall be visual, without aid of magnification. (Prescription eyeglasses for vision correction are acceptable.)

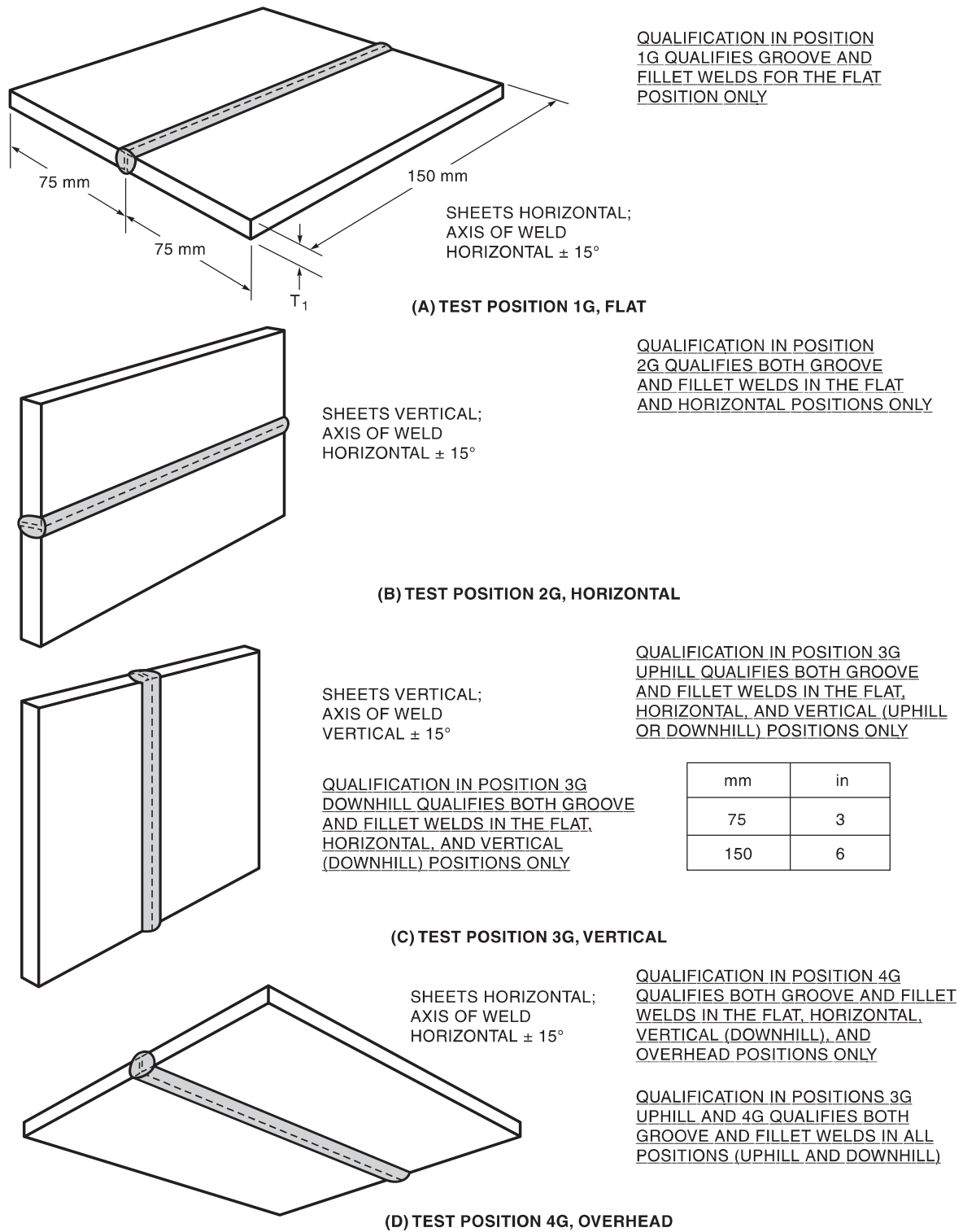
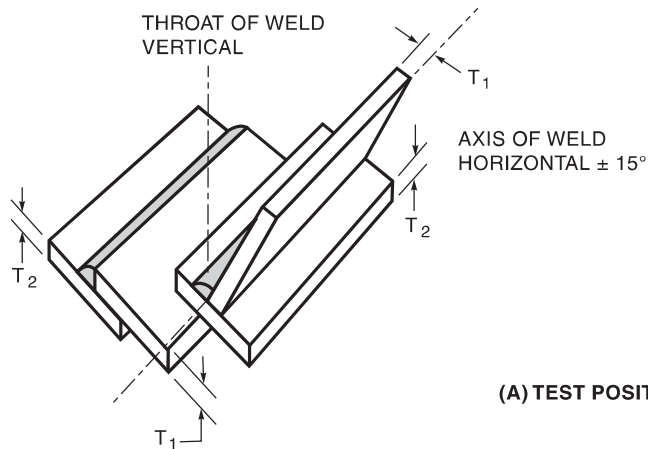
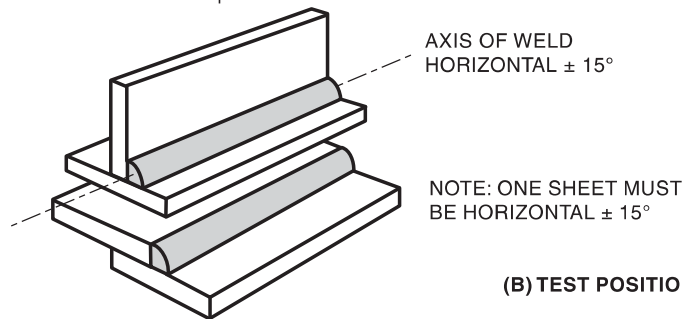


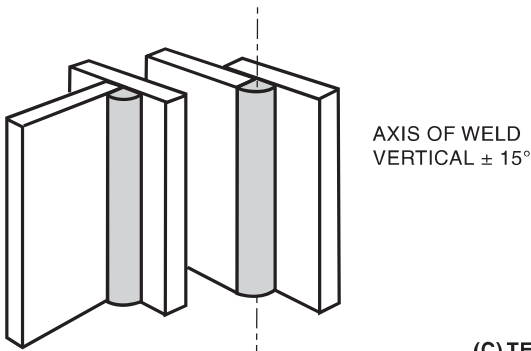
Figure 2—Butt Joint Groove Weld Test Positions

**(A) TEST POSITION 1F, FLAT**

QUALIFICATION IN POSITION
1F QUALIFIES FILLET WELDS
FOR THE FLAT POSITION ONLY

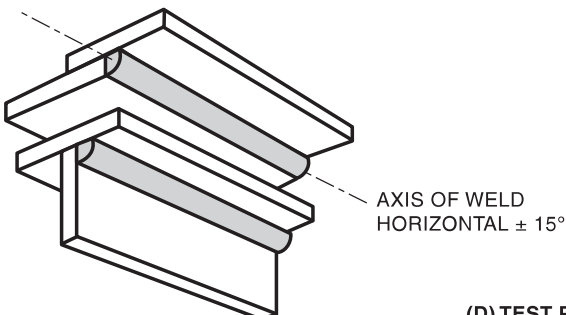
**(B) TEST POSITION 2F, HORIZONTAL**

QUALIFICATION IN POSITION
2F QUALIFIES FILLET WELDS
IN THE FLAT AND HORIZONTAL
POSITIONS ONLY

**(C) TEST POSITION 3F, VERTICAL**

QUALIFICATION IN POSITION 3F
DOWNHILL QUALIFIES FILLET
WELDS IN THE FLAT, HORIZONTAL,
AND VERTICAL (DOWNHILL)
POSITIONS ONLY

QUALIFICATION IN POSITION 3F
UPHILL QUALIFIES FILLET WELDS
IN THE FLAT, HORIZONTAL, AND
VERTICAL (UPHILL OR DOWNHILL)
POSITIONS ONLY

**(D) TEST POSITION 4F, OVERHEAD**

QUALIFICATION IN POSITION 4F
QUALIFIES FILLET WELDS IN THE
FLAT, HORIZONTAL, VERTICAL
(DOWNHILL), AND OVERHEAD
POSITIONS ONLY

QUALIFICATION IN POSITION 3F
UPHILL AND 4F QUALIFIES FILLET
WELDS IN ALL POSITIONS (UPHILL
AND DOWNHILL)

Figure 3—Fillet Weld Test Positions

5.4.1 Groove Welds. Except for the first and last 13 mm [0.5 in], the weld, as shown in Figure 1(A), shall exhibit the following:

- (1) Complete fusion;
- (2) Complete joint penetration;
- (3) A maximum of 3.2 mm [1/8 in] face reinforcement and 3.2 mm [1/8 in] root reinforcement;
- (4) No more than one visible pore or inclusion in any 25 mm [1 in] of weld. The size of any pore or inclusion shall not exceed $0.25T$, where T is the thickness of the thinner member;
- (5) No undercut exceeding $0.15T$; and
- (6) No cracks.

5.4.2 Fillet Welds. Except for the first and last 13 mm [0.5 in], the weld, as shown in Figure 1(B) and (C), shall exhibit the following:

- (1) Complete fusion;
- (2) The minimum effective throat shall be as specified for the application with maximum convexity not to exceed 3.2 mm [1/8 in];
- (3) No more than one visible pore or inclusion in any 25 mm [1 in] of weld. The size of any pore shall not exceed $0.25T$, where T is the thickness of the thinner member;
- (4) Undercut may not exceed $0.15T$ when the base metal thickness being welded is 4.8 mm [0.187 in] or thinner, or exceed $0.25T$ when the base metal thickness being welded is greater than 4.8 mm [0.187 in]; and
- (5) No cracks.

5.5 Responsibility for Qualification

5.5.1 Each Contractor shall be responsible for the qualification of procedures, whether the qualification testing is conducted by the Contractor or an independent third party, subject to the following conditions:

- (1) The Procedure Qualification Record (PQR) shall meet all of the procedure qualification requirements of this code, and
- (2) The Contractor shall assume specific responsibility for the procedure qualification work completed by signing and dating the Welding Procedure Specification (WPS) and Procedure Qualification Record (PQR).

5.5.2 Records of welding procedures qualified in accordance with this code shall be maintained by the Contractor and shall be available for inspection as required by the Engineer, the Owner, or their representative (see Annexes D and E for suggested forms).

5.6 Duration of Procedure Qualification

5.6.1 Welding procedures qualified to a previous editions of AWS D9.1 remain qualified in this edition except as required by 5.6.2.

5.6.2 Procedures shall be requalified whenever a change is made in an essential variable that is outside the range allowed by the variable (see 5.3).

6. Qualification of Arc Welders and Arc Welding Operators

6.1 Prior Welder and Welding Operator Qualification

6.1.1 The Engineer, exercising proper discretion, may accept evidence of previous qualification of welders and welding operators to be used on work being performed under this code.

6.1.2 Welders and welding operators performing procedure qualification test welds meeting the procedure qualification acceptance criteria in Clause 5, Arc Welding Procedure Qualification, shall be considered as qualified to perform welding without additional qualification testing, subject to the limitations defined in 6.3.

6.2 Required Welder and Welding Operator Qualification Tests

6.2.1 General. All welders and welding operators permitted to weld under this code shall be qualified. Welding shall be performed in accordance with a WPS qualified under Clause 5, Arc Welding Procedure Qualification. Contractors, at their option, may administer a general knowledge test of the welder's and welding operator's general welding knowledge (see Annex J).

6.2.2 Groove Welds. Test coupon dimensions and test positions for qualification of groove welds are given in Figure 2.

6.2.3 Fillet Welds. Welders and welding operators who qualify for groove welds under 6.2.2 are automatically granted qualification for fillet welds (see Figure 3 or Annex G). Qualification testing using either a lap joint fillet, T-joint fillet, or the actual joint fillet configuration is permitted at the option of the Contractor, unless otherwise specified in the WPS. Test positions for qualification of fillet welds are given in Figure 3.

6.2.4 Typical Joints. Qualification of any groove weld shown in Annex G provides qualification for any groove or fillet weld. Qualification of any fillet weld shown in Annex G provides qualification for any fillet weld. Qualification of a fillet weld does NOT provide qualification for a groove weld.

6.3 Limitations of Welder and Welding Operator Qualifications. The limits of essential variables governing welder and welding operator qualification are described in 6.3.1 through 6.3.10.

6.3.1 Base Metal. A change from one of the following base metal groups to another, or a change to a weld between dissimilar metals requires separate qualification:

- (1) Carbon steels with 0.30% maximum carbon and 0.50% maximum chromium
- (2) High-strength, low-alloy steels
- (3) Chromium and chromium-nickel stainless steels
- (4) Copper and copper alloys
- (5) Nickel and nickel alloys
- (6) Aluminum and aluminum alloys
- (7) Titanium and titanium alloys

6.3.2 Coating Material. The addition or change, but not deletion, of coating material on the base metal requires requalification. Anti-spatter compound is not considered a coating material.

6.3.3 Base Metal Thickness

(1) A change in thickness to less than $0.5T$ or to greater than $2T$, where T is the thickness of the thinner base metal qualified requires requalification.

(2) As an alternate to 6.3.3(1), the following qualification tests may be used to cover the complete range of all sheet metal thicknesses as defined in Annex C.

(a) A qualification weld performed on 18 gage metal shall provide qualification for the welder or welding operator for metal 16 gage and thinner (see Annex C for equivalents).

(b) A qualification weld performed on 10 gage metal shall provide qualification for the welder or welding operator for metal as thin as 16 gage and thicker, up to 6.07 mm [0.239 in] max. thicknesses (see Annex C for equivalents).

6.3.4 The omission, but not the addition, of backing material requires requalification. Shielding gas is not considered a backing material.

6.3.5 A change in filler metal “F” number requires requalification (see Annex A, Table A.1).

6.3.6 A change in welding process, or a change in the method of application (manual, semiautomatic, automatic) requires requalification, except as noted below:

- (1) Qualification for manual welding also qualifies for semiautomatic and automatic application.
- (2) Qualification for semiautomatic welding also qualifies for automatic, but not for manual application.
- (3) Qualification for automatic welding qualifies for automatic welding only.

6.3.7 A change in the type of welding current from AC to DC, or vice versa, requires requalification.

6.3.8 For GMAW and FCAW, a change in the mode of metal transfer, as indicated below, requires requalification:

- (1) Short circuiting transfer to any other mode of metal transfer.
- (2) Any mode of metal transfer to short circuiting transfer.

6.3.9 Shielding Gas

6.3.9.1 Deletion, but not the addition, of backing gas requires requalification.

6.3.10 Position Qualification. Changes in the welding position (see Figures 2 and 3) require requalification other than listed below:

- (1) Qualification in the 1G or 1F position shall qualify the welder or welding operator only in the flat position.
- (2) Qualification in the 2G or 2F position shall qualify the welder or welding operator in both the flat and horizontal positions.
- (3) Qualification in the 3G or 3F position (with downhill progression) shall qualify the welder or welding operator in the flat, horizontal, and vertical positions (with downhill progression only).
- (4) Qualification in the 3G or 3F position (with uphill progression) shall qualify the welder or welding operator in the flat, horizontal, and vertical positions (with either uphill or downhill progression).
- (5) Qualification in the 4G or 4F position shall qualify the welder or welding operator in the flat, horizontal, vertical (with downhill progression only), and overhead positions.
- (6) Qualification in the 3G or 3F position (with uphill progression) and the 4G or 4F positions respectively, shall qualify the welder or welding operator in all positions (with either uphill or downhill progression).

6.4 Inspection of Welder and Welding Operator Qualification Test Welds. Inspection of all test welds shall be visual, without aid of magnification. (Prescription eyeglasses for vision correction are acceptable.) Except for the first and last 13 mm [0.5 in], welds shall exhibit the following:

- (1) Complete fusion;
- (2) Complete joint penetration (groove weld in a butt joint) or required minimum effective throat (fillet weld);
- (3) A maximum of 3.2 mm [1/8 in] face reinforcement and 3.2 mm [1/8 in] root reinforcement for welds in butt joints or a minimum effective throat equal to the thickness of the thinner member joined with convexity, not to exceed 3.2 mm [1/8 in] for fillet welds;
- (4) No more than one visible pore or inclusion in any 25 mm [1 in] of weld. The size of any pore or inclusion shall not exceed $0.25T$, where T is the base-metal thickness of the thinner member;
- (5) For groove welds, no undercut exceeding $0.15T$;
- (6) For fillet welds, no undercut exceeding $0.15T$ when the base metal being welded is 4.8 mm [0.187 in] or thinner in thickness, nor exceeding $0.25T$ when the base-metal thickness being welded is greater than 4.8 mm [0.187 in]; and
- (7) No cracks.

6.5 Responsibility for Qualification

6.5.1 Each Contractor shall be responsible for the qualification of welders or welding operators, whether the qualification testing is conducted by the Contractor or an independent third party, subject to the following conditions:

- (1) The welder was qualified meeting all of the welder qualification requirements of this code,
- (2) The requirements of 6.6 shall be met, and
- (3) The Contractor shall assume specific responsibility for the welder qualification by signing and dating the Welder Qualification Test Record (see Annex F).

6.5.2 Records of welder or welding operator qualification testing in accordance with this code shall be maintained by the Contractor and shall be available for inspection as required by the Engineer, the Owner, or their representative (see Annexes D and E for suggested forms). All required information for welder or welding operator qualification shall be recorded on an adequate form similar to the recommended form shown as Annex F.

6.6 Duration of Qualification. Qualification of welders or welding operators tested to the requirements of this code shall remain in effect unless:

- (1) The welder or welding operator has not been engaged in performing welding operations utilizing the process for which the welder originally qualified for a period exceeding twelve months.
- (2) There is a specific reason to question the welder's or welding operator's ability.

7. Arc Welding Workmanship

Work performed under this code shall exhibit qualities of workmanship described below.

7.1 Uniformity. Surfaces to be joined shall be uniform and free of rejectable indications.

7.2 Joint Cleanliness

7.2.1 Joint surfaces, as well as surfaces adjacent to a joint, shall be free of loose scale, oxides, rust, grease, and foreign matter.

7.2.2 Tightly adherent spatter is not a cause for rejection.

7.3 Position. If a welding position is not specified explicitly by the Engineer or dictated by a job condition, joints shall be welded in the most favored position for which both the procedure and the welder or welding operator are qualified.

7.4 Current and Polarity. Welding current and polarity shall be in accordance with the qualified welding procedure.

7.5 Inspection of Workmanship. Welds shall be visually inspected and shall meet the acceptance criteria of Clause 8, Inspection of Production Arc Welding Work.

8. Inspection of Production Arc Welding Work

Inspection of all production welds shall be visual, without aid of magnification. (Prescription eyeglasses for vision correction are acceptable.)

Acceptance criteria for production welds different from those specified in this code may be used for a particular application provided they are suitably documented and approved by the Engineer.

The Contractor shall conduct inspections to ensure conformance to the acceptance criteria. The Owner, Owner's Representative, or Engineer shall have the option to inspect the Contractor's workmanship. The specified acceptance criteria for the work shall be as follows:

8.1 Fusion. Complete fusion shall be obtained.

8.2 Penetration. Required joint penetration as specified for the application shall be present (see 1.1.3).

8.3 Reinforcement of Groove Welds. A maximum of 3.2 mm [1/8 in] face reinforcement and 3.2 mm [1/8 in] root reinforcement shall be acceptable.

8.4 Throat and Convexity of Fillet Welds. The minimum throat shall be as specified for the application with maximum convexity not to exceed 3.2 mm [1/8 in] (see 1.1.3).

8.5 Porosity or Inclusions. Some limited porosity or inclusion is acceptable, consistent with 8.1 and limited to the following:

(1) One visible pore or inclusion no larger than $0.5T$ is permitted in any 25 mm [1 in] of weld, where T is the thickness of the thinner member.

(2) Three visible pores or inclusions no larger than $0.25T$ also are permitted in any 25 mm [1 in] of weld, where T is the thickness of the thinner member.

8.6 Undercut

8.6.1 Groove Welds. Undercut may not exceed $0.15T$.

8.6.2 Fillet Welds. Undercut may not exceed $0.15T$ when the base-metal thickness being welded is 4.8 mm [0.187 in] or thinner, or exceed $0.25T$ when the base metal thickness being welded is greater than 4.8 mm [0.187 in].

8.7 Cracks. There shall be no cracks.

8.8 Conformance. Completed welds shall be visually inspected for location, size, and length in accordance with the engineering drawing and specification requirements.

Part B Braze Welding

9. General Provisions for Braze Welding

9.1 Base Metal

9.1.1 Base metals to be joined under this code include coated and uncoated forms of carbon steel, low-alloy steel, chromium and chromium-nickel stainless steel alloys, aluminum and aluminum alloys, copper and copper alloys, nickel and nickel alloys, and titanium and titanium alloys.

9.1.2 Rust inhibitive coatings (including weldable primers), galvanized or aluminized coatings, or anti-spatter compounds may remain on the metal to be joined.

9.2 Filler Metal

9.2.1 Filler metals shall be compatible with the base metal designated on the drawings or specified by the Engineer.

9.2.2 Recommended filler metals are shown in Annex A, Table A.1. Only those filler metals with a melting temperature below that of the base metal are suitable for braze welding.

9.3 Processes. Joining processes under this code shall include gas tungsten arc welding (GTAW), gas metal arc welding (GMAW), and carbon arc braze welding (CABW). Other processes may be used, provided they are qualified to the requirements of this code.

10. Braze Welding Procedure Qualification

10.1 Prior Procedure Qualification

10.1.1 Braze welding procedures qualified in accordance with AWS B2.1, *Standard for Welding Procedure and Performance Qualification*, shall be accepted for welding to this code. Standard Welding Procedure Specifications (SWPSs) published by AWS shall be accepted as qualified procedures.

10.1.2 The Engineer, exercising proper discretion, may accept evidence of previous qualification of specific procedures to be used on work being performed under this code.

10.2 Required Procedure Qualification Tests

10.2.1 Welding Procedure Specification. The qualification of a WPS shall be the responsibility of the Contractor. Each welding procedure to be used in conjunction with this code shall be prepared as a Welding Procedure Specification (WPS). An independent third party may perform the actual procedure qualification tests and prepare the form; however, the Contractor shall be responsible for certifying acceptance in accordance with the requirements of this code (see 10.5.1). All required information for the WPS shall be recorded on an adequate form similar to that shown in Annex D.

10.2.2 Typical Joints. Qualification of any groove weld shown in Annex G provides qualification for any groove or fillet weld. Qualification of any fillet weld shown in Annex G provides qualification for any fillet weld. Qualification of a fillet weld does NOT provide qualification for a groove weld.

10.2.3 Preparing Joint Chosen for Testing. The chosen joint type shall be prepared as a longitudinal weld joint between two 75 mm [3 in] by 150 mm [6 in] sheets, assembled using one of the joints types shown in Figure 4 or by using the actual joint to be used. Qualification testing using the butt joint in Figure 4 shall qualify all groove and fillet weld joint types.

10.2.4 Braze Welding the Test Joint. The joint shall be braze welded using the process specified in the WPS (see 10.2.1).

10.3 Limitations of Procedure Qualification. A qualified braze welding procedure shall be used only within the range of operating variables tested during qualification. These limits of essential variables are described in 10.3.1 through 10.3.9. The variables shall be recorded on an adequate PQR form such as shown in Annex E.

10.3.1 Base Metals. A change from one of the following base-metal groups to another, or a change to a weld between dissimilar metals, requires separate qualification:

- (1) Carbon steels with 0.30% maximum carbon and 0.50% maximum chromium
- (2) High-strength, low-alloy steels
- (3) Chromium and chromium-nickel stainless steels
- (4) Copper and copper alloys
- (5) Nickel and nickel alloys
- (6) Aluminum and aluminum alloys
- (7) Titanium and titanium alloys

10.3.2 Coating Material. The addition or change, but not deletion, of coating material on the base metal requires requalification. Anti-spatter compound is not considered a coating material.

10.3.3 Base Metal Thickness

(1) A change in thickness to less than $0.5T$ or to greater than $2T$, where T is the thickness of the thinner base metal qualified, requires requalification.

(2) As an alternate to 10.3.3(1), the following qualification tests may be used to cover the complete range of all sheet metal thicknesses as defined in Annex C.

(a) A qualification braze weld performed on 18 gage metal shall provide qualification for the procedure for metal 16 gage and thinner (see Annex C for equivalents).

(b) A qualification braze weld performed on 10 gage metal shall provide qualification for the procedure for metal as thin as 16 gage and thicker, up to 6.07 mm [0.239 in] max. thicknesses (see Annex C for equivalents).

10.3.4 The omission, but not the addition, of backing material requires requalification. Shielding gas is not considered a backing material.

10.3.5 A change in filler metal “F” number requires requalification (see Annex A, Table A.1).

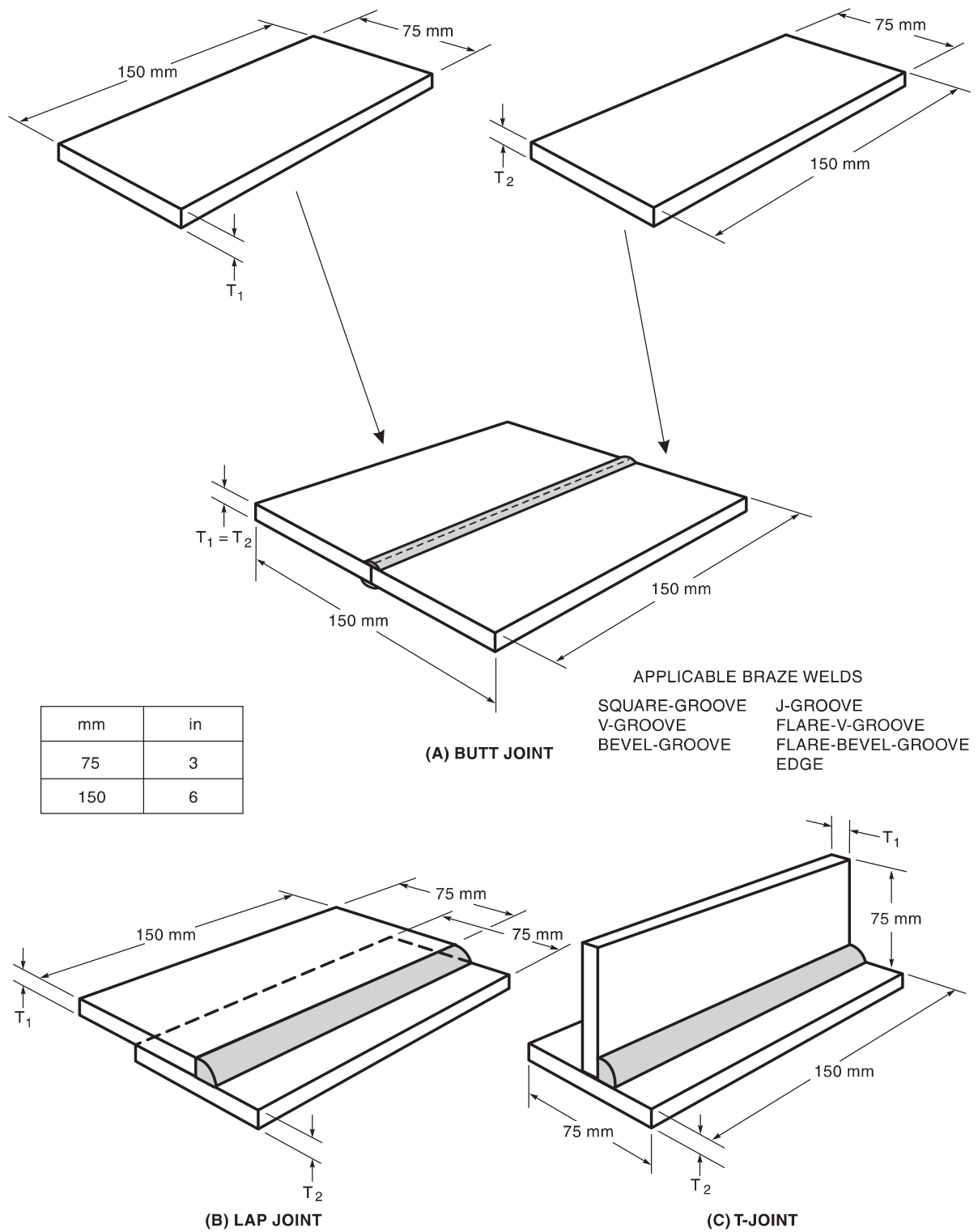


Figure 4—Braze Weld Procedure Qualification Test Assemblies

10.3.6 A change in braze welding process, or a change in the method of application (manual, semiautomatic, automatic) requires requalification.

10.3.7 A change in the type of current or polarity, as indicated below, requires requalification:

- (1) AC to DC, or vice versa.
- (2) DCEN to DCEP, or vice versa.

10.3.8 Shielding Gas. A change in the minor constituents of the shielding gas mixture of more than $\pm 10\%$ or the deletion, but not the addition, of backing gas requires requalification except that, for carbon steel base metals, a change between 100% CO₂ [AWS A5.32 (ISO 14175)-C1-C] and a mixture of 75% Ar – 25% CO₂ [AWS A5.32 (ISO 14175)-M21-ArC-25] does not require requalification.

10.3.9 Position Qualification. Changes in the welding position (see Figures 5 and 6) require requalification, other than listed below:

- (1) Qualification in the 1G or 1F position shall qualify the procedure only in the flat position.
- (2) Qualification in the 2G or 2F position shall qualify the procedure in both the flat and horizontal positions.
- (3) Qualification in the 3G or 3F position (with downhill progression) shall qualify the procedure in the flat, horizontal, and vertical positions (with downhill progression only).
- (4) Qualification in the 3G or 3F position (with uphill progression) shall qualify the procedure in the flat, horizontal, and vertical positions (with either uphill or downhill progression).
- (5) Qualification in the 4G or 4F position shall qualify the procedure in the flat, horizontal, vertical (with downhill progression only), and overhead positions.
- (6) Qualification in the 3G or 3F position (with uphill progression) and the 4G or 4F positions respectively, shall qualify the procedure in all positions (with either uphill or downhill progression).

10.4 Inspection of Procedure Qualification Test Braze Welds. Inspection of all test braze welds shall be visual without aid of magnification. (Prescription eyeglasses for vision correction are acceptable.)

10.4.1 Groove Braze Welds. Except for the first and last 13 mm [0.5 in], the braze groove weld, as shown in Figure 4(A), shall exhibit the following:

- (1) Complete metallic bonding at the joint;
- (2) Face reinforcement shall be a minimum of $0.5T$, where t is the thickness of the thinner base metal and shall not exceed 3.2 mm [1/8 in]. Root reinforcement shall not exceed 3.2 mm [1/8 in];
- (3) No more than one visible pore or inclusion in any 25 mm [1 in] of braze weld. The size of any pore or inclusion shall not exceed $0.25T$, where T is the base-metal thickness of the thinner member; and
- (4) No cracks.

10.4.2 Fillet Braze Welds. Except for the first and last 13 mm [0.5 in], the braze fillet weld, as shown in Figure 4(B) and (C), shall exhibit the following:

- (1) Metallic bonding adequate for the intended application;
- (2) The minimum effective throat shall be as specified for the application with the convexity not to exceed 3.2 mm [1/8 in];
- (3) No more than one visible pore or inclusion in any 25 mm [1 in] of braze weld. The size of any pore or inclusion shall not exceed $0.25T$, where T is the base-metal thickness of the thinner member; and
- (4) No cracks.

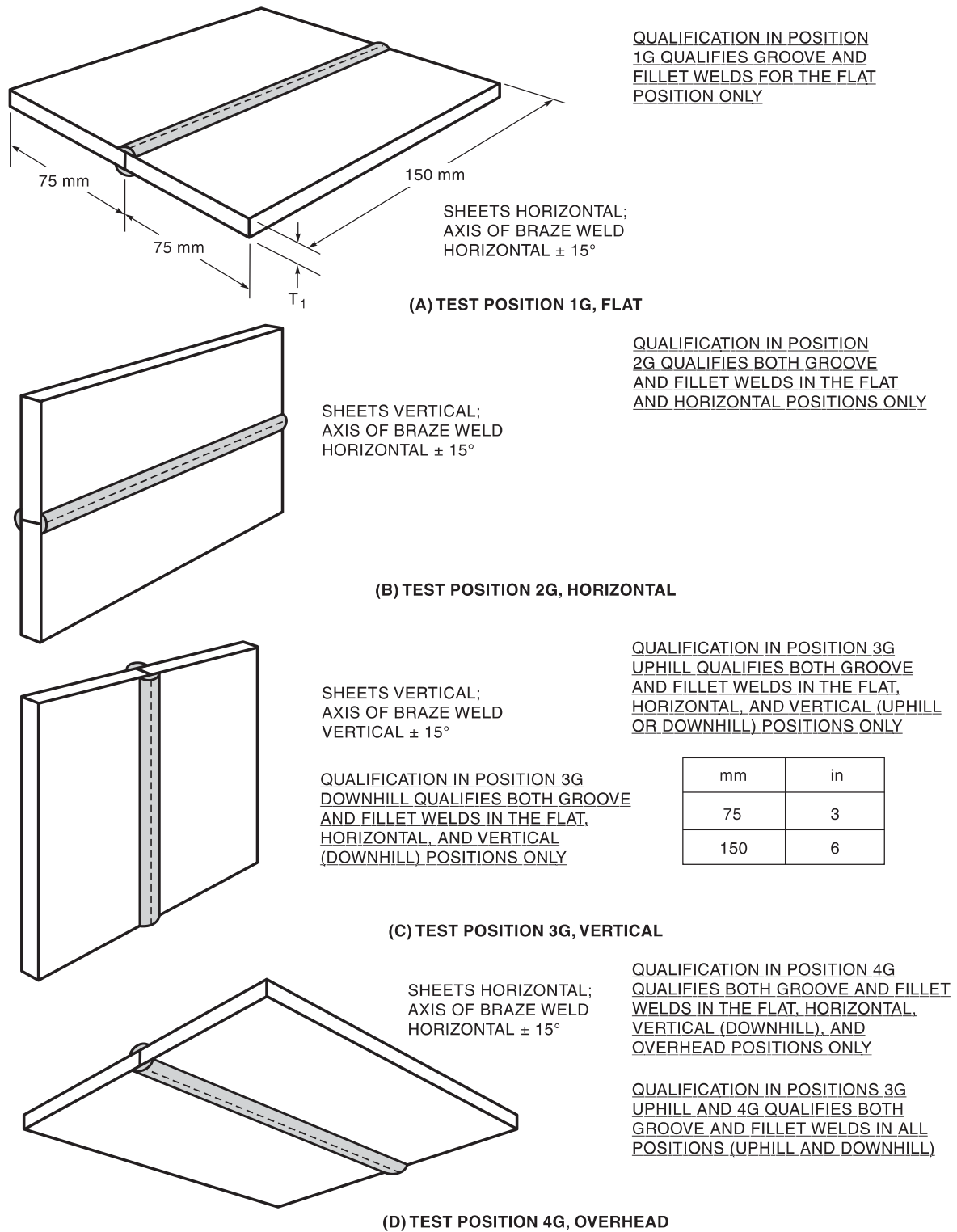


Figure 5—Braze Groove Weld Test Positions

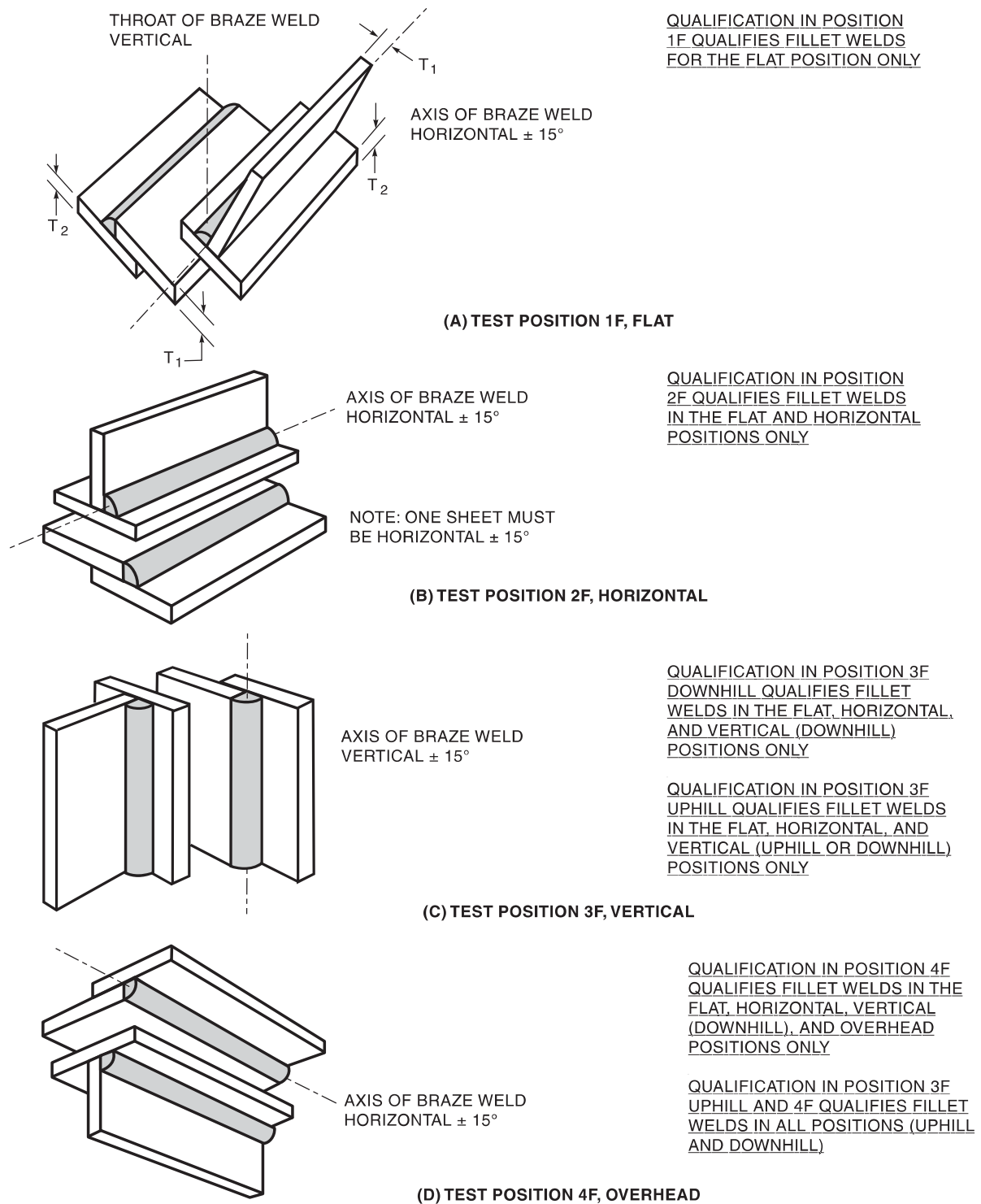


Figure 6—Braze Fillet Weld Test Positions

10.5 Responsibility for Qualification

10.5.1 Each Contractor shall be responsible for the qualification of procedures, whether the qualification testing is conducted by the manufacturer, Contractor, or an independent third party, subject to the following conditions:

- (1) The Procedure Qualification Record (PQR) shall meet all of the procedure qualification requirements of this code, and
- (2) The Contractor shall assume specific responsibility for the procedure qualification work completed by signing and dating the Welding Procedure Specification (WPS) and Procedure Qualification Record (PQR).

10.5.2 Records of braze welding procedures qualified in accordance with this code shall be maintained by the Contractor and shall be available for inspection as required by the Engineer, the Owner, or their representative (see Annexes D and E for suggested forms).

10.6 Duration of Procedure Qualification

10.6.1 Braze welding procedures qualified to a previous editions of AWS D9.1 remain qualified in this edition except as required by 10.6.2.

10.6.2 Procedures shall be requalified whenever a change is made in an essential variable that is outside the range allowed by the variable (see 10.3).

11. Qualification of Braze Welders and Braze Welding Operators

11.1 Prior Braze Welder and Braze Welding Operator Qualification

11.1.1 The Engineer, exercising proper discretion, may accept evidence of previous qualification of braze welders and braze welding operators to be used on work being performed under this code.

11.1.2 Braze welders or braze welding operators performing procedure qualification test braze welds, which meet the procedure qualification acceptance criteria in Clause 10, Braze Welding Procedure Qualification, shall be considered as qualified to perform braze welding without additional qualification testing, subject to the limitations defined in 11.3.

11.2 Required Braze Welder and Braze Welding Operator Qualification Tests

11.2.1 General. All braze welders and braze welding operators permitted to braze weld under this code shall be qualified. Braze welding shall be performed in accordance with a WPS qualified under Clause 10, Braze Welding Procedure Qualification, of this code. Contractors, at their option, may administer a general knowledge test of the welder's and welding operator's general welding knowledge (see Annex J).

11.2.2 Braze Groove Welds. Test coupon dimensions and test positions for qualification for groove braze welds are given in Figure 5.

11.2.3 Braze Fillet Welds. Welders and welding operators who qualify for groove welds under 11.2.2 are automatically granted qualification for fillet welds (see Figure or Annex G). A qualification test using either a lap joint fillet, T-joint fillet, or the actual fillet joint to be welded is permitted at the option of the Contractor unless otherwise specified in the WPS. Test positions for qualification of fillet welds are given in Figure 6.

11.2.4 Typical Joints. Qualification of any groove weld shown in Annex G provides qualification for any groove or fillet weld. Qualification of any fillet weld shown in Annex G provides qualification for any fillet weld. Qualification of a fillet weld does NOT provide qualification for a groove weld.

11.3 Limitations of Braze Welder and Braze Welding Operator Qualifications. The limits of essential variables governing braze welder and braze welding operator qualifications are described in 11.3.1 through 11.3.10.

11.3.1 Base Metal. A change from one of the following base-metal groups to another or a change to a weld between dissimilar metals requires separate qualification:

- (1) Carbon steel with 0.30% maximum carbon and 0.50% maximum chromium
- (2) High-strength, low-alloy steels

- (3) Chromium and chromium-nickel stainless steels
- (4) Copper and copper alloys
- (5) Nickel and nickel alloys
- (6) Aluminum and aluminum alloys
- (7) Titanium and titanium alloys

11.3.2 Coating Material. The addition or change, but not deletion, of coating material on the base metal requires requalification. Anti-spatter compound is not considered a coating material.

11.3.3 Base Metal Thickness

(1) A change in thickness to less than $0.5T$ or to greater than $2T$, where T is the thickness of the thinner base metal qualified, requires requalification.

(2) As an alternate to 11.3.3(1), the following qualification tests may be used to cover the complete range of all sheet metal thicknesses as defined in Annex C.

(a) A qualification braze weld performed on 18 gage metal shall provide qualification for the welder or welding operator for metal 16 gage and thinner (see Annex C for equivalents).

(b) A qualification braze weld performed on 10 gage metal shall provide qualification for the welder or welding operator for metal as thin as 16 gage and thicker, up to 6.07 mm [0.239 in] max. thicknesses (see Annex C for equivalents).

11.3.4 The omission, but not the addition, of backing material requires requalification. Shielding gas is not considered a backing material.

11.3.5 A change in filler metal “F” number requires requalification (see Annex A, Table A.1).

11.3.6 A change in braze welding process, or a change in the method of application (manual, semiautomatic, automatic) requires requalification, except as noted below:

- (1) Qualification for manual braze welding also qualifies for semiautomatic and automatic application.
- (2) Qualification for semiautomatic braze welding also qualifies for automatic, but not for manual application.
- (3) Qualification for automatic braze welding qualifies for automatic braze welding only.

11.3.7 Changes in the type of welding current or polarity, as indicated below, requires requalification:

- (1) AC to DC, or vice versa.
- (2) DCEN to DCEP, or vice versa.

11.3.8 For GMAW, a change in the mode of metal transfer, as indicated below, requires requalification:

- (1) Short circuiting transfer to any other mode of metal transfer.
- (2) Any mode of metal transfer to short circuiting transfer.

11.3.9 Shielding Gas

11.3.9.1 Deletion, but not the addition, of backing gas requires requalification.

11.3.10 Position Qualification. Changes in the welding position (see Figures 5 and 6) require requalification, other than listed below:

- (1) Qualification in the 1G or 1F position shall qualify the welder or welding operator only in the flat position.
- (2) Qualification in the 2G or 2F position shall qualify the welder or welding operator in both the flat and horizontal positions.
- (3) Qualification in the 3G or 3F position (with downhill progression) shall qualify the welder or welding operator in the flat, horizontal, and vertical positions (with downhill progression only).

(4) Qualification in the 3G or 3F position (with uphill progression) shall qualify the welder or welding operator in the flat, horizontal, and vertical positions (with either uphill or downhill progression).

(5) Qualification in the 4G or 4F position shall qualify the welder or welding operator in the flat, horizontal, vertical (with downhill progression only), and overhead positions.

(6) Qualification in the 3G or 3F position (with uphill progression) and the 4G or 4F positions respectively, shall qualify the welder or welding operator in all positions (with either uphill or downhill progression).

11.4 Inspection of Braze Welder and Braze Welding Operator Qualification Test Braze Welds. Inspection of all test braze welds shall be visual, without aid of magnification. (Prescription eyeglasses for vision correction are acceptable.) Except for the first and last 13 mm [0.5 in], braze welds shall exhibit the following:

- (1) Metallic bonding shall be adequate for the intended application;
- (2) Face reinforcement of butt joint braze welds shall be a minimum of $0.5T$, when T is the thickness of the thinner base metal and shall not exceed 3.2 mm [1/8 in]. Root reinforcement shall not exceed 3.2 mm [1/8 in];
- (3) For fillet braze welds, the minimum effective throat shall be as specified for the application. Convexity shall not exceed 3.2 mm [1/8 in];
- (4) No more than one visible pore or inclusion in any 25 mm [1 in] of weld. The size of any pore or inclusion shall not exceed $0.25T$, where T is the thickness of the thinner member; and
- (5) No cracks.

11.5 Responsibility for Qualification

11.5.1 Each Contractor shall be responsible for the qualification of braze welders or braze welding operators, whether the qualification testing is conducted by the manufacturer, Contractor, or an independent third party, subject to the following conditions:

- (1) The braze welder was qualified meeting all of the braze welder qualification requirements of this code,
- (2) The requirements of 11.6 shall be met, and
- (3) The Contractor shall assume specific responsibility for the welder qualification by signing and dating the Welder Qualification Test Record (see Annex F).

11.5.2 Records of welder or welding operator qualification testing in accordance with this code shall be maintained by the Contractor and shall be available for inspection as required by the Engineer, the Owner, or their representative (see Annexes D and E for suggested forms). All required information for braze welder or braze welding operator qualification shall be recorded on an adequate form similar to the recommended form shown as Annex F.

11.6 Duration of Qualification. Qualification of braze welders or braze welding operators tested to the requirements of this code shall remain in effect unless:

- (1) The braze welder or braze welding operator has not been engaged in performing braze welding operations utilizing the process for which the welder originally qualified for a period exceeding twelve months.
- (2) There is a specific reason to question the braze welder's or braze welding operator's ability.

12. Braze Welding Workmanship

Work performed under this code shall exhibit qualities of workmanship described below.

12.1 Uniformity

12.1.1 Surfaces to be joined shall be uniform and free from cracks.

12.1.2 A thin layer of filler metal may flow irregularly beyond the weld area. Unless otherwise specified by contract, this flow should not be a cause for rejection.

12.2 Joint Cleanliness

12.2.1 Joint surfaces, as well as surfaces adjacent to a joint, shall be free of loose scale, oxides, rust, grease, oil, and foreign matter.

12.2.2 Tightly adherent spatter is not a cause for rejection.

12.3 Position. If a welding position is not specified explicitly by the Engineer or dictated by a job condition, joints shall be braze welded in the most favored position for which both the procedure and the braze welder or braze welding operator are qualified.

12.4 Current and Polarity. Welding current and polarity shall be in accordance with the qualified braze welding procedure.

12.5 Inspection of Workmanship. Welds shall be inspected visually and shall meet the acceptance criteria of Clause 13, Inspection of Production Braze Welding Work.

13. Inspection of Production Braze Welding Work

Inspection of all production braze welds shall be visual, without aid of magnification. (Prescription eyeglasses for vision correction are acceptable.)

Acceptance criteria for production braze welds different from those specified in this code may be used for a particular application, provided they are suitably documented and approved by the Engineer.

The Contractor shall conduct inspections to ensure conformance to the acceptance criteria. The Owner, Owner's Representative, or Engineer shall have the option to inspect the Contractor's workmanship. The specified acceptance criteria for the work shall be as follows:

13.1 Bonding. Metallic bonding, adequate for the intended application shall be obtained (see 1.1.3).

13.2 Reinforcement of Groove Braze Welds. A maximum of 3.2 mm [1/8 in] face reinforcement and 3.2 mm [1/8 in] root reinforcement shall be acceptable.

13.3 Throat and Convexity of Fillet Braze Welds. The minimum effective throat shall be as specified for the application with maximum convexity not to exceed 3.2 mm [1/8 in] (see 1.1.3).

13.4 Porosity or Inclusions. Some limited porosity or inclusions are acceptable, consistent with 11.1 and limited to the following:

(1) One visible pore or inclusion no larger than $0.5T$ is permitted in any 25 mm [1 in], where T is the thickness of the thinner member.

(2) Three visible pores or inclusions no larger than $0.25T$ are also permitted in any 25 mm [1 in] where T is the thickness of the thinner member.

13.5 Cracks. There shall be no cracks.

13.6 Conformance. Completed braze welds shall be inspected visually for location, size, and length, in accordance with the engineering drawing and specification requirements. (*Note: In braze welding, minute surface contamination is frequently observed and is not a basis for rejection.*)

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Annex A (Informative)

Recommended Filler Metals

This annex is not part of AWS D9.1M/D9.1:2012, *Sheet Metal Welding Code*,
but is included for informational purposes only.

Table A.1
F Number Grouping of Welding Electrodes and Rods

F-No.	AWS Specification	AWS Classification
Steel		
1	A5.1	EXX20, EXX22, EXX24, EXX27, EXX28
	A5.4	EXXX(X)-26
	A5.5	EXX20- <u>XX</u> , EXX27- <u>XX</u>
2	A5.1	EXX12, EXX13, EXX14, EXX19
	A5.5	E(X)XX13- <u>XX</u>
3	A5.1	EXX10, EXX11
	A5.5	E(X)XX10- <u>XX</u> , E(X)XX11- <u>XX</u>
4	A5.1	EXX15, EXX16, EXX18, EXX18M, EXX48
	A5.4 other than austenitic and duplex	EXXX(X)-15, EXXX(X)-16, EXXX(X)-17
	A5.5	E(X)XX15- <u>XX</u> , E(X)XX16- <u>XX</u> , E(X)XX18- <u>XX</u> , E(X)XX18M, E(X)XX18M1, <u>E(X)XX45-P2</u>
5	A5.4 austenitic and duplex	EXXX(X)-15, EXXX(X)-16, EXXX(X)-17
6	A5.2	<u>RX</u> Classifications
	A5.9	All Classifications
	A5.17/A5.17M	All Classifications
	A5.18	All Classifications
	A5.20	All Classifications
	A5.22	All Classifications
	A5.23/A5.23M	All Classifications
	<u>A5.25</u>	<u>All Classifications</u>
	<u>A5.26</u>	<u>All Classifications</u>
	A5.28	All Classifications
	A5.29	All Classifications
	<u>A5/30</u>	<u>INMs-X, IN5XX, IN3XX(X)</u>
	<u>A5.36</u>	<u>All Classifications</u>

(Continued)

Table A.1 (Continued)
F Number Grouping of Welding Electrodes and Rods

F-No.	AWS Specification	AWS Classification
Aluminum and Aluminum Alloys		
21	A5.3/A5.3M	E1100, E3003
	A5.10	ER1100, R1100, ER1188, R1188
22	A5.10	ER5183, R5183, ER5356, R5356, ER5554, R5554, ER5556, R5556, ER5654, R5654
23	A5.3/A5.3M	E4043
	A5.10	ER4009, R4009, ER4010, R4010, R4011, ER4043, R4043, ER4047, R4047, ER4145, R4145, ER4643, R4643
24	A5.10	R206.0, R-C355.0, R-A356.0, R357.0, R-A357.0
25	A5.10	ER2319, R2319
Copper and Copper Alloys		
31	A5.6 and A5.7	ECu, ERCu
32	A5.6 and A5.7	ECuSi, ERCuSi-A
33	A5.6 and A5.7	ECuSn-A, ECuSn-C, ERCuSn-A
34	A5.6, A5.7, and A5.30	ECuNi, ERCuNi, IN67
35	A5.8	RBCuZn-A, RBCuZn-B, RBCuZn-C, RBCuZn-D
36	A5.6 and A5.7	ERCuAl-A1, ERCuAl-A2, ERCuAl-A3, ECuAl-A2, ECuAl-B
37	A5.6 and A5.7	ECuNiAl, ECuMnNiAl, ERCuNiAl, ERCuMnNiAl
Nickel and Nickel Alloys		
41	A5.11/A5.11M, A5.14/A5.14M, and A5.30	ENi-1, ERNi-1, IN61
42	A5.11/A5.11M, A5.14/A5.14M, and A5.30	ENiCu-7, ERNiCu-7, ERNiCu-8, IN60
43	A5.11/A5.11M, A5.14/A5.14M, and A5.30	ENiCrFe-1, 2, 3, 4, 7, 9, 10, and <u>12</u> , ENiCrMo-2, 3, 4, <u>5</u> , 6, <u>7</u> , 10, 12, <u>13</u> , 14, 17, 18, and 19, ENiCrCoMo-1, ENiCr-4, ENiCrWMo-1, ERNiCr-3, 4, and 6, ERNiCrFe-5, 6, 7, 7A, 8, 11, and 12, ERNiCrCoMo-1, ERNiCrMo-2, 3, 4, 7, 10, 13, 14, 16, 17, 18, 19, 20, and 21, ERNiCrFeAl-1, ERNiCrWMo-1, IN6A, IN62, IN82, <u>IN52</u>
44	A5.11/A5.11M and A5.14/A5.14M	ENiMo-1, 3, 7, 8, 9, 10, and <u>11</u> , ENiCrMo-1, 2, 3, 7, 8, 9, 10, <u>11</u> , and <u>12</u>
45	A5.11/A5.11M and A5.14/A5.14M	ENiCrMo-1, 9, and 11, ERNiCrMo-1, 8, 9, and 11, ERNiFeCr-1
<u>46</u>	<u>A5.11/A5.11M and A5.14/A5.14M</u>	<u>ENiCrFeSi-1, ERNiCrFeSi-1, ERNiCoCrSi-1</u>
Titanium and Titanium Alloys		
51	A5.16	ERTi-1, <u>2</u> , 3, 7, 11, 13, 14, 15A, 16, 17, 26, 27, 30, 31, 33, and <u>34</u>
52	A5.16	ERTi- <u>4</u>
53	A5.16	ERTi-9, ERTi-9ELI, <u>ERTi-18</u> , <u>ERTi-28</u>
54	A5.16	ERTi-12
55	A5.16	ERTi-5, <u>23</u> , <u>24</u> , <u>25</u> , and <u>29</u>
<u>56</u>	<u>A5.16</u>	<u>ERTi-32</u>
Zirconium and Zirconium Alloys		
<u>62</u>	A5.24	ERZr2, ERZr3, ERZr4
Hardfacing Weld Metal Overlay		
<u>71</u>	<u>A5.13</u>	<u>EXXX-X</u>
<u>72</u>	<u>A5.21</u>	<u>RXXX-X, ERXX-X, ERCXX-X</u>
Magnesium Alloys		
91	A5.19	<u>ERAZ61A, ERAZ92A, EREZ33A, ERAZ101A, RAZ61A, RAZ92A, RAZ101A, REZ33A</u>

Annex B (Informative)

Supplemental Terms and Definitions

This annex is not part of AWS D9.1M/D9.1:2012, *Sheet Metal Welding Code*,
but is included for informational purposes only.

The terms and definitions in this annex are of significant importance to sheet metal welding and supplement those in the latest edition of AWS A3.0M/A3.0, *Standard Welding Terms and Definitions, Including Terms for Adhesive Bonding, Brazing, Soldering, Thermal Cutting, and Thermal Spraying*.

backing strip. Backing in the form of a strip.

base metal specification. The recognized specification [usually the American Society of Testing and Materials (ASTM)] designating the composition or properties, or both, of the selected base metal.

carbon arc braze welding (CABW). A braze welding process variation that uses an arc between a carbon electrode and the base metal as the heat source.

coating. A relatively thin layer of material applied for the purpose of corrosion prevention, resistance to high-temperature scaling, wear resistance, lubrication, or other purposes.

corner joint, with backing. A joint between two members located approximately at right angles to each other with backing.

corner joint, open. An offset corner joint.

crater crack. A crack in the crater of a weld bead.

defective weld. A weld containing one or more defects.

filler metal classification. The AWS designation of the chosen filler metal, as listed in an AWS Specification, to be inserted in the Procedure Qualification Test Record (see Annex A).

filler metal specification. The AWS Specification number to be inserted in the Procedure Qualification Test Record (see Annex A).

lap joint, offset. A sheet metal joint in which the lap is offset to preserve the alignment of the working surfaces.

open corner joint. An offset corner joint with only a line of contact between the members (see Annex G, Figure GA.12).

partial joint penetration. Joint penetration that is intentionally less than complete.

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

sheet metal. A light gage ferrous or nonferrous metal as thick as 3 gage, 6.07 mm [0.239 in], which may or may not be coated.

slag inclusion. Nonmetallic solid material entrapped in weld metal or between weld metal and base metal.

toe crack. A crack in the base metal occurring at the toe of a weld.

torch braze welding. A braze welding process that uses heat from a fuel gas flame.

weld metal grade. The description of the filler metal (e.g., mild steel, chromium-nickel steel, aluminum) to be inserted, as required, when the filler metal has no AWS classification.

welding process. A joining process that produces coalescence of materials by heating them to suitable temperatures, with or without the application of pressure alone, and with or without the use of filler metal.

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Annex C (Informative)

Gage Numbers and Equivalent Thicknesses in SI Units and U.S. Customary Units

This annex is not part of AWS D9.1M/D9.1:2012, *Sheet Metal Welding Code*,
but is included for informational purposes only.

Table C.1
Hot-Rolled and Cold-Rolled Steel Sheet

Manufacturer's Standards Gage No.	Thickness	
	mm	in
3	6.07	0.2391
4	5.70	0.2242
5	5.31	0.2092
6	4.94	0.1943
7	4.55	0.1793
8	4.18	0.1644
9	3.80	0.1495
10	3.42	0.1345
11	3.04	0.1196
12	2.66	0.1046
13	2.78	0.0897
14	1.90	0.0747
15	1.71	0.0673
16	1.52	0.0598
17	1.37	0.0538
18	1.21	0.0478
19	1.06	0.0418
20	0.91	0.0359
21	0.84	0.0329
22	0.76	0.0299
23	0.68	0.0269
24	0.61	0.0239
25	0.53	0.0209
26	0.46	0.0179
27	0.42	0.0164
28	0.38	0.0149

Table C.2
Galvanized Steel Sheet

Galvanized Sheet Gage No.	Thickness	
	mm	in
8	4.27	0.1681
9	3.89	0.1532
10	3.51	0.1382
11	3.13	0.1233
12	2.75	0.1084
13	2.37	0.0934
14	1.99	0.0785
15	1.80	0.0710
16	1.61	0.0635
17	1.46	0.0575
18	1.31	0.0516
19	1.16	0.0456
20	1.01	0.0396
21	0.93	0.0366
22	0.85	0.0336
23	0.78	0.0306
24	0.70	0.0276
25	0.63	0.0247
26	0.55	0.0217
27	0.51	0.0202
28	0.48	0.0187
29	0.44	0.0172
30	0.40	0.0157
31	0.36	0.0142
32	0.34	0.0134

Table C.3
Stainless Steel Sheet

Manufacturers' Standard Gage No.	Thickness	
	mm	in
8	4.37	0.1719
9	3.97	0.1563
10	3.57	0.1406
11	3.18	0.1250
12	2.78	0.1094
13	2.38	0.0938
14	1.98	0.0781
15	1.79	0.0703
16	1.59	0.0625
17	1.43	0.0563
18	1.27	0.0500
19	1.11	0.0438
20	0.95	0.0375
21	0.87	0.0344
22	0.80	0.0313
23	0.71	0.0281
24	0.64	0.0250
25	0.56	0.0219
26	0.48	0.0188
27	0.44	0.0172
28	0.40	0.0156
29	0.36	0.0141
30	0.32	0.0125
31	0.28	0.0109

Table C.4
Aluminum and Aluminum Alloy Sheet

Browne and Sharp Gage No.	Thickness	
	mm	in
8	3.26	0.1285
9	2.91	0.1144
10	2.59	0.1019
11	2.30	0.0907
12	2.05	0.0808
13	1.83	0.0720
14	1.63	0.0641
15	1.45	0.0571
16	1.29	0.0508
17	1.15	0.0453
18	1.02	0.0403
19	0.91	0.0359
20	0.81	0.0320
21	0.72	0.0285
22	0.64	0.0253
23	0.57	0.0226
24	0.51	0.0201
25	0.45	0.0179
26	0.40	0.0159
27	0.36	0.0142
28	0.32	0.0126
29	0.29	0.0113
30	0.25	0.0100
31	0.23	0.0089

Table C.5
Copper and Copper Alloy Sheet

Weight per		Thickness	
square meter (kg)	square foot (oz)	mm	in
14.5	48	1.64	0.0645
9.7	32	1.09	0.0431
7.3	24	0.82	0.0323
6.1	20	0.69	0.0270
4.9	16	0.55	0.0216
3.6	12	0.41	0.0161
2.4	8	0.27	0.0108

Annex D (Informative)

Welding Procedure Specification (WPS) Form

This annex is not part of AWS D9.1M/D9.1:2012, *Sheet Metal Welding Code*,
but is included for informational purposes only.

WPS Number _____ Supported by PQR No.(s) _____
WPS Rev. No. _____ WPS Rev. Date _____

VARIABLES

Base metal _____
Metal thickness _____
Coating type _____
Joint preparation _____
Backing material _____
Position of welding _____
Welding process _____
Manual, semiautomatic, or automatic _____
*Filler metal spec. _____
*Filler metal class/weld metal grade _____
Filler metal F Number _____
Electrical characteristics _____ ac _____ dcep _____ dcen _____
Mode of transfer _____
Shielding gas/combination _____
Gas flow L/min [CFH] _____
*See Definitions

JOINING PROCEDURE

Filler Metal Size	Welding Power		Speed of Travel	Joint Detail
	Current Range	Voltage Range		

Manufacturer or Contractor _____

Signature _____

Date _____

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Annex E (Informative)

Procedure Qualification Record (PQR) Form

This annex is not part of AWS D9.1M/D9.1:2012, *Sheet Metal Welding Code*,
but is included for informational purposes only.

VARIABLES

Base metal _____ Metal thickness _____ Coating _____ Joint preparation _____ Backing _____ Position of welding _____ Welding process _____ Manual, semiautomatic, or automatic _____ *Filler metal spec. _____ *Filler metal class. _____ Filler metal F No. _____ Electrical char. _____ ac _____ dcep _____ dcen _____ Mode of transfer _____ Shielding gas/combination _____ Gas flow L/min [CFH] _____ Welder's name _____ Welder's ID no. _____ *See Definitions	PQR Number _____ WPS Number _____ Weld in butt joint visual exam results (see 5.4.1 or 10.4.1) _____ Fusion _____ Penetration _____ Reinforcement _____ Porosity _____ Undercut _____ Cracks _____ Fillet weld visual exam results (see 5.4.2 or 10.4.2) _____ Fusion _____ Effective throat _____ Convexity _____ Porosity _____ Undercut _____ Cracks _____
--	--

JOINING PROCEDURE

Filler Metal Size	Welding Power		Speed of Travel	Joint Detail
	Current Range	Voltage Range		

We, the undersigned, certify that the statements in this record are correct and that the test specimens were prepared, joined, and examined in accordance with the requirements of AWS D9.1M/D9.1, *Sheet Metal Welding Code*.

Manufacturer or Contractor _____

Signature _____

Date _____

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Annex F (Informative)

Welder and Welding Operator Qualification Test Record Form

This annex is not part of AWS D9.1M/D9.1:2012, *Sheet Metal Welding Code*,
but is included for informational purposes only.

QUALIFICATION TEST PERFORMED

Name _____ WPS number _____
 I.D. no. _____ Square groove (butt joint) _____
 Date of Welding Test _____ Fillet _____
 Date of Knowledge Test _____ Weld test _____
☐ Oral ☐ Written ☐ Passed ☐ Failed Braze weld test _____

ESSENTIAL VARIABLES QUALIFIED BY TEST

Types of base metal _____ Welding process _____
 _____ Mode of transfer (GMAW) _____
 Coating material on sheet ☐ yes ☐ no Welding current _____
 Backing material _____ ☐ ac ☐ dcep ☐ dcen
 Filler metal F number _____ Shielding gas used _____
 Method of application _____ Position welded _____
☐ manual ☐ semi-auto ☐ auto ☐ flat ☐ horz ☐ vert ☐ overhead

VISUAL INSPECTION RESULTS

Square Groove (Butt Joint) Weld	Acceptance Criteria			
	Weld		Braze Weld	
	Yes	No	Yes	No
Joint Fusion (metallic bond)				
Required joint penetration			NA	NA
Face reinforcement				
More than one pore or inclusion over 0.25T				
Undercut exceeding 0.15T			NA	NA
Cracks				

Fillet Weld	Acceptance Criteria			
	Weld		Braze Weld	
	Yes	No	Yes	No
Joint Fusion (metallic bond)				
Required minimum effective throat				
Required maximum convexity				
Pore or inclusion over 0.25T				
Undercut exceeding 0.15T, or 0.25T			NA	NA
Cracks				

Thickness range qualified _____
 Position qualified _____

Inspection performed by _____
 Types of joints qualified _____

We, the undersigned, certify that the statements in this record are correct and that the test specimens were prepared, joined, and examined in accordance with the requirements of AWS D9.1M/D9.1, *Sheet Metal Welding Code*.

Manufacturer or Contractor _____

Signature _____

Date _____

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Annex G (Informative)

Joint Design and Details

This annex is not part of AWS D9.1M/D9.1:2012, *Sheet Metal Welding Code*, but is included for informational purposes only.

Following are some of the typical welds that are commonly used in sheet metal fabrication. These welds are grouped into groove and fillet types for use in qualifying procedures and welders.

Groove Welds—Arc Welding

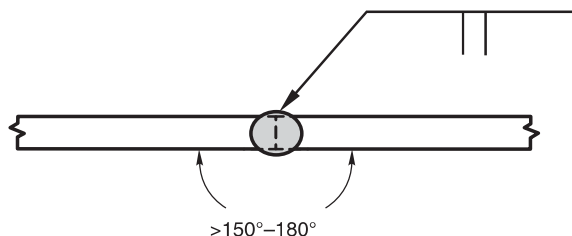


Figure GA.1—Square-Groove Weld

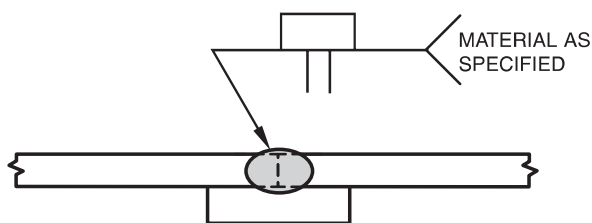


Figure GA.2—Square-Groove Weld with Backing

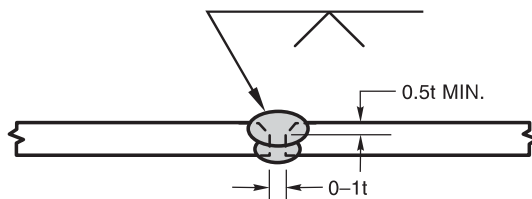


Figure GA.3—Single-V-Groove Weld

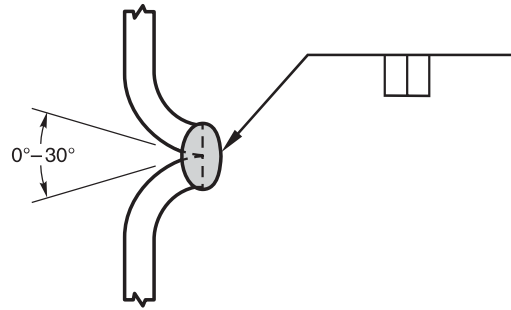


Figure GA.4—Edge Weld (in a Flanged Joint)

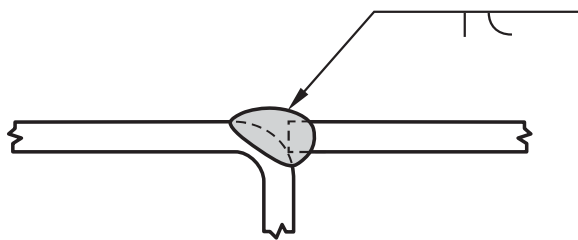


Figure GA.5—Flare-Bevel-Groove Weld (in T-Joint or Inside Corner Joint)

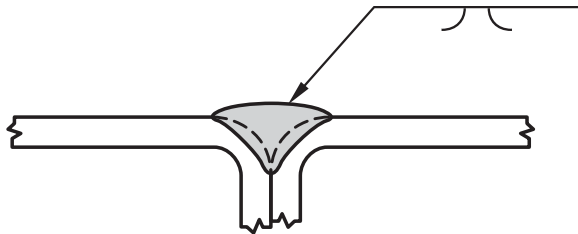


Figure GA.6—Flare-V-Groove Weld

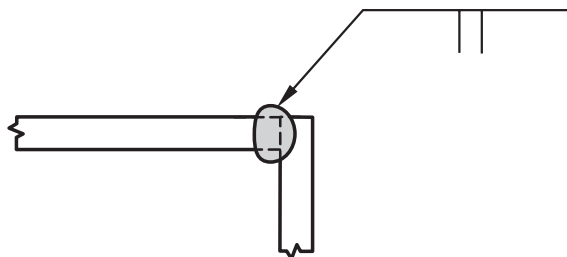


Figure GA.7—Square-Groove Corner Weld

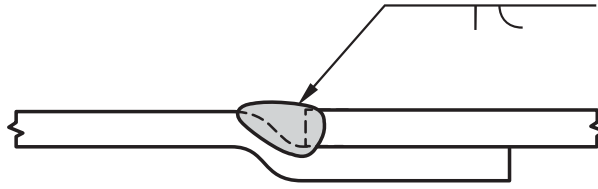


Figure GA.8—Flare-Bevel Weld (in an Offset Lap Joint)

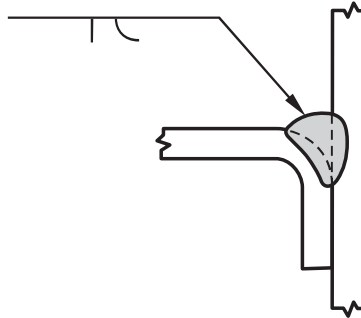


Figure GA.9—Flare-Bevel-Groove Weld

Fillet Welds—Arc Welding

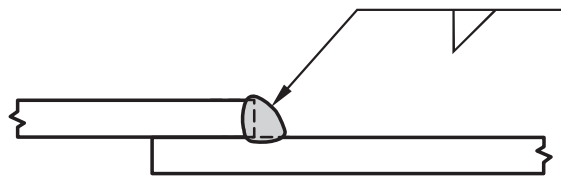


Figure GA.10—Plain Lap Joint Fillet Weld

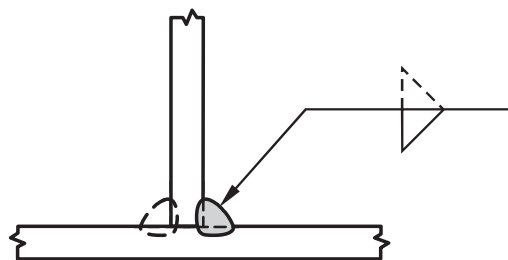
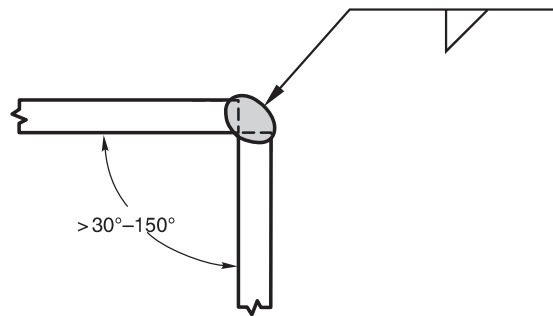


Figure GA.11—Fillet Weld in T-Joint (One or Both Sides)



**Figure GA.12—Fillet Weld in Open (Offset) Corner Joint
(Angle May Vary from 90°)**

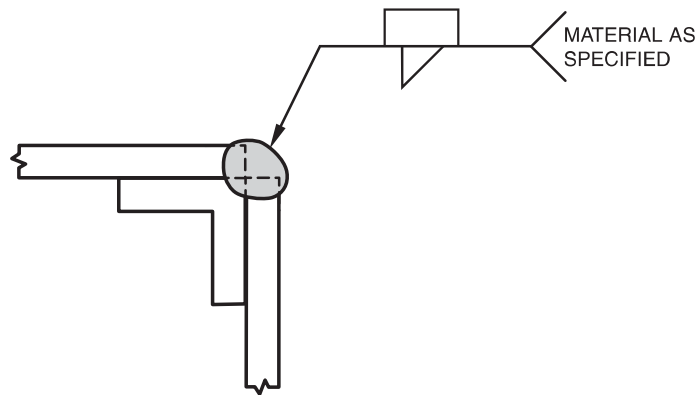


Figure GA.13—Corner Weld with Backing

Braze Welding

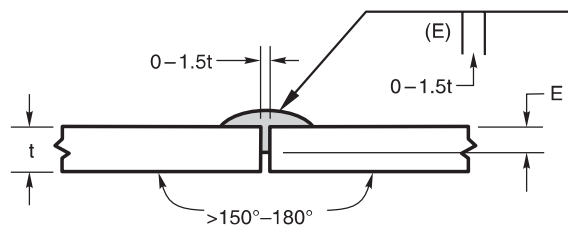


Figure GB.1—Square-Groove Braze Weld

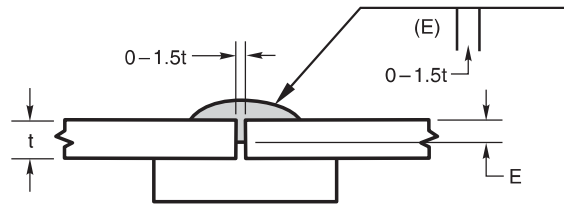


Figure GB.2—Square-Groove Braze Weld with Backing

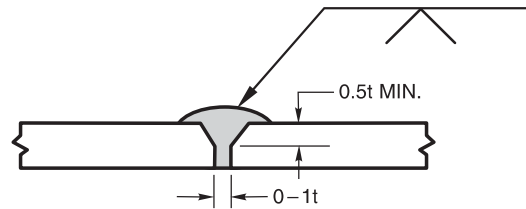


Figure GB.3—Single-V-Groove Braze Weld

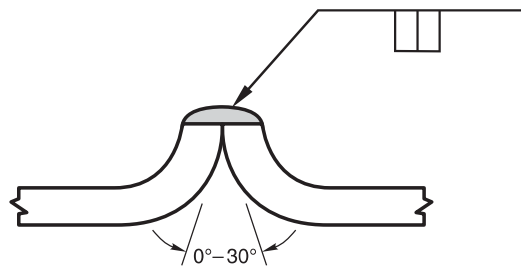


Figure GB.4—Edge Braze Weld (in a Flanged Joint)

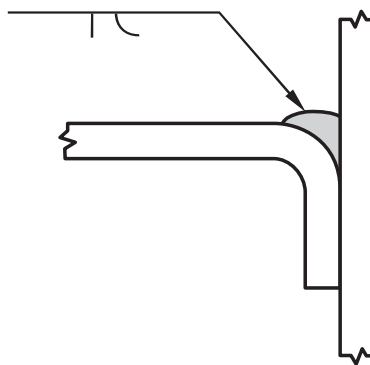


Figure GB.5—Flare-Bevel-Groove Braze Weld (in T-Joint or Inside Corner)

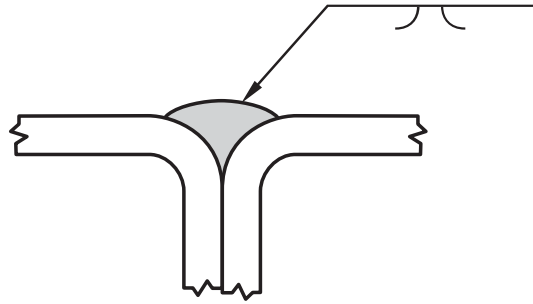


Figure GB.6—Flare-V-Groove Braze Weld

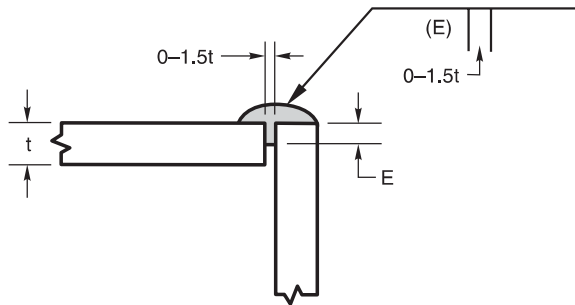


Figure GB.7—Square-Groove Corner Braze Weld

Fillet Braze Welds

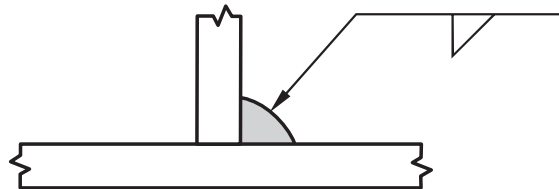
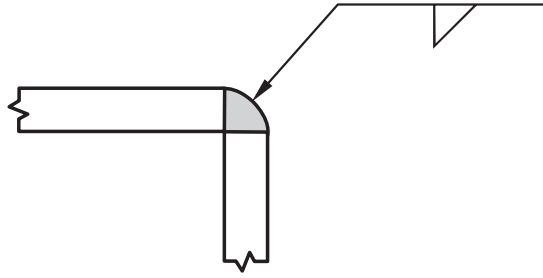


Figure GB.8—Fillet Braze Weld T-Joint



**Figure GB.9—Fillet Braze Weld in Open (Offset) Corner Joint
(Angle May Vary from 90°)**

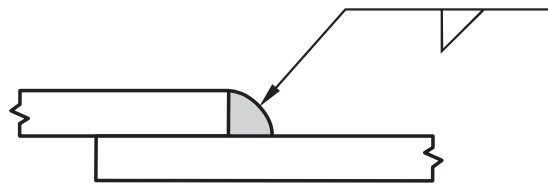


Figure GB.10—Plain Lap Joint Braze Weld

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Annex H (Informative)

Recommended Arc Welding Practices

This annex is not part of AWS D9.1M/D9.1:2012, *Sheet Metal Welding Code*, but is included for informational purposes only.

H1. Introduction

These recommended practices have been prepared by the AWS D9 Committee on Welding, Brazing, and Soldering of Sheet Metal. It has long been recognized that the welding of sheet metal has its own particular techniques. The Committee does not propose that these recommended practices are the only possible methods of welding sheet metal. The recommended practices are of a general nature and are offered only as guidelines indicative of sheet metal industry experience. There are, of course, many variations of sheet metal welding. Therefore, some of the practices contained herein may, in some instances, be subject to the manufacturer's discretion. Additional information may be found in Volume 2, Ninth Edition, *AWS Welding Handbook*, and the latest editions of AWS C5.1, *Recommended Practices for Plasma Arc Welding*, and AWS C5.6, *Recommended Practices for Gas Metal Arc Welding*. welded joints and seams. This was usually both slow and expensive.

H2. Brief History of Sheet Metal Arc Welding

The term *sheet metal* is usually associated with very thin galvanized sheet steel. Actually, *sheet metal* can mean a coated or uncoated ferrous or nonferrous metal as thick as 3 gage, 6.07 mm [0.239 in].

For many years after welding had become everyday practice in structural steel work, heavy wall pipe, and pressure vessel work, the sheet metal industry was still joining thin materials with riveted and soldered joints and various sheet metal locks and seams. In a few instances the sheet metal industry gas welded or braze welded joints and seams. This was usually both slow and expensive.

With the introduction of low voltage power sources and smaller diameter electrodes for SMAW and the development of the GMAW, GTAW, and PAW processes, welding became a practical method of joining sheet metal components. As the equipment and processes became more versatile, the practice of arc welding increased in the sheet metal industry to a point that today, virtually all sheet metal shops use arc welding equipment.

In today's marketplace, one will find an abundance of welded components in heating, ventilating, and air conditioning; industrial sheet metal applications; food and beverage dispensing systems; food processing equipment; air pollution and "airveyor" systems; and architectural metal installations.

H3. Fit-Up

Fit-up is important in sheet metal welding because of the thinness of the base metal. Gaps that occur from hand cutting of contours and radii may cause the molten weld pool (puddle) to fall through because the base metal edges melt. This problem is significantly magnified when a job requires welding out of position. Backing may be used in sheet metal welding to compensate for poor fit-up, but this is costly, time consuming, and gives the appearance of poor workmanship. Additional time should be taken on fit-up to facilitate good weldments. Because thin sheet metal warps from welding heat, tack welds should be placed closer together, in some cases as close as 51 mm [2 in] or less from each other.

H4. Processes

H4.1 Shielded Metal Arc Welding (SMAW). Shielded metal arc welding is used extensively in the sheet metal industry. Its versatility lends itself to all position welding of ferrous and nonferrous metals, including galvanized metal. However, the level of skill required to weld metals thinner than 3.2 mm [1/8 in] increases as the thickness of metal decreases. Electrodes are produced in 2.0 mm [5/64 in] and 1.6 mm [1/16 in] diameter which may be used with currents as low as 20 A. Table H.1 presents suggested current ranges for welding sheet metal of various gages.

H4.1.1 Power Sources. Sheet metal is welded with either direct current (dc) or alternating current (ac). The power supply or welding machine should deliver the low current ranges needed for sheet metal with a steep (drooping) volt-ampere characteristic and high open-circuit voltage, so changes in arc length will produce little change in current output. Gasoline or diesel engine-driven power sources can be used for on-site welding.

H4.1.2 Technique. When arc welding sheet metal, the highest current that does not cause excessive melt-through should be used. The welder should determine the current setting and travel speed on scrap test pieces to avoid damage or faulty welds on the actual job.

The welder should also tilt the electrode in the direction of travel more than would be required for thicker plates. For fillet welds in T-joints or lap joints between sheet metal and thicker reinforcing or backing metal, the arc should be concentrated mostly on the thicker member to create a fillet with an effective throat equal to the thickness of the sheet metal, without burning through the thinner member.

H4.1.3 Welding Carbon Steel and Low-Alloy Steel Sheet Metal. Electrodes designed specifically for light sheet metal work in carbon steel are only available as a standard commercial product in Classifications EXX12 and EXX13 (see the latest edition of AWS A5.1, *Specification for Carbon Steel Electrodes for Shielded Metal Arc Welding*). The EXX12 electrodes operate on ac and dc electrode negative (straight polarity). The EXX13 electrodes operate on ac and dc, either electrode negative (straight polarity) or electrode positive (reverse polarity). Electrode positive (reverse polarity), however, is not normally used for sheet metal welding because of the deeper penetrating characteristics of the arc using that polarity. The 2.4 mm [3/32 in] diameter electrode is the smallest electrode size available in some carbon and alloy steel electrode classifications, thus restricting their application to metals thicker than approximately 16 gage, 1.6 mm [0.063 in]. Table H.1 presents suggested current ranges for welding sheet metal of various gages.

Electrodes should be stored under conditions that prevent the accumulation of excessive moisture content in the coating. Electrodes are manufactured with their moisture content within acceptable limits, consistent with the type of covering and the strength of the weld metal. They are packaged in containers designed to provide the degree of moisture protection needed. Table H.2 gives typical storage conditions for various AWS electrode classifications. Some of these are seldom used for sheet metal welding because of their deep penetration characteristics or the unavailability of small diameter electrodes, but the complete table has been reproduced for reference. It is prudent to follow the electrode manufacturer's storage recommendations.

H4.1.4 Welding Stainless Steel Sheet Metal. Shielded metal arc welding is commonly used to join stainless steel sheet metal. Electrodes are available in sizes as small as 1.6 mm [1/16 in] in all compositions (see the latest edition of AWS A5.4, *Specification for Stainless Steel Electrodes for Shielded Metal Arc Welding*). Classification EXXX-15 is used only with DCEP polarity. Classifications EXXX-16 and EXXX-17 are used with AC or DCEP or DCEN polarity.

Table H.1
Suggested Covered Electrode Size for Various Currents and Gages

Electrode Diameter		Welding Current A ^a	Thickness of Metal to be Welded
mm	in		
1.6	1/16	20 to 40	20 to 16 gage
2.0	5/64	25 to 60	18 to 14 gage
2.4	3/32	35 to 85	16 to 12 gage
3.2	1/8	80 to 130	14 to 7 gage

^a Irrespective of polarity.

Table H.2
Typical Storage and Drying Conditions for Covered Arc Welding Electrodes

AWS Classification	Storage Conditions ^a		Drying Conditions ^b
	Ambient Air	Holding Ovens	
EXX10, EXX11	Ambient temperature	Not recommended	Not recommended
EXX12, EXX13, EXX19, EXX20, EXX22, EXX27, EXX14, EXX24, EXX27	30°C ± 10°C [80°F ± 20°F] 50% max. relative humidity	12°C [20°F] to 24°C [40°F] above ambient temperature	1 hour at temperature 135°C ± 15°C [275°F ± 25°F]
EXX15, EXX16, EXX18, EXX28, EXX18M, EXX48	Not Recommended ^c	30°C [50°F] to 140°C [250°F] above ambient temperature	2 hours at temperature 260°C to 427°C [500°F to 800°F]

^a After removal from manufacturer's packaging.

^b Because of inherent differences in covering composition, the manufacturers should be consulted for the exact drying conditions.

^c Some of these electrode classifications may be designated as meeting low moisture absorbing requirements. This designation does not imply that storage in ambient air is recommended.

The electrode classification should be chosen to match the composition of the base metal. There are more than 30 different compositions in AWS A5.4 to provide the correct composition and properties to match a variety of sheet metal weldments. In general, a matching type is used: for example, Type 410 stainless steel is welded with E410-15, -16, or -17 electrodes; Types 302 and 304 are welded with E308-15, -16, or -17 electrodes, or E308L -15, -16, or -17 electrodes. In the case of 300 series stainless steel, it is often helpful to water quench the welds in order to control distortion. Specific instructions are usually given in customer's job specification and drawings.

H4.1.5 Welding Aluminum Sheet Metal. Shielded metal arc welding of aluminum sheet metal is not recommended. Better results can be obtained with other processes, particularly gas metal arc (pulsed spray welding), gas tungsten arc, and plasma arc welding.

H4.1.6 Welding Copper Sheet Metals. As in welding aluminum sheet metal, better results can be obtained using gas metal arc (pulsed spray welding), gas tungsten arc, and plasma arc welding.

H4.2 Gas Metal Arc Welding (GMAW). This process is used extensively for welding sheet metal. The process uses a continuous wire filler metal which also serves as a terminal for the electric arc. GMAW operates on electrode positive (reverse polarity). An external gas is used to shield the arc and molten weld pool. The shielding gases have a dual purpose: protecting the arc and weld zone from air, and providing the desired arc characteristics. Various gases are used, depending upon the metal reactivity and nature of the joint being welded. Caution should be exercised that GMAW is not performed in a draft or direct wind strong enough to dissipate the gas shield. This condition may be avoided by protecting the weld with an adequate shelter of appropriate material and shape. Various power supplies have been developed to expand the versatility of the process for sheet metal applications (see Table H.3).

The gas metal arc welding process provides the following benefits:

- (1) The reduced amount of fume and smoke is more comfortable to a welder, and the molten weld pool (puddle) can be seen more clearly;
- (2) There are no slag inclusions;
- (3) Little or no postweld cleaning is required;
- (4) A continuous spooled welding wire is used, and there is almost no filler metal waste;
- (5) The wire feeder controls automatically maintain a steady wire feed rate;
- (6) The absence of flux on the filler metal wire makes humidity less of a problem during electrode wire storage; and
- (7) The pulsed spray and short circuiting arc ("dip," "short arc") variations give the welder excellent control of the weld bead and will produce strong, neat welds in all positions on light gage metal.

Table H.3
Suggested Welding Conditions for Carbon Steel and Low Alloy Steel Sheet Metal

GMAW Process Variation	Wire Diameter		Operating Current Range A	Operating Voltage Range V	Thickness of Metal to be Welded		Shielding Gas	Gage
	mm	in			mm	in		
Pulsed spray	0.9	0.035	60–200	15–23	1.0 to 3.2	0.039 to 0.125	<5%–15% CO ₂ , Balance Argon [AWS A5.32 (ISO 14175)-M20-ArC-5 through M20-ArC-15]	20 to 11
	1.2	0.045	90–300	17–28	1.6 to 4.8	0.062 to 0.187		16 to 7
	1.6	1/16	110–300	18–30	4.8 and over	0.187 and over	<15%–20% CO ₂ , Balance Argon [AWS A5.32 (ISO 14175)-M21-ArC-16 through M21-ArC-20]	7 and over
Spray transfer	0.8	0.030	150–260	25–31	2.8 to 4.6	0.11 to 0.18	<5%–15% CO ₂ , Balance Argon [AWS A5.32 (ISO 14175)-M20-ArC-5 through M20-ArC-15]	12 to 7
	0.9	0.035	125–300	20–28	1.0 to 3.2	0.039 to 0.125		20 to 11
	1.2	0.045	155–450	22–32	1.6 to 4.8	0.062 to 0.187	<15%–20% CO ₂ , Balance Argon [AWS A5.32 (ISO 14175)-M21-ArC-16 through M21-ArC-20]	16 to 7
	1.6	1/16	210–500	24–34	4.8 and over	0.187 and over	or 2%–5% O ₂ , Balance Argon [AWS A5.32 (ISO 14175)-M22-ArO-2 through M22-ArO-5]	7 and over
Short circuiting transfer	0.8	0.030	35–130	14–22	0.6 to 3.4	0.024 to 0.135	100% CO ₂ [AWS A5.32 (ISO 14175)-C1-C]	24 to 10
	0.9	0.035	55–200	15–23	1.0 to 3.2	0.039 to 0.125	or 8%–15% CO ₂ , Balance Argon [AWS A5.32 (ISO 14175)-M20-ArC-8 through M20-ArC-15]	20 to 11
	1.2	0.045	75–200	16–24	1.6 to 4.8	0.062 to 0.187	<15%–20% CO ₂ , Balance Argon [AWS A5.32 (ISO 14175)-M21-ArC-16 through M21-ArC-25]	16 to 7

H4.2.1 Process Variations. In GMAW, variations of shielding gases, power supplies, and electrodes have significant effects resulting in several process variations. Two variations are commonly used with low average currents suitable for sheet metal welding. The pulsed spray variation requires argon-rich gas mixtures; the short circuiting arc variation generally uses carbon dioxide, alone or in gas mixtures.

(1) *Pulsed Spray Welding.* If intermittent high amplitude pulses of current are superimposed on a low level steady current, the average current can be reduced appreciably while producing a metal spray transfer during the pulse intervals.

Argon-rich gases are essential to achieve the spray. This type of metal transfer, produced through the utilization of a unique power supply, characterizes the pulsed arc process variation. With it, reasonably large electrode diameters can be employed to weld thin sections in all positions.

Proper operation and adjustment of the power supply may require additional training. The pulsed spray welding process is used frequently to weld thin sections in all positions.

(2) *Short Circuiting Arc.* With short circuiting arc welding, the average current and deposition rates can be reduced by using power supplies which allow metal to be transferred only during intervals of controlled short circuits occurring at rates in excess of 50 per second. The short circuiting arc is easy to use to weld thin sections in all positions.

H4.2.2 Welding Equipment. Both of the GMAW process variations used on sheet metal utilize similar equipment that requires the following:

- (1) An electrode wire feeder with a variable speed motor and motor control to power feed rolls which drive the electrode at a preset and uniform rate;
- (2) An arc welding gun which houses a switch to initiate and stop the electrode feed, flow of gas, electrical current to the arc, and, if used, water for cooling the torch; a nozzle which directs the shielding gas to the arc and weld pool; a contact tube at the axis of the nozzle to transfer welding current to the electrode; and a system of cable, hoses, electrical connections, and casings to direct the gas, electrode, power, and water if used;
- (3) A mount for the spooled or coiled electrode;
- (4) A control station containing the relays, solenoids, and timers needed to integrate the system;
- (5) A source of shielding gas and a device for metering the flow rate of the gas;
- (6) A power supply to provide an appropriate amount and type of current; and
- (7) A water supply for cooling, if a water-cooled arc welding gun is used.

Less manipulative skill is needed to master the variations of this process when compared to the SMAW process. If the welding is highly repetitive and the equipment controls are preset, only a relatively short time is needed to train a welder. The short circuiting arc process variation is easy to master for use in all positions. The pulsed spray welding process may require additional time to train the operator to set the automatic controls. After the welding parameters have been established, welding of thin sections in any position is possible.

A reasonable amount of preventive maintenance is required to ensure that the gas passages are clear and the contact tube is not worn. The feeders and control units are simple electro-mechanical devices and, therefore, quite reliable. Maintenance skills can be developed rapidly.

H4.2.3 Shielding Gas. Welding grade shielding gas should be correctly selected and regulated. The following are shielding gases commonly used in GMAW:

- (1) Argon [AWS A5.32 (ISO 14175)-I1-Ar];
- (2) Helium [AWS A5.32 (ISO 14175)-I2-He];
- (3) CO₂ [AWS A5.32 (ISO 14175)-C1-C]; and
- (4) Various mixtures of the above with each other and with oxygen, especially when welding ferrous metals, to prevent undercut and irregular welds.

Mixtures of argon and CO₂ are commonly used for welding light gage mild steel and low-alloy steel. Gas costs can be decreased by increasing the percentage of CO₂, but spatter and costs of cleanup will increase.

H4.2.4 Electrode Wire. The filler metal used in the GMAW process is quite small in diameter, ranging from 0.7 mm [0.025 in] to 1.6 mm [1/16 in]. Electrode wire should be clean and free from contaminants because of the high surface-to-volume ratio. Any foreign matter on the electrode has an exaggerated effect in relation to the amount of metal present, which may cause weld defects such as porosity and cracking. Carbon steel wire has a very thin protective coating (usually copper) while most other wires are bare.

H4.2.5 Welding Carbon Steel Sheet Metal. The thickness of joints that can be welded depends upon the process. The short circuiting arc is ideal for welding ferrous metals in all positions, if they are thinner than 6.07 mm [0.239 in] and with square butt joint designs. The pulsed arc is used to weld sheet as thin as 18 gage, 1.27 mm [0.050 in] in all positions.

Every type of joint can be welded with GMAW if both the appropriate process and welding conditions are selected.

H4.2.6 Welding Stainless Steel Sheet Metal. The GMAW short circuiting transfer variation excels in economy for welding stainless steel. When welding stainless steel, the electrode wire size and current settings are very similar to mild steel welding, except that stainless steel will tolerate a slightly lower current setting. The most critical aspect of GMAW stainless steel is matching the electrode wire composition with the base metal composition. The normal shielding gas for short circuiting transfer welding of stainless steel is a helium-argon-carbon dioxide blend such as 90% He – 7.5% Ar – 2.5% CO₂ [AWS A5.32 (ISO 14175)-M12-HeArC-7.5/2.5].

Table H.4
Suggested Welding Conditions for Aluminum Sheet Metal

GMAW Process Variation	Wire Diameter		Operating Current Range A	Operating Voltage Range V	Thickness of Metal to be Welded		Shielding Gas
	mm	in			mm	in	
Pulsed spray	0.8	0.030	25–90	16–20	0.81 to 2.59	0.032 to 0.102	Argon or 75% He + 25% A [AWS A5.32 (ISO 14175)-11-Ar or AWS A5.32 (ISO 14175)-13-HeAr-25]
	1.2	3/64	40–150	17–23	1.29 to 4.75	0.051 to 0.187	
	1.6	1/16	45–300	17–28	2.59 and over	0.102 and over	
	2.4	3/32	100–300	19–29			
Spray transfer	0.8	0.030	90–200	18–27	0.81 to 2.59	0.032 to 0.102	Argon or 75% He + 25% A [AWS A5.32 (ISO 14175)-11-Ar or AWS A5.32 (ISO 14175)-13-HeAr-25]
	1.2	3/64	130–300	21–32	1.29 to 4.75	0.051 to 0.187	
	1.6	1/16	155–400	22–35	2.59 and over	0.102 and over	
	2.4	3/32	200–450	23–35			

H4.2.7 Welding Aluminum Sheet Metal. Unlike stainless and mild steel welding, best results are obtained using argon as a shielding gas. With the work electrically negative, arc action effectively removes surface oxides.

Using a DCEP (current) and argon shielding gas, it is possible to weld thin aluminum of approximately 1.27 mm [0.050 in]. Electrode wire sizes of 0.8 mm to 1.6 mm [0.030 in to 1/16 in] are commonly used. With these diameter wires, base metal melt-through and spatter are both minimized. The pulsed arc variation of GMAW produces good results when welding aluminum sheet metal. Table H.4 suggests current ranges for welding aluminum sheet metal.

H4.3 Flux Cored Arc Welding (FCAW). This process is similar in application and equipment to GMAW. Flux cored arc welding uses cored electrodes instead of solid electrodes for joining ferrous metal. Minerals and ferrous alloys in the core provide additional protection and help control the weld contour. Many cored electrodes are designed to be used with carbon dioxide-rich gases, and many now are of a self-shielded variety. These electrodes are designed to prevent porosity from forming in the weld metal by the addition of significant amounts of deoxidizers such as aluminum. This allows them to be used without a shielding gas. By controlling the ionizable materials in the core, the process can employ either direct current electrode positive (reverse polarity) or direct current electrode negative (straight polarity). The self-shielded FCAW process is commercially available in mild steel and stainless steel filler metals.

In general, the GMAW and FCAW processes are cost effective. The deposition efficiencies are particularly high, approaching 95% to 100% with solid electrode (depending upon the shielding gas), 85% to 90% with gas-shielded cored electrodes, and 80% to 85% with the self-shielded cored electrodes. Welders can work continuously with both GMAW and FCAW processes. The wire is fed continuously, and only duty cycle limitations of the power source, welder fatigue, or a need to change position would require the arc to be interrupted.

H4.4 Gas Tungsten Arc Welding (GTAW). Gas tungsten arc welding uses a nonconsumable tungsten electrode shielded with an inert gas. The arc fuses the metal being welded as well as the filler metal, if used. The gas shield protects the electrode and weld pool and provides the required arc characteristics.

The process may employ either DCEN or ac. In general, ac is preferred for aluminum. DCEN is preferred for the other metals and alloys listed in 3.3.1. DCEP is not used because the tungsten electrode overheats if not oversized.

When ac is used with argon shielding, arc action loosens oxides on the surface during the half cycle when the electrode current is positive. Oxide removal is beneficial in reducing porosity when welding aluminum.

Helium is not used for sheet metal because of its deeper penetrating arc.

Regardless of polarity, a constant current (drooping volt-ampere characteristic) welding supply is required. In addition, a high frequency oscillator is generally an integral part of the power supplies intended for GTAW. High frequency can be employed with dc to initiate the arc instead of touch starting to minimize tungsten electrode contamination. It is normally turned off automatically after arc ignition. High frequency is employed with ac for initiating the arc and to ensure its reignition at each half cycle while welding. It remains on throughout the welding operation.

Some specialized power sources provide pulsating direct current at high or low frequency. With these power sources better control of weld metal fusion and solidification characteristics is possible.

A variety of tungsten electrodes is used with the process. The thoriated, zirconiated, ceriated, and lanthanated tungsten electrodes have higher current-carrying capacity and emit electrons better than pure tungsten electrodes, making them more suitable for dc operations. The electrode is normally ground to a point or to a truncated cone configuration to minimize arc wandering. Pure tungsten has the poorest electron emission but causes the least current imbalance with ac welding power supplies. Alternating current is advantageous when welding aluminum because arc action accelerates removal of oxides from the surface.

The equipment needed consists of a welding torch, welding power supply, and a source of inert gas with suitable pressure regulators and flowmeters.

Gas tungsten arc welding requires more training time, manual dexterity, and operator coordination than does SMAW or GMAW. The equipment is portable and usable with all metal in a wide range of thicknesses and in all welding positions. Welds of the highest quality can be produced with the versatile GTAW process.

The process allows welding of all types of grooves and joint geometries. It is particularly appropriate for welding metals in sheet metal thicknesses.

Although often slower than SMAW or GMAW, GTAW can provide the highest weld quality while accommodating a wider range of thicknesses, positions, and geometries than either SMAW or GMAW.

H4.5 Plasma Arc Welding (PAW). The equipment includes a control circuit, power supply, torch, workpiece connection and work lead assembly, shielding gas hose, orifice gas hose, inert gas regulators, and flowmeters. The needle arc variation could have application to extremely thin sheet metal welding below 1.5 mm [0.062 in] in thickness. Its needle-like arc is long and easily controlled. The weld is smooth and made without filler metal. Out-of-position welding is possible.

The basic elements of the plasma arc torch are the tungsten electrode and the orifice. A small flow of argon is supplied through the orifice to form the arc plasma. The arc and weld shielding is obtained from a second gas flow through an encircling outer nozzle cup assembly. The shielding gas can be argon, helium, or mixtures of argon with helium. A low current pilot arc between the electrode and the orifice insert (commonly referred to as a nontransferred arc) heats the orifice gas to very high temperatures so that it becomes ionized and produces a plasma. The plasma forms a conductive path between the electrode and the weldment to permit instant ignition of a welding arc (between electrode and workpiece) which, in this case, is called a transferred arc. If filler metal is used, it is fed into the arc as in the GTAW process.

H4.6 Carbon Arc Welding (CAW). The carbon arc welding process has been superseded to a great extent by other welding processes. There still are many applications for which it can be used to good advantage.

The carbon electrode is used only as a source of heat. Amperages are chosen to give longest electrode life. Arc temperatures range from 3900°C to 5000°C [7000°F to 9000°F], depending upon the current used, with very slow burnoff of the electrode on DCEN. If the proper composition of filler metal is supplied from a separate source, welds of high tensile strength and ductility are produced.

There is still a considerable amount of carbon arc braze welding being done in the sheet metal industry in the form of braze welding using silicon-bronze or aluminum-bronze filler wire. This process, which is commonly called “everdurning,” has achieved a high degree of usage in the sheet metal industry for joining light gage galvanized fittings used on high and medium pressure duct systems. This type of braze welding is used extensively in small to medium sized sheet metal shops. In the larger shops, most of this type of welding is done using GMAW with silicon-bronze welding wire.

H5. Summary

SMAW and GMAW are the most used methods for joining sheet metal components for heating, ventilating, air conditioning, industrial sheet applications, and air pollution applications.

GTAW and PAW are other methods for joining sheet metal components for food and beverage dispensing systems, food processing equipment, and architectural metal installations. Due to the sanitary and cosmetic appearance required for this type of component, these processes offer some unique advantages to the sheet metal industry.

Annex I (Informative)

Recommended Braze Welding Practices

This annex is not part of AWS D9.1M/D9.1:2012, *Sheet Metal Welding Code*, but is included for informational purposes only.

I1. Introduction

These recommended practices have been prepared by the AWS D9 Committee on Welding, Brazing, and Soldering of Sheet Metal. The Committee does not propose that these are the only possible methods for the braze welding of sheet metal. These recommended practices are of a general nature and are offered only as guidelines indicative of sheet metal industry experience. More detailed information may be found in the latest edition of AWS A5.8, *Specification for Filler Metals for Brazing and Braze Welding*, AWS *Brazing Handbook*, and Volume 2, Ninth Edition, AWS *Welding Handbook*.

I2. Brief History of Sheet Metal Braze Welding

The term *sheet metal* is usually associated with very thin galvanized sheet steel. Actually, *sheet metal* can mean a coated or uncoated ferrous or nonferrous metal as thick as 3 gage, 6.07 mm [0.239 in].

For many years after welding had become every day practice in structural work, heavy wall pipe work, and heavy wall pressure vessel work, the sheet metal industry was still joining thin materials with riveted and soldered joints and various sheet metal locks and seams. In a few instances, the sheet metal industry gas welded or braze welded joints and seams. This was usually both slow and expensive.

With the introduction of low voltage power sources and smaller diameter electrodes for SMAW and the development of the GMAW, GTAW, and PAW processes, braze welding became a practical method of joining sheet metal components. As the equipment and processes became more versatile, the practice of braze welding increased in the sheet metal industry to a point that today, virtually all sheet metal shops own arc welding equipment.

In today's marketplace, one will find an abundance of welded components in heating, ventilating, and air conditioning; industrial sheet metal applications; food and beverage dispensing systems; food processing equipment; air pollution and conveyor systems; and architectural metal installations.

I3. Description

Braze welding is a welding process variation in which a filler metal is deposited in a specific joint configuration in which bonding is obtained by a wetting action. Braze welding requires heating, but not melting of the base metal and requires by definition, to distinguish from soldering, a filler metal having a melting temperature above 450°C [840°F]. In sheet metal applications, the braze welding heat source employed most commonly is the electric arc. In common usage today also are carbon arc welding (CAW) (often referred to in the sheet metal industry as "everduring"), gas metal arc welding (GMAW), and gas tungsten arc welding (GTAW) processes.

I4. Fitup

Stringent fitup is not critical because the filler metal is deposited in grooves and spaces exactly where the molten filler metal wets the base metal. Refer to typical joint designs in Annex G, Part B.

I5. Base Metals

Most similar or dissimilar metal joints may be braze welded, some with a greater degree of ease than others. Some dissimilar metal joints are more suitable for braze welding than for fusion welding.

I6. Filler Metals

All filler metals for braze welding have a melting (liquidus) temperature above 450°C [840°F] and below that of the base metal being joined. The braze welding filler metal may be fed in the form of wire, rod, or strips. Most braze welding filler metals contain two or more elements alloyed to provide certain desirable characteristics. The two filler metals most commonly used in the sheet metal industry today are silicon bronze (ERCuSi-A1) and aluminum bronze (ERCuAl-A2). When selecting a suitable filler metal for braze welding, application requirements must be considered; i.e., if the braze welded assembly is to be used in a corrosive environment, the filler metal should be as resistant to the corrosive environment as the base metal.

I7. Joint Strength

Strength of braze weld joints is dependent on the properties of the filler metal used. Experience has shown that braze welded joints made with the gas metal arc or gas tungsten arc process offer optimum strength and integrity.

I8. Base Metal Cleaning and Preparation

Clean surfaces, free of oxide film or scale, dirt, grease, oil, etc., are essential to braze welding. Foreign material on faying and adjacent surfaces may inhibit the wetting action, prevent uniform flow and bonding of the filler metal, and result in voids or inclusions, or both. Because heavy deposits of oil usually are present on sheet metal working equipment, cleaning is emphasized on joints prepared with, or exposed to, such machinery. Cleaning can be accomplished chemically or mechanically. Selection of chemical cleaning agents will depend on the nature of the contamination and may include solvents, alkaline commercial mixtures, vapor degreasing, emulsions, or electrolytic cleaning.

In all cases, chemical residue should be removed completely before braze welding to prevent the formation of other equally undesirable films or coatings. Mechanical cleaning or descaling of oxide, scale, etc., may be accomplished by grinding, wire brushing, or abrasive blasting. Blasting material should be clean and not leave a deposit on the surface. Mechanical cleaning will not effectively remove oil or lubricants. To prevent new contamination from the atmosphere or handling, or both, it is recommended that braze welding should be accomplished as soon as possible after the joint has been cleaned.

I9. Shielding Gas

GMA and GTA braze welding processes utilize a shielding gas to control the arc atmosphere. Suggested shielding gases are argon, helium, or combinations thereof.

I10. Summary

Braze welding offers some unique advantages to the sheet metal industry. The process can be accomplished with most of the electric arc power sources found in many sheet metal shops or on job sites. The low temperature required for braze welding minimizes the distortion and burn-through sometimes experienced in fusion welding of thin sheet metal, especially in out-of-position job site conditions. Braze welding done with silicon bronze, copper silicon, silicon-aluminum bronze, or aluminum bronze filler metal using an electric arc process does not require fluxing. For job specifications requiring maximum retention of metallic coatings on the base metal, the manufacturer should consider that the lower temperature used for braze welding can minimize the loss of the protective coating.

Annex J (Informative)

General Knowledge Test

This annex is not part of AWS D9.1M/D9.1:2012, *Sheet Metal Welding Code*,
but is included for informational purposes only.

In order to promote training of welders and welding operators, a general knowledge test of a minimum of 10 questions is recommended. Contractors, at their option, may administer a general knowledge test of the welder's and welding operator's general welding knowledge. The knowledge test shall be considered independent of the welder and welding operator qualification test.

Welders and welding operators should pass a general knowledge test consisting of a minimum of 10 questions with a score greater than or equal to 70%. An immediate retest may be administered in the event of failure. In the event of second and subsequent failures, further training should be administered before repeat testing. Sample test questions may be selected from any of the various processes given below.

J1. SMAW Sample Test

Please circle the letter corresponding to the best answer in each of the following questions:

1. In the welding circuit, the greatest resistance to current flow is:
 - A. Through the power source
 - B. Through the welding cable
 - C. Through the electrode
 - D. Across the arc length
2. In most cases, reverse polarity produces:
 - A. Deep penetration
 - B. Medium penetration
 - C. Shallow penetration
3. SMAW can be used in what position?
 - A. Horizontal
 - B. Vertical
 - C. Overhead
 - D. All positions
4. SMAW power sources allow the welder to adjust the:
 - A. Voltage
 - B. Ohms
 - C. Watts
 - D. Amperage
5. An EXX10 electrode will weld in all positions, this is indicated by the:
 - A. First number
 - B. Second number
 - C. Third number
 - D. Last number

6. The acceptable term for reverse polarity is:
 - A. Alternating Current
 - B. Direct Current
 - C. Alternating Current Electrode Negative
Direct Current Electrode Positive
7. EXX10 electrodes are designed to weld using:
 - A. DCEN
 - B. ACHF
 - C. DCEP
8. A long arc length in the SMAW process will force the weld metal to:
 - A. Spread over a wider bead profile
 - B. Become narrow
 - C. Decrease the arc voltage
 - D. Increase the amperage
9. The proper SMAW arc length usually equals:
 - A. 1.625 mm to 6.5 mm [1/16 in to 1/4 in]
 - B. 3.25 mm [1/8 in]
 - C. The diameter of the electrode's core wire
 - D. The outside diameter of the electrode including the flux coating
10. Arc strikes on the base material of a welded project will do no harm.
 - A. True
 - B. False
11. Your workpiece connection gets hot; this is caused by:
 - A. The clamp is too small for the amperage being used
 - B. The weld lead connection to the clamp is loose
 - C. The workpiece lead is too small
 - D. The connection is frayed to half of its diameter
 - E. All of the above
 - F. None of the above

J2. GMAW Sample Test

Please circle the letter corresponding to the best answer in each of the following questions :

1. In most cases, reverse polarity produces:
 - A. Deep penetration
 - B. Medium penetration
 - C. Shallow penetration
2. GMAW generally has what type of power source?
 - A. Constant current
 - B. Alternating current with high frequency
 - C. Constant voltage
3. What is the most common mode of metal transfer used for thin gage material?
 - A. Globular transfer
 - B. Spray transfer
 - C. Pulsed spray transfer
 - D. Short circuit transfer

4. Your weld has a high reinforcement and does not have a smooth transition at the toes of the weld. What should you do?
 - A. Increase the arc voltage
 - B. Decrease the arc voltage
 - C. Hold a tighter electrode extension and it will make the weld closer to the base metal
 - D. Increasing the shielding gas will help the weld wet in at the toes of the weld
5. Short circuit transfer for sheet metal welding normally occurs in the voltage range of:
 - A. 5 volts to 12 volts
 - B. 16 volts to 21 volts
 - C. 23 volts to 27 volts
 - D. 28 volts to 35 volts
6. The wire feed speed in a GMA welding process usually determines the:
 - A. Voltage
 - B. Amperage
 - C. Slope
 - D. None of the above
7. When using short circuit transfer mode, the filler metal is transferred to the base metal:
 - A. Across the open arc
 - B. By direct contact with the base metal
 - C. Large droplets transfer across the arc
 - D. It is drawn to the metal by electro-magnetic force
8. The preferred electrical extension (which is the distance from the contact tip to the end of the wire) when using the short circuiting transfer mode with 0.9 mm [0.035 in] electrode should be:
 - A. 3.25 mm [1/8 in]
 - B. 6.5 mm [1/4 in]
 - C. 9.5 mm [3/8 in]
 - D. 19 mm [3/4 in]
9. At the same deposition rate, when changing the shielding gas from a 75% Argon 25% CO₂ [AWS A5.32 (ISO 14175)-M21-ArC-25] gas mixture to 100% CO₂ [AWS A5.32 (ISO 14175)-C1-C], the primary adjustment that must be made is:
 - A. An increase in wire speed
 - B. An decrease in wire speed
 - C. A increase in voltage
 - D. A decrease in voltage
10. For sheet metal, short circuiting transfer operates at:
 - A. Low voltage and high amperage
 - B. Low voltage and low amperage
 - C. High voltage and low amperage
 - D. High voltage and high amperage

J3. GTAW Sample Test

Please circle the letter corresponding to the best answer in each of the following questions:

1. The GTAW process normally requires what type of power source?
 - A. Constant voltage
 - B. Constant potential
 - C. Constant current

2. Welding Stainless Steel requires what type of current?
 - A. DCEN
 - B. DCEP
 - C. ACHF
 - D. AC
3. Argon is a better electrical conductor than Helium.
 - A. True
 - B. False
4. Argon demonstrates better heat conductivity across the arc column than Helium.
 - A. True
 - B. False
5. The smoothest arc is obtained using what type of current?
 - A. AC
 - B. Rectified single phase current
 - C. Rectified three phase current
 - D. ACHF
6. Aluminum and Aluminum Alloys are welded using a power source that produces this type of current.
 - A. ACHF
 - B. DCEN
 - C. DCEP
 - D. D.AC
 - E. DC
7. Select the tungsten tip angle that will product the deepest penetration when using thoriated tungsten electrodes:



A.



B.



C.



D.

8. Select the tungsten that demonstrates proper grinding techniques.



A.



B.

9. Select the tungsten grind in question 7 (seven) that will work best for inside corner welds. _____

10. Select the GTAW filler metal that helps control porosity when welding carbon steel.
- A. ERXXS-2
 - B. ERXXS-3
 - C. ERXXS-4
 - D. ERXXS-5
 - E. ERXXS-6

J4. Braze Welding Sample Test

Please circle the letter corresponding to the best answer in each of the following questions:

1. What type of current is used in the CAW Process?
 - A. DCEP
 - B. AC
 - C. DCEN
 - D. ACHF
2. CAW requires the arc melt the base metal.
 - A. True
 - B. False
3. The CAW filler material melts above:
 - A. 1000°C [1840°F]
 - B. 450°C [840°F]
 - C. 815°C [1500°F]
 - D. 1090°C [2000°F]
4. The gases given off during the electrode erosion are:
 - A. Helium and argon
 - B. Argon and carbon dioxide
 - C. Carbon monoxide and carbon dioxide
 - D. Carbon dioxide and oxygen
5. The welding arc must be directed to the:
 - A. The joint root
 - B. The base metal
 - C. The root opening
 - D. The filler material
6. Which of the following statements is the most correct?
 - A. Melt the filler metal and never the base metal
 - B. Melt the filler metal and the base metal
 - C. Melt the filler metal and the galvanized coating
 - D. Melt the filler metal and not the base metal and any base metal coatings
7. A fabricated copper sleeve will keep the electrode holder from breaking the electrode and allow more electrode angle adjustment.
 - A. True
 - B. False
8. What are the two types of electrodes used in the CAW process?

9. It is important to sharpen the electrode to help concentrate the arc on the filler metal and not on the base metal.
A. True
B. False
10. What type of power source is used for CAW?
A. Constant voltage
B. Constant current

J5. Welding Safety Sample Test

Please circle the letter corresponding to the best answer in each of the following questions:

1. What distance can sparks travel horizontally from the point of operation?
A. 7.5 meters [25 feet]
B. 10.5 meters [35 feet]
C. 15.25 meters [50 feet]
D. 30.5 meters [100 feet]
2. What two organizations have safety standards you should know?
A. OSHA & ASME
B. OSHA & AWS
C. ASME & AWS
D. ASME & ASTM
3. During welding, voltage will not harm the human body.
A. True, as long as you are in good shape.
B. False, during welding, voltage can cause direct physiological harm.
4. Shock currents that are considered primary because they are capable of causing direct physiological harm are greater than approximately:
A. 6 milliamperes
B. 60 amperes
C. 10 milliamperes
D. 100 amperes
5. Finishes formulated with pigments having low reflectivity are recommended for painted surfaces in a welding area. These pigments include:
A. Zinc dioxide
B. Titanium oxide
C. Zinc oxide
D. Titanium dioxide
E. A & B
F. C & D
6. Welding helmets are adequate protection against slag chips, grinding fragments, wire bristles, and similar hazards.
A. True, as long as it has a clear cover lens.
B. False, safety glasses with side shields that comply with ANSI Z87 must be worn in addition to the welding helmet.
7. Degreasing and cleaning compounds containing chlorinated hydrocarbons must be kept away from the welding area to prevent exposure to the ultraviolet radiation of the arc and the formation of highly toxic phosgene gas.
A. True
B. False
8. Welders should be protected to prevent shock induced falls.
A. True
B. False

9. Conduit and pipelines should be used for work lead connections.
 - A. True
 - B. False
10. To minimize shock hazard, DC machines that are sufficiently close to each other must be on the same polarity.
 - A. True
 - B. False

Answer Page

J1. SMAW Sample Test

ANSWERS:

1. D
2. A
3. D
4. D
5. C
6. D
7. C
8. A
9. C
10. B
11. E

J2. GMAW Sample Test

ANSWERS:

1. A
2. C
3. D
4. A
5. B
6. B
7. B
8. C
9. C
10. B

J3. GTAW Sample Test

ANSWERS:

1. C
2. A
3. A

4. B
5. C
6. A
7. C
8. A
9. D
10. A

J4. Braze Welding Sample Test

ANSWERS:

1. C
2. B
3. B
4. C
5. D
6. D
7. A
8. Pure Graphite and Baked Carbon
9. A
10. B

J5. Welding Safety Sample Test

ANSWERS:

1. B
2. B
3. B
4. A
5. F
6. B
7. A
8. A
9. B
10. A

Annex K (Informative)

Guidelines for the Preparation of Technical Inquiries for Structural Welding Committee

This annex is not part of AWS D9.1M/D9.1:2012, *Sheet Metal Welding Code*,
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
8669 Doral Blvd.
Doral, FL 33166

All inquiries shall contain the name, address, and affiliation of the inquirer, and they shall provide enough information for the committee to understand the point of concern in the inquiry. When the point is not clearly defined, the inquiry will be returned for clarification. For efficient handling, all inquiries should be typewritten and in the format specified below.

K2.1 Scope. Each inquiry shall address one single provision of the code, 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 code 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 either to obtain an interpretation of a code's requirement, or to request the revision of a particular provision in the code.

K2.3 Content of the Inquiry. The inquiry should be concise, yet complete, to enable the committee to quickly and fully understand the point of the inquiry. Sketches should be used when appropriate and all paragraphs, figures, and tables (or the Annex), which bear on the inquiry shall be cited. If the point of the inquiry is to obtain a revision of the code, the inquiry must 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 the wording for a proposed revision, if that is what inquirer seeks.

K3. Interpretation of Code Provisions

Interpretations of code provisions are made by the Structural Welding Committee. The secretary of the committee refers all inquiries to the chair of the particular subcommittee that has jurisdiction over the portion of the code 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 Structural Welding 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 shall appear in the *Welding Journal* and will be posted on the AWS web site.

K5. Telephone Inquiries

Telephone inquiries to AWS Headquarters concerning the *Structural Welding Code* should be limited to questions of a general nature or to matters directly related to the use of the code. The AWS Board of Directors' policy 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. The Structural Welding Committee

The activities of the Structural Welding Committee regarding interpretations are limited strictly to the interpretation of code provisions 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, or (2) code requirements applied to fabrications outside the scope of the code or points not specifically covered by the code. In such cases, the inquirer should seek assistance from a competent engineer experienced in the particular field of interest.

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