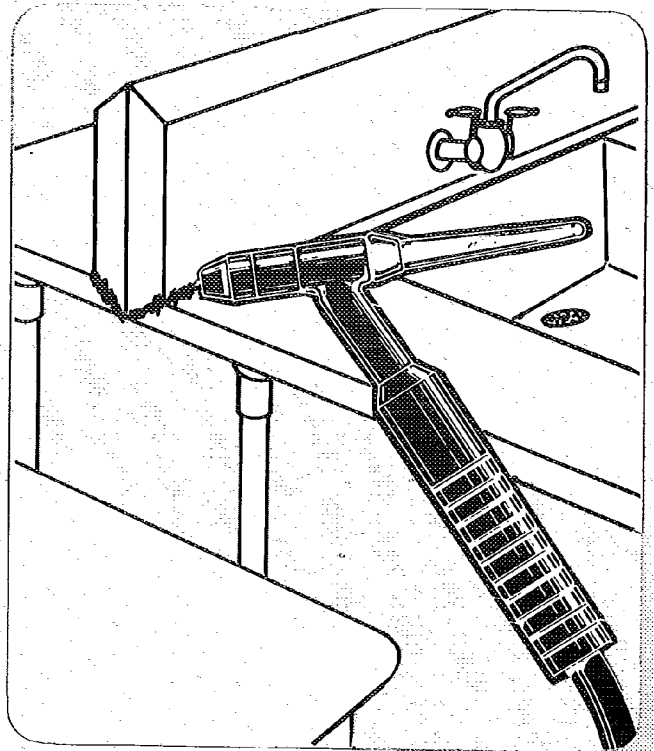
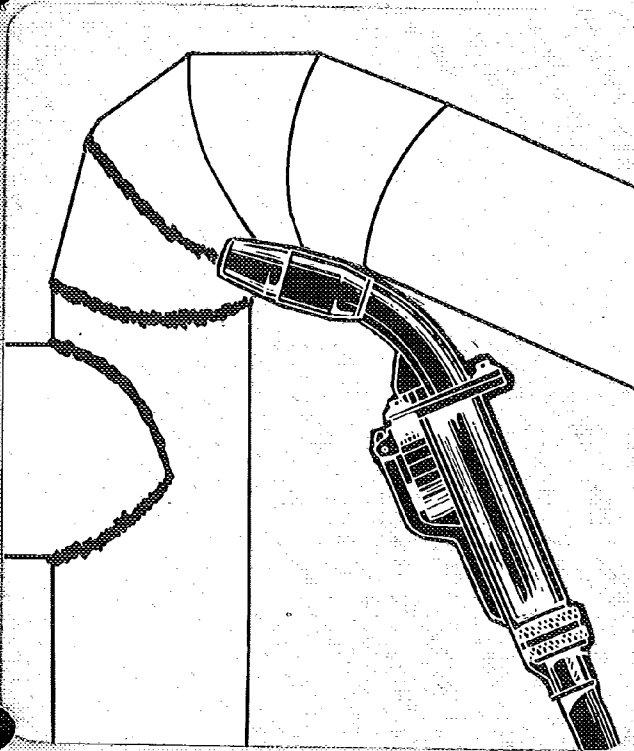
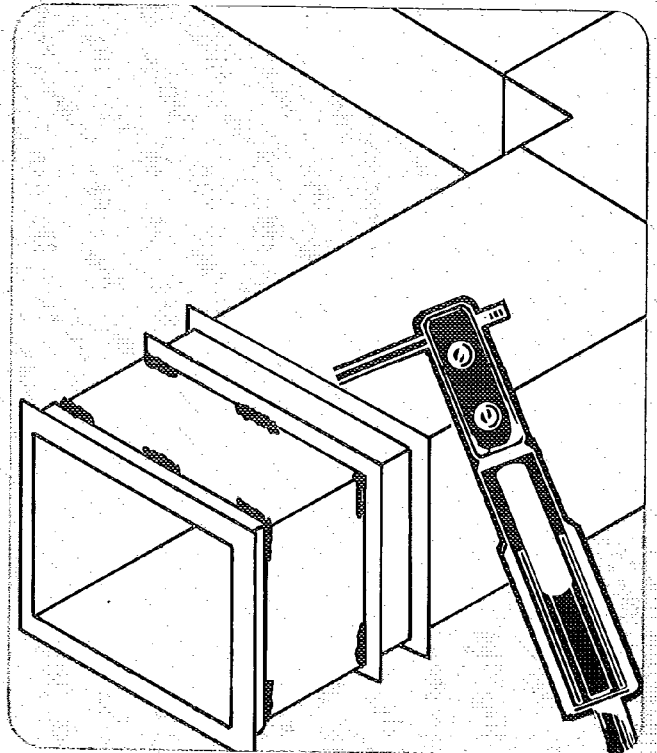


Sheet Metal Welding Code



American Welding Society

Keywords — Sheet metal, arc welding,
brazing, joint designs,
qualification, workmanship,
inspection, base metals,
filler metals

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American National Standards Institute
January 12, 1990

Sheet Metal Welding Code

Superseding D9.1-84

Prepared by
AWS Committee on Welding, Brazing,
and Soldering of Sheet Metal

Under the Direction of
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 nonmandatory appendices supply useful information on materials and processes.



American Welding Society

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Statement on Use of AWS Standards

All standards (codes, specifications, recommended practices, methods, classifications, and guides) of the American Welding Society are voluntary consensus standards that have been developed in accordance with the rules of the American National Standards Institute. When AWS standards are either incorporated in, or made part of, documents that are included in federal or state laws and regulations, or the regulations of other governmental bodies, their provisions carry the full legal authority of the statute. In such cases, any changes in those AWS standards must be approved by the governmental body having statutory jurisdiction before they can become a part of those laws and regulations. In all cases, these standards carry the full legal authority of the contract or other document that invokes the AWS standards. Where this contractual relationship exists, changes in or deviations from requirements of an AWS standard must be by agreement between the contracting parties.

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This standard is subject to revision at any time by the AWS Committee on Welding, Brazing, and Soldering of Sheet Metal. It must be reviewed every five years and if not revised, it must be either reapproved or withdrawn. Comments (recommendations, additions, or deletions) and any pertinent data that may be of use in improving this standard are requested and should be addressed to AWS Headquarters. Such comments will receive careful considerations by the AWS 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 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, 550 N.W. LeJeune Road, P. O. Box 351040, Miami, Florida 33135.

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Foreword

(This Foreword is not a part of ANSI/AWS D9.1-90, *Sheet Metal Welding Code*, but is included for information purposes only.)

This standard was developed to provide a document for use in arc and braze welding performed by the sheet metal industry. 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 two previous versions of D9.1.

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

The present revision, D9.1-90, *Sheet Metal Welding Code*, was undertaken 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.

As new applications are developed and more experience is gathered, it is anticipated that changes in this standard will be required. A constructive response from users to each of the distinctive areas of this standard is encouraged. All correspondence should be addressed to: Secretary, AWS Committee on Welding, Brazing and Soldering of Sheet Metal, American Welding Society, 550 N.W. LeJeune Road, P.O. Box 351040, Miami, Florida 33135.

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Sheet Metal Welding Code

1. Scope, Purpose and Applications

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.

1.2 Purpose. It was written to standardize acceptance criteria for sheet metal fabrication in nonstructural applications.

1.3 Applications. This Code has general applications 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

It covers the thickness range for sheet metal up to as thick as 3 gauge, or 0.239 in. (6.07 mm). See Appendix C. It applies to the attachment and joining of any member, regardless of thickness, whose sole purpose is stiffening, supporting, or reinforcing the sheet metal. It also applies to the attachment of accessories or components of the system.

Where vacuum or pressure exceeds 120 in. of water (30 kPa) or where structural requirements are concerned, other standards shall be used.

Part A — Arc Welding

2. General Provisions for Arc Welding

2.1 Base Metal

2.1.1 Base metals to be joined under this Code shall include carbon steel, low alloy steel, chromium and chromium-nickel steel alloys, aluminum and aluminum

alloys, copper and copper alloys, nickel and nickel alloys, and coated metals.

2.1.2 Rust inhibitive coatings, galvanized coatings, or anti-spatter compounds may remain on the metal to be joined. (See section 12, Safety and Health, and Appendix J for safety precautions.)

2.2 Filler Metal

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

2.2.2 Suggested filler metals are listed in Appendix A.

2.3 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 to the requirements of this Code.

2.4 Terms and Definitions

2.4.1 Terms and definitions shall be interpreted in accordance with the latest edition of ANSI/AWS A3.0, *Standard Welding Terms and Definitions*.

2.4.2 Supplemental definitions (marked with an asterisk) and terms of significant importance to sheet metal welding are given in Appendix B.

2.4.3 The Engineer referred to herein is the duly designated person who acts on behalf of the owner in all matters within the scope of this Code.

2.4.4 The contractor designates the party responsible for performing the welding under the Code. The term is used collectively to mean contractor, fabricator, erector, or manufacturer.

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

2.6 Standard Units of Measurement. The values stated in U.S. Customary Units are to be regarded as the standard. The metric (SI) values of U.S. Customary Units are approximate.

3. Arc Welding Procedure Qualification

3.1 Prior Procedure Qualification

3.1.1 This Code does NOT provide prequalified status to any welding procedure for sheet metal.

3.1.2 The Engineer, exercising proper discretion, may accept evidence of previous qualification of specific procedures to be used on work being performed under this Code. All required information shall be recorded on an adequate Procedure Qualification Record (PQR) form similar to that shown in Appendix E.

Welding procedures qualified in accordance with section 2 of ANSI/AWS B2.1-84, *Standard for Welding Procedure and Performance Qualification*, may be used, provided they also meet the requirements of section 3 of this code.

3.2 Required Procedure Qualification Tests

3.2.1 Welding Procedure Specification. Each welding procedure to be used in conjunction with this Code shall be prepared as a Welding Procedure Specification (WPS) to be used in fabrication and installation. The use of a qualified procedure shall be the responsibility of the Contractor. All required information for the WPS shall be recorded on an adequate form similar to that shown in Appendix D.

3.2.2 Typical Joints. Typical joint designs and details of joints are given in Appendix G, Part A, of this Code. Qualification of a groove weld may be used as a qualification of a fillet weld, but not vice versa.

3.2.3 Preparing Joint Chosen for Testing. The chosen joint design shall be prepared as a longitudinal joint between two 3 in. (75 mm) by 6 in. (150 mm) sheets, assembled as one of the designs sketched in Figure 1 or as the actual joint to be used. Qualification testing using the butt joint in Figure 1 shall qualify all groove and fillet weld joint designs.

3.2.4 Welding the Test Joint. The joint shall be welded using the process specified in the WPS (3.2.1).

3.3 Limitations of Procedure Qualifications. A qualified welding procedure shall be used only within the

range of operating variables tested during qualification. These limits of essential variables are described in the following paragraphs. The variables shall be recorded on an adequate PQR form similar to that shown in Appendix E.

3.3.1 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 percent maximum carbon and 0.50 percent maximum chromium
- (2) High-strength, low alloy steels
- (3) Chromium and chromium-nickel steels
- (4) Copper and copper alloys
- (5) Nickel and nickel alloys
- (6) Aluminum and aluminum alloys

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

3.3.3 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 3.3.3(1), the following qualification tests may be used to cover the complete range of all sheet metal thicknesses as defined in Appendices B and C.

(a) A qualification weld performed on 18 gauge metal shall provide qualification for that procedure for metal 16 gauge and thinner. (See Appendix C for Equivalents.)

(b) A qualification weld performed on 10 gauge metal shall provide qualification for that procedure for metal as thin as 16 gauge and thicker, up to 2t, where t is the thickness of the thinner base metal qualified. (See Appendix C for Equivalent.)

(c) Procedures qualified under (a) and (b) also qualify fillet welds for all thicknesses of base metal.

3.3.4 The omission, but not the addition, of backing material requires requalification.

3.3.5 A change in filler metal "F" number requires requalification (see Appendix A, Table A1)

3.3.6 A change in welding process, or a change in the method of application (manual, semi-automatic, automatic) requires requalification.

3.3.7 Changes in the type of welding current, polarity or mode of metal transfer as indicated below, require requalification (Reference to metal transfer applies to GMAW and FCAW):

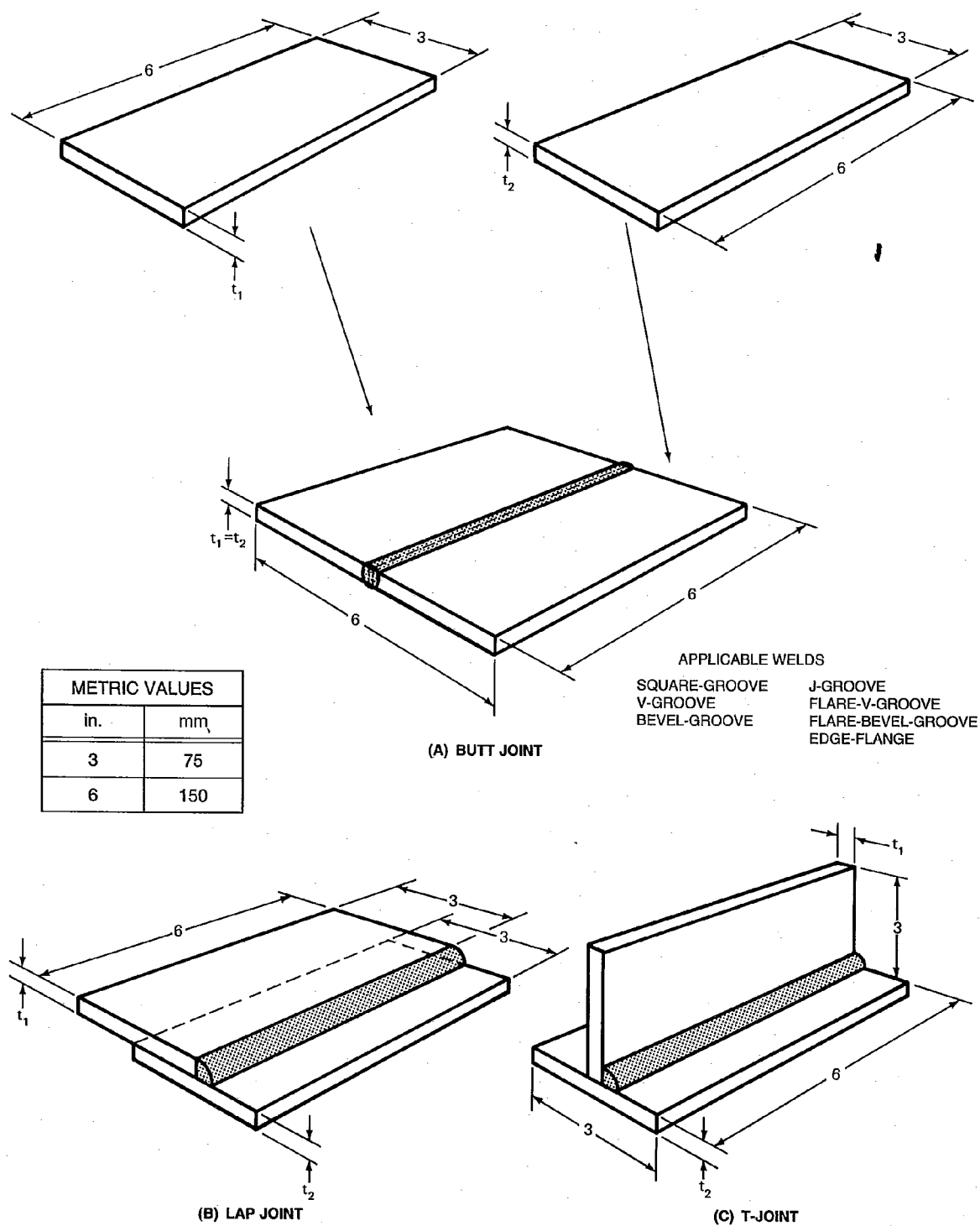


Figure 1 — Procedure Qualification Test Assemblies

- (1) ac to dc or vice versa
- (2) dcen to dcep or vice versa
- (3) short circuiting to globular or spray transfer, or vice versa

3.3.8 A change in shielding gas requires requalification.

3.3.9 Requalification is required when the welding position (Figures 2 and 3) is changed except as noted below:

- (1) Qualification in the flat position shall qualify the procedure only in the flat position.
- (2) Qualification in the horizontal position shall qualify the procedure in both the flat and horizontal positions.
- (3) Qualification in the vertical position shall qualify the procedure in the flat, horizontal and vertical positions.
- (4) Qualification in the overhead position shall qualify the procedure in all positions.

3.4 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).

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

- (1) Complete fusion.
- (2) Complete joint penetration.
- (3) A maximum of 1/8 in. (3.2 mm) face reinforcement and 1/8 (3.2 mm) root reinforcement.
- (4) No more than one visible pore or inclusion in any 1 in. (25 mm) of weld. Size of any pore or inclusion shall not exceed 0.25t, where t is the base metal thickness.
- (5) No undercut exceeding 0.15t, where t is the base metal thickness being welded.
- (6) No cracks.

3.4.2 Fillet Welds. Except for the first and last 0.5 in. (13 mm), welds 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 1/8 in. (3.2 mm).
- (3) No more than one visible pore or inclusion in any 1 in. (25 mm) of weld. Size of any pore shall not exceed 0.25t, where t is the thickness of the thinner member.
- (4) No undercut exceeding 0.15t when the base metal being welded is 0.187 in. (4.8 mm) or thinner, nor exceeding 0.25t when the base metal thickness being welded is greater than 0.187 in. (4.8 mm).
- (5) No cracks.

3.5 Responsibility for Test

3.5.1 The Contractor performing work in accordance with this Code shall be responsible for qualification of the welding procedures to be used. However, to avoid duplication of effort and subject to the approval of the Customer, welding procedures qualified by a technically competent group or agency may be used, subject to the following conditions:

- (a) The welding procedure specification shall meet all of the procedure qualification requirements of this Code.
- (b) The Contractor shall accept the procedure thus qualified.
- (c) The Contractor shall qualify at least one welder to the procedure.
- (d) The Contractor shall assume specific responsibility for the procedure qualification work done by signing and dating the Welding Procedure Specification.

3.5.2 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 (see Appendices D and E for suggested forms).

3.6 Duration of Procedure Qualification

3.6.1 Welding procedures qualified under this Code and previous editions of AWS D9.1 superseded by this Code, shall remain qualified until a revision of the Code requires requalification.

3.6.2 Procedures shall be requalified whenever a change is made in an essential variable.

4. Qualification of Arc Welders and Arc Welding Operators

4.1 Prior Welder and Welding Operator Qualification

4.1.1 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.

4.1.2 Welders and welding operators performing procedure qualification test welds meeting the procedure qualification acceptance criteria in section 3, Arc Welding Procedure Qualification, shall be considered as qualified to perform welding without additional qualification testing, subject to the limitations defined in 4.3.

4.2 Required Welder and Welding Operator Qualification Tests

4.2.1 General. All welders and welding operators permitted to weld under this Code shall be qualified by test.

4.2.2 Groove Welds in a Butt Joint. Test coupon dimensions and test positions for qualification of groove welds in a butt joint are given in Figure 2.

4.2.3 Fillet Welds. Qualification for fillet welds is automatically granted to welders and welding operators who qualify for a groove weld in a butt joint (Figure 2). Either a lap joint fillet or a T-joint fillet may be welded at the option of the contractor unless otherwise specified in the WPS. Test positions for qualification for fillet welds are given in Figure 3.

4.3 Limitations of Welder and Welding Operator Qualifications. The limits of essential variables governing welder and welding operator qualification are described in the following paragraphs.

4.3.1 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 percent maximum carbon and 0.50 percent maximum chromium
- (2) High-strength, low alloy steels
- (3) Chromium and chromium-nickel steels
- (4) Copper and copper alloys
- (5) Nickel and nickel alloys
- (6) Aluminum and aluminum alloys

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

4.3.3 Base Metal Thickness

(1) A change in base metal 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 4.3.3 (1), the following qualification tests may be used to cover the complete range of all sheet metal thickness as defined in Appendix B and C.

(a) A qualification weld performed on 18 gauge metal shall provide qualification for that welder or welding operator for metal 16 gauge and thinner. (See Appendix C for Equivalents.)

(b) A qualification weld performed on 10 gauge metal shall provide qualification for that welder and welding operator, for metals as thin as 16 gauge and thicker, up to 2t thickness, where t is the thickness of the thinner base metal qualified. (See Appendix C for Equivalents.)

(c) Welders qualified under (a) and (b) are qualified to make fillet welds on all thicknesses of base metal.

4.3.4 The omission, but not the addition, of backing material requires requalification.

4.3.5 A change in filler metal "F" number requires requalification. (see Appendix A, Table A1.)

4.3.6 A change in welding process, including method of application requires requalification except as listed 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.

4.3.7 Changes in the type of welding current, polarity, or mode of metal transfer as indicated below require requalification. (Reference to metal transfer applies to GMAW and FCAW):

- (1) ac to dc or vice-versa
- (2) dcen to dcep or vice-versa
- (3) short-circuiting to globular or spray transfer, or vice versa

4.3.8 A change in shielding gas requires requalification.

4.3.9 Requalification is required when the welding position (see Figures 2 and 3) is changed except as noted below.

(1) Qualification in the flat position shall qualify the welder or welding operator only in the flat position.

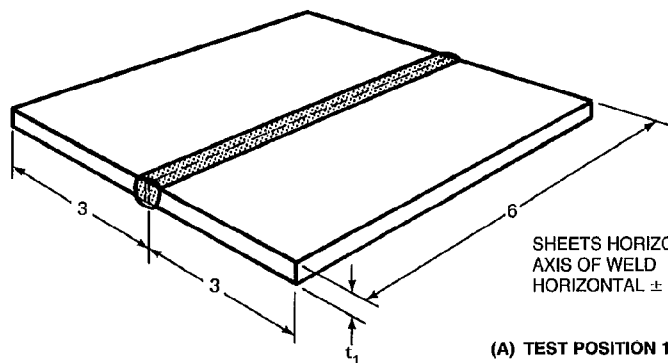
(2) Qualification in the horizontal position shall qualify the welder or welding operator in both the flat and horizontal positions.

(3) Qualification in the vertical position shall qualify the welder or welding operator in the flat, horizontal, and vertical positions.

(4) Qualification in the overhead position shall qualify the welder or welding operator in all positions.

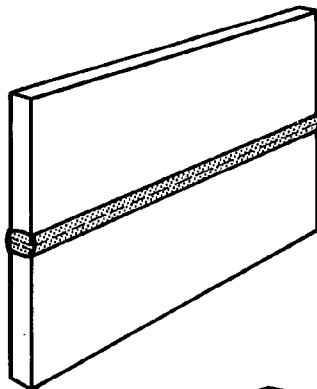
4.4 Inspection of Welder and Welding Operator Qualification Test Welds. Inspection of all test welds shall be visual without aid of magnification (prescription eyeglasses for vision correction are acceptable). Except for the first and last 0.5 in. (13 mm), welds shall exhibit the following:

- (1) Complete fusion.
- (2) Complete joint penetration (groove weld in a butt joint) or required minimum effective throat (fillet weld).
- (3) A maximum of 1/8 in. (3.2 mm) face reinforcement and 1/8 in. (3.2 mm) 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 1/8 in. (3.2 mm) for fillet welds.
- (4) No more than one visible pore or inclusion in any 1 in. (25 mm) of weld. Size of any pore or inclusion shall not exceed 0.25t, where t is the base metal thickness of the thinner member.



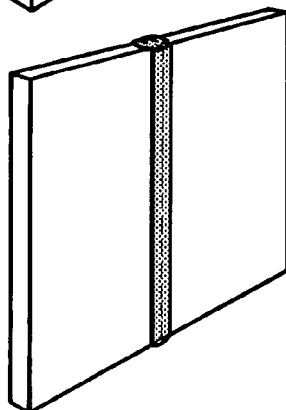
(A) TEST POSITION 1G, FLAT

QUALIFICATION IN POSITION
1G QUALIFIES FOR POSITIONS
1G AND 1F
(SEE FIG. 3)



(B) TEST POSITION 2G, HORIZONTAL

QUALIFICATION IN POSITION
2G QUALIFIES FOR POSITIONS
1G, 2G, 1F, AND 2F
(SEE FIG. 3)

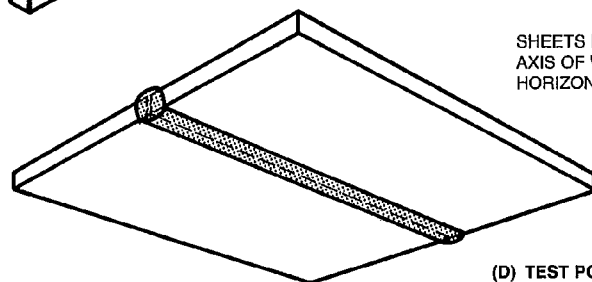


(C) TEST POSITION 3G, VERTICAL

SHEETS VERTICAL;
AXIS OF WELD
VERTICAL $\pm 15^\circ$

QUALIFICATION IN POSITION
3G QUALIFIES FOR POSITIONS
1G, 2G, 3G, 1F, 2F, AND 3F
(SEE FIG. 3)

METRIC VALUES	
in.	mm
3	75
6	150



(D) TEST POSITION 4G, OVERHEAD

SHEETS HORIZONTAL;
AXIS OF WELD
HORIZONTAL $\pm 15^\circ$

QUALIFICATION IN POSITION
4G QUALIFIES FOR POSITIONS
1G, 2G, 3G, 4G, 1F, 2F, 3F,
AND 4F
(SEE FIG. 3)

Figure 2 — Butt Joint Groove Weld Test Positions

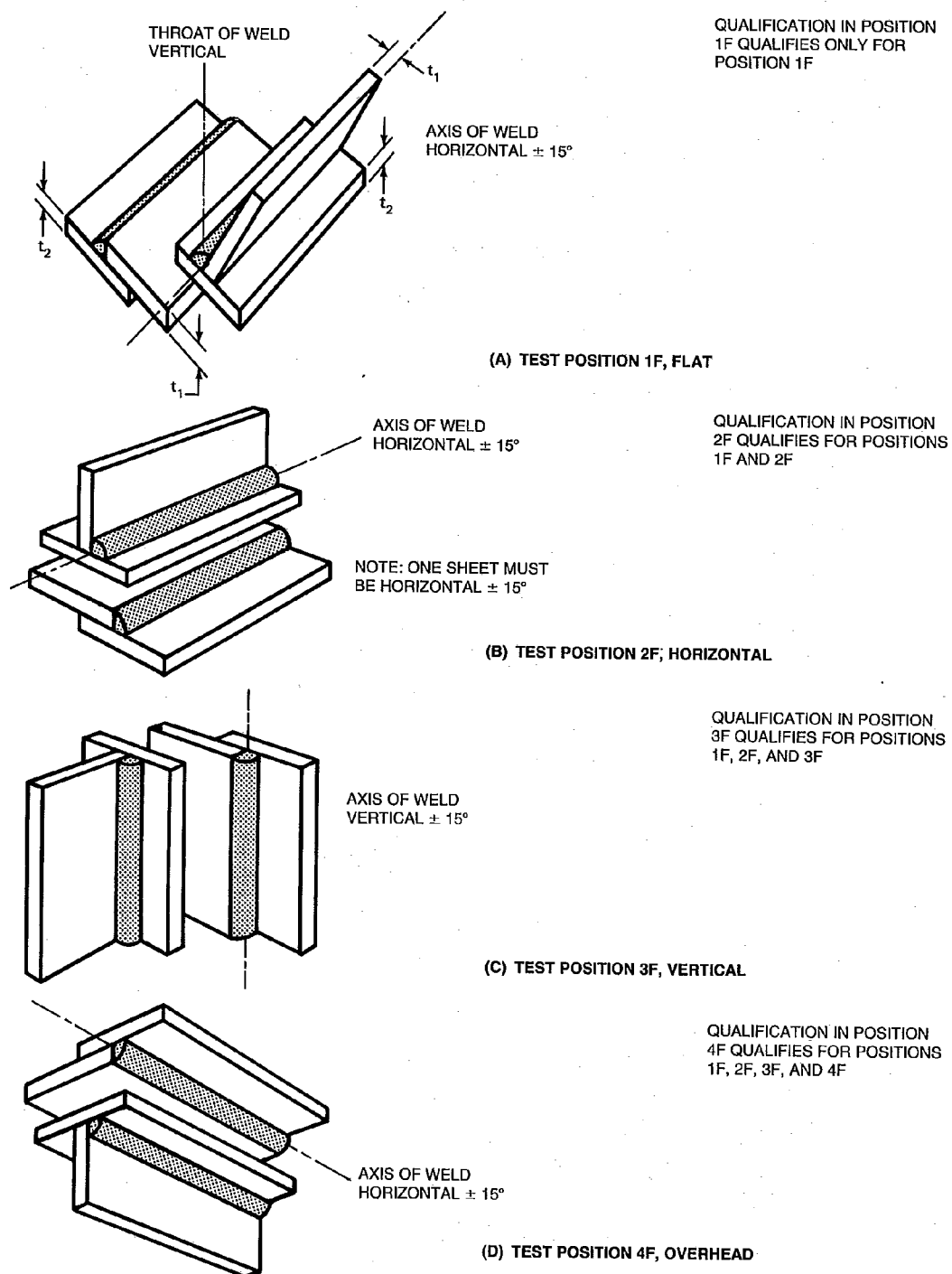


Figure 3 — Fillet Weld Test Positions

(5) No undercut exceeding 0.15t when the base metal being welded is 0.187 in. (4.8 mm) or thinner in thickness, nor exceeding 0.25t when the base metal thickness being welded is greater than 0.187 in. (4.8 mm).

(6) No cracks.

4.5 Responsibility for Tests

4.5.1 The Contractor shall be responsible for the qualification of welders or welding operators in accordance with this Code.

4.5.2 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. All required information for welder or welding operator qualification shall be recorded on an adequate form similar to the recommended form shown as Appendix F.

4.6 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 ceases to be employed by the Contractor's organization for which original qualification requirements were satisfied.

(2) 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.

(3) There is a specific reason to question the welder's or welding operator's ability.

5. Arc Welding Workmanship

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

5.1 Uniformity. Surfaces to be joined shall be uniform and free from cracks.

5.2 Cleanliness

5.2.1 Surfaces of, and adjacent to, a joint shall be free of loose scale, rust, grease, or foreign matter.

5.2.2 Tightly adherent spatter is not a cause for rejection.

5.3 Position. If a welding position is not explicitly specified by the Engineer or dictated by job conditions, joints shall be welded in the most favored position for which both the procedure and the welder are qualified (see 3.3.1.9 and 4.3.1.9).

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

5.5 Inspection of Workmanship. Welds shall be visually inspected and shall meet the acceptance criteria of section 6.

6. Inspection of 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 by the proposer and approved by the Engineer.

The Contractor shall conduct inspections to assure conformance to the acceptance criteria. The Engineer, with mutual agreement between the Owner and Contractor, may also conduct inspections of the work to assure conformance to the acceptance criteria. The specified acceptance criteria for the work shall be as follows:

6.1 Fusion. Complete fusion shall be obtained.

6.2 Penetration. Required joint penetration as specified for the application shall be present.

6.3 Reinforcement of Groove Welds. A maximum of 1/8 in. (3.2 mm) face reinforcement and 1/8 in. (3.2 mm) root reinforcement shall be acceptable.

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

6.5 Porosity or Inclusions. Some limited porosity or inclusion is acceptable, consistent with 6.1 of this Code and limited to the following:

6.5.1 One visible pore or inclusion no larger than 0.5t is permitted in any 1 in. (25 mm) of weld, where t equals the thickness of the thinner member.

6.5.2 Three visible pores or inclusions no larger than 0.25t also are permitted in any 1 in. (25 mm) of weld, where t equals the thickness of the thinner member.

6.6 Undercut. Undercut may not exceed 0.15t when the base metal thickness being welded is 0.187 in. (4.8 mm) or thinner, or exceed 0.25t when the base metal thickness being welded is greater than 0.187 in. (4.8 mm).

6.7 Crack. There shall be no cracks.

6.8 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

7. General Provisions for Braze Welding

7.1 Base Metal

7.1.1 Base metals to be joined under this Code shall include carbon steel, low alloy steel, chromium and chromium-nickel alloys, aluminum and aluminum alloys, copper and copper alloys, nickel and nickel-base alloys and coated metals.

7.1.2 Rust inhibitive coatings, galvanized coatings, or anti-spatter compounds may remain on the metal to be joined. (see section 12, Safety and Health, and Appendix J, for Safety Precautions.)

7.2 Filler Metal

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

7.2.2 Suggested filler metals are shown in Appendix A, Table A1. Only those filler metals with a melting temperature below that of the base metal are suitable for braze welding.

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

7.4 Terms and Definitions

7.4.1 Terms and definitions shall be interpreted in accordance with the latest edition of ANSI/AWS A3.0, *Standard Welding Terms and Definitions*, including terms for braze welding.

7.4.2 Supplemental definitions (marked with an asterisk) and terms of significant importance to sheet metal braze welding taken from A3.0 are given in Appendix B.

7.4.3 The Engineer referred to in this Code is the duly designated person who acts on behalf of the owner in all matters within the scope of this Code.

7.4.4 The Contractor designates the party responsible for performing the braze welding under the Code. The term is used collectively to mean Contractor, Fabricator, Erector, or Manufacturer.

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

7.6 Standard Units of Measurements. The values stated in U.S. Customary Units are to be regarded as the standard. The metric (SI) values of U.S. Customary Units are approximate.

8. Braze Welding Procedure Qualification

8.1 Prior Procedure Qualification

8.1.1 This Code does NOT provide prequalified status for any braze welding procedure for sheet metal.

8.1.2 The Engineer exercising proper discretion may accept evidence of previous qualification of specific procedures to be used on work being performed under this Code (all required information shall be recorded on an adequate Procedure Qualification Record (PQR) form similar to that shown in Appendix E).

Braze welding procedures qualified in accordance with section 2 of AWS B2.1-84 may be used, provided they also meet the requirements of section 8 of this code.

8.2 Required Procedure Qualification Tests

8.2.1 Welding Procedure Specification. Each braze welding procedure to be used in conjunction with this Code shall be prepared as a Welding Procedure Specification (WPS) to be used in fabrication and installation. The use of a qualified procedure shall be the responsibility of the Contractor. All required information for the WPS shall be recorded on an adequate form similar to that shown in Appendix D.

8.2.2 Typical Joints. Typical joint designs and details of joints are given in Appendix G, Part B of this Code. Qualification of a groove weld joint may be used as a qualification of a fillet weld joint, but not vice versa.

8.2.3 Preparing Joint Chosen for Testing. The chosen joint design shall be prepared as a longitudinal joint between two 3 in. (75 mm) by 6 in. (150 mm) sheets, assembled as one of the designs sketched in Figure 4 or as the actual joint to be used. Qualification testing using the butt joint in Figure 4 shall qualify all groove and fillet weld joint designs.

8.2.4 Braze Welding the Test Joint. The joint shall be braze welded using the process specified in the WPS (see 8.2.1).

8.3 Limitations of Procedure Qualifications. 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 the following paragraphs. The variables shall be recorded on an adequate PQR form such as shown in Appendix E.

10

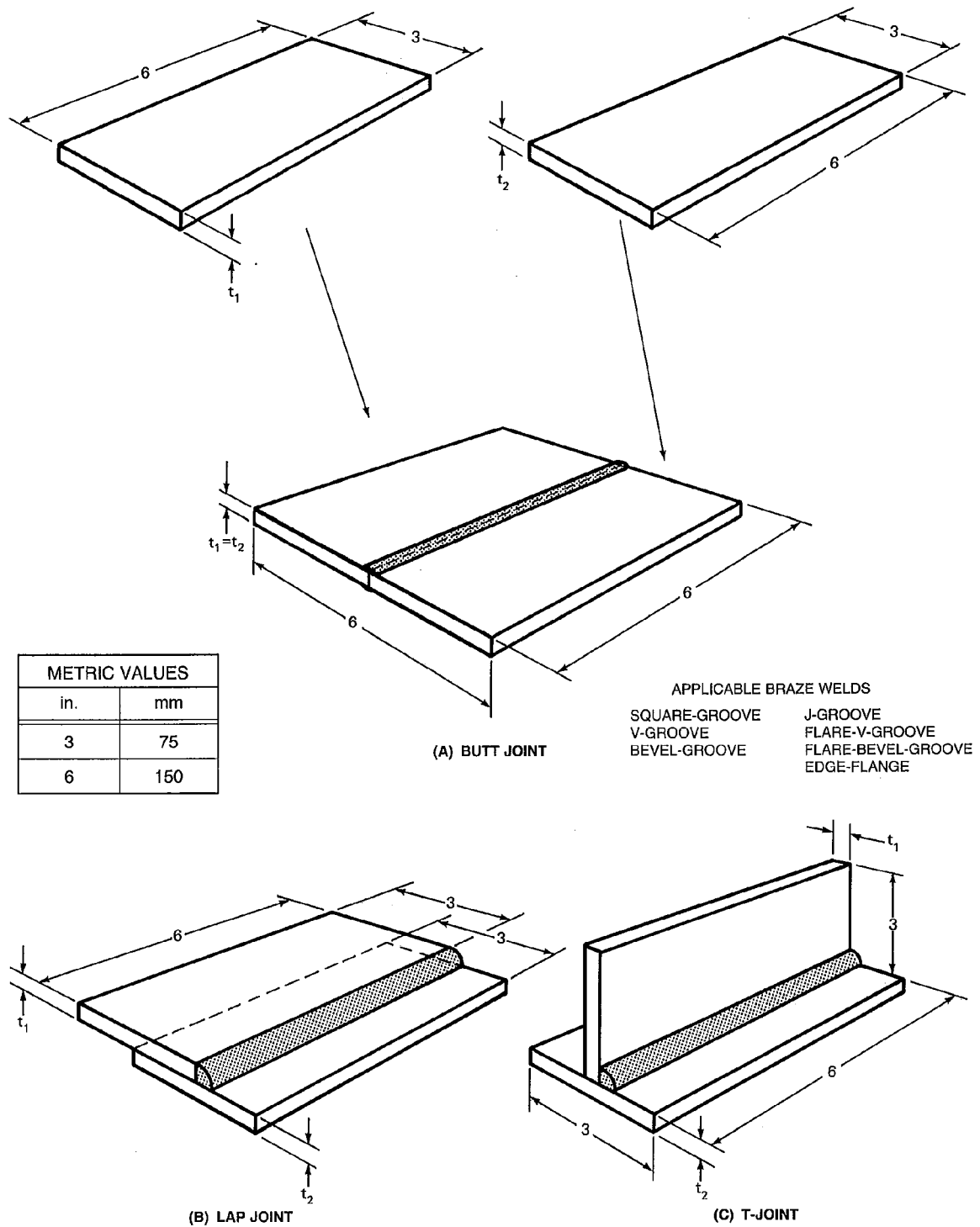


Figure 4 — Braze Weld Procedure Qualification Test Assemblies

8.3.1 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 percent maximum carbon and 0.50 percent maximum chromium
- (2) High-strength, low alloy steels
- (3) Chromium and chromium-nickel steels
- (4) Copper and copper alloys
- (5) Nickel and nickel alloys
- (6) Aluminum and aluminum alloys

8.3.2 Coating material. The addition or change, but not deletion of coating material on the base metal requires requalification. (Note: Anti-spatter compound is not considered a coating material.)

8.3.3 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 8.3.3 (1), the following qualification tests may be used to cover the complete range of all sheet metal thicknesses as defined in Appendix B and C.

(a) A qualification braze weld performed on 18 gauge metal shall provide qualification for that procedure for metals 16 gauge and thinner. (See Appendix C for Equivalents)

(b) A qualification braze weld performed on 10 gauge metal shall provide qualification for that procedure for metal as thin as 16 gauge and thicker, up to $2t$ thickness, where t is the thickness of the thinner sheet qualified. (See Appendix C for Equivalents.)

(c) Procedures qualified under (a) and (b) qualify braze fillet welds for all thicknesses of base metal.

8.3.4 The omission, but not the addition, of backing material requires requalification.

8.3.5 A change in filler metal "F" number requires requalification. (see Appendix A, Table A1)

8.3.6 A change in braze welding process, including method of application (manual, semiautomatic, automatic), requires requalification.

8.3.7 Changes in the type of current or polarity as indicated below require requalification.

- (1) ac to dc or vice versa
- (2) dcen to dcep or vice versa

8.3.8 A change in shielding gas requires requalification.

8.3.9 Requalification is required when the braze welding position (Figures 5 and 6) is changed except as noted below.

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

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

(3) Qualification in the vertical position shall qualify the procedure in the flat, horizontal and vertical positions.

(4) Qualification in the overhead position shall qualify the procedure in all positions.

8.4 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).

8.4.1 Groove Braze Welds. Except for the first and last 0.5 in. (13 mm), the braze groove weld shall exhibit the following:

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

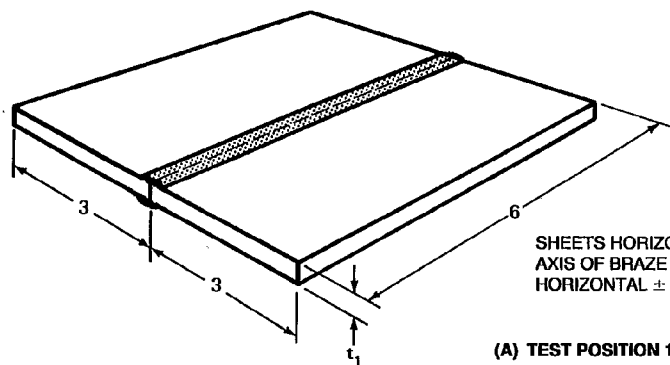
8.4.2 Fillet Welds. Except for the first and last 0.5 in. (13 mm), braze welds shown in Figure 4 (b) and (c), shall exhibit the following:

- (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 1/8 in. (3.2 mm).
- (3) No more than one visible pore or inclusion in any 1 in. (25 mm) of braze weld. Size of any pore or inclusion shall not exceed $0.25t$, where t is the base metal thickness of the thinner member.
- (4) No cracks.

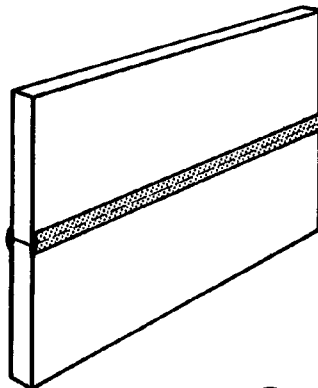
8.5 Responsibility for Test

8.5.1 The Contractor performing work in accordance with this Code shall be responsible for qualification of the welding procedures to be used. However, to avoid duplication of effort and, subject to the approval of the Customer, welding procedures qualified by a technically competent group or agency may be used, subject to the following conditions:

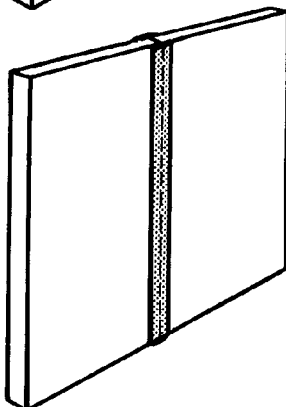
(1) The welding procedure specification shall meet all of the procedure qualification requirements of this Code.

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

QUALIFICATION IN POSITION
1G QUALIFIES FOR POSITIONS
1G AND 1F
(SEE FIG. 6)

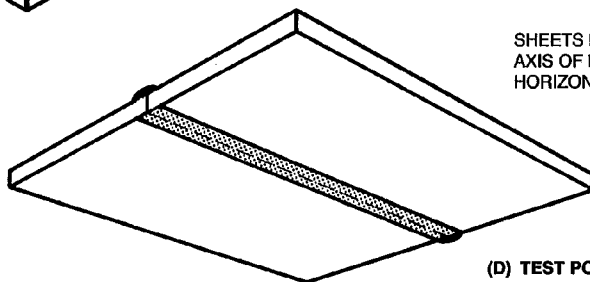
**(B) TEST POSITION 2G, HORIZONTAL**

QUALIFICATION IN POSITION
2G QUALIFIES FOR POSITIONS
1G, 2G, 1F, AND 2F
(SEE FIG. 6)

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

QUALIFICATION IN POSITION
3G QUALIFIES FOR POSITIONS
1G, 2G, 3G, 1F, 2F, AND 3F
(SEE FIG. 6)

METRIC VALUES	
in.	mm
3	75
6	150

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

QUALIFICATIONS IN POSITION
4G QUALIFIES FOR POSITIONS
1G, 2G, 3G, 4G, 1F, 2F, 3F,
AND 4F
(SEE FIG. 6)

Figure 5 — Braze Groove Weld Test Positions

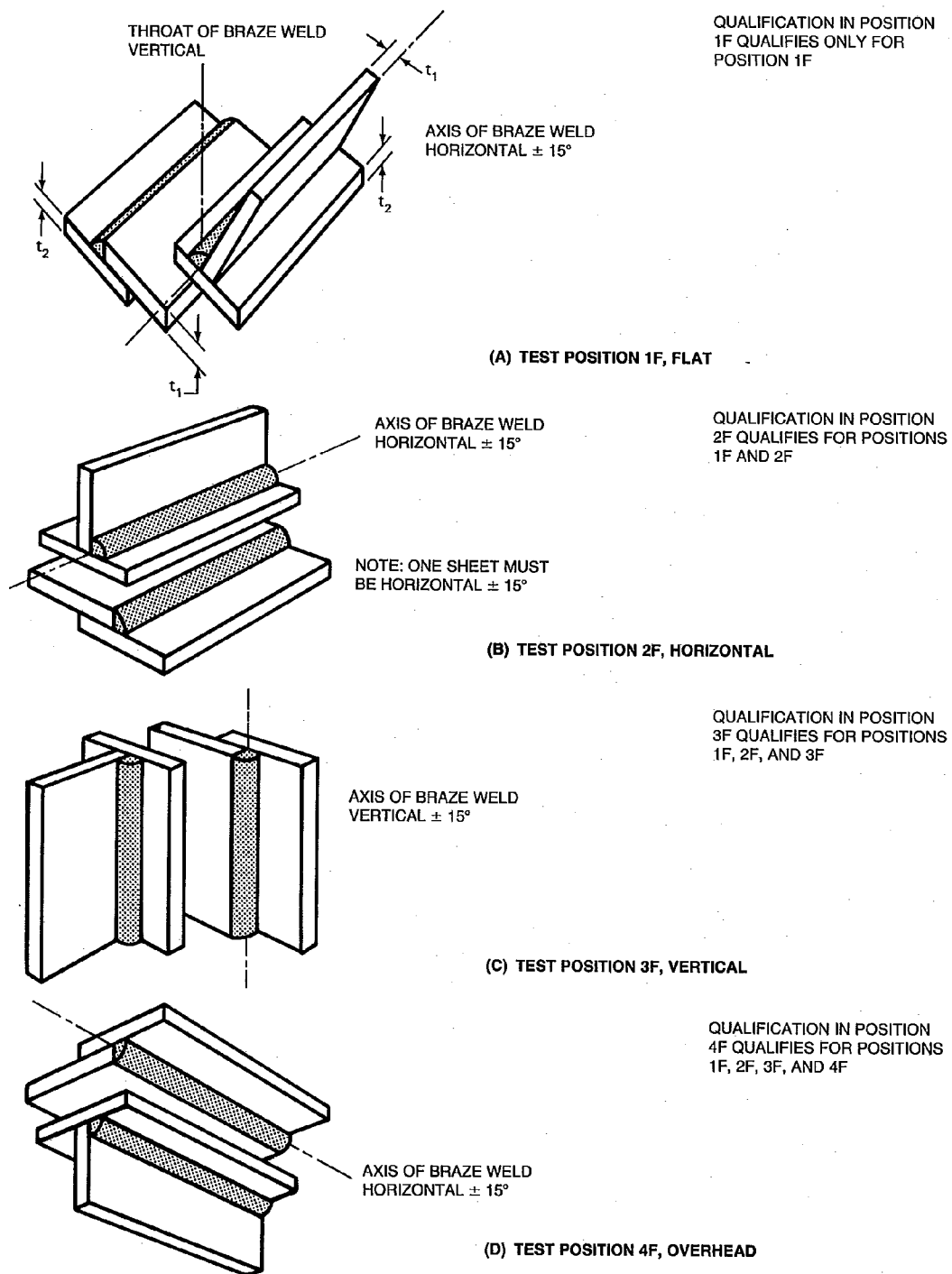


Figure 6 — Braze Fillet Weld Test Positions

(2) The Contractor shall accept the procedure thus qualified.

(3) The Contractor shall qualify at least one welder to the procedure.

(4) The Contractor shall assume specific responsibility for the procedure qualification work done by signing and dating the Welding Procedure Specification.

8.5.2 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 (see Appendix D and E for suggested forms).

8.6 Duration of Procedure Qualification

8.6.1 Braze welding procedures qualified under this Code and previous editions of ANSI/AWS D9.1 superseded by this Code, shall remain qualified until a revision of the Code requires requalification.

8.6.2 Procedures shall be requalified whenever a change is made in an essential variable.

9. Qualification of Braze Welders and Braze Welding Operators

9.1 Prior Braze Welder and Braze Welding Operator Qualifications

9.1.1 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.

9.1.2 Braze welders or braze welding operators performing procedure qualification test braze welds meeting the procedure qualification acceptance criteria in section 8, Braze Welding Procedure Qualifications, shall be considered as qualified to perform braze welding without additional qualification testing, subject to the limitations defined in 9.3.

9.2 Required Braze Welder and Braze Welding Operator Qualification Tests

9.2.1 General. All braze welders and braze welding operators permitted to braze weld under this Code shall be qualified by test.

9.2.2 Braze Groove Welds in a Butt Joint. Test coupon dimensions and test positions for qualification for braze welds in a butt joint are given in Figure 5.

9.2.3 Braze Fillet Welds. Qualification for braze fillet welds is automatically granted to braze welders and braze welding operators who qualify for a braze groove weld in a butt joint (Figure 5). Either a lap joint fillet or a T-joint fillet may be braze welded at the option of the

Contractor, unless otherwise specified in the WPS. Test positions for qualification for fillet braze welds are given in Figure 6.

9.3 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 the following paragraphs.

9.3.1 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 percent maximum carbon and 0.50 percent maximum chromium
- (2) High-strength, low alloy steels
- (3) Chromium and chromium-nickel steels
- (4) Copper and copper alloys
- (5) Nickel and nickel alloys
- (6) Aluminum and aluminum alloys

9.3.2 Coating material. The addition or change, but not deletion, of coating material on the base metal requires requalification. (Note: Anti-spatter compound is not considered a coating material.)

9.3.3 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 9.3.3 (1), the following qualification tests may be used to cover the complete range of all sheet metal thicknesses as defined in Appendices B and C.

(a) A qualification braze weld performed on 18 gauge metal shall provide qualification for that braze welder or braze welding operator for metals 16 gauge and thinner. (See Appendix C for Equivalents.)

(b) A qualification braze weld performed on 10 gauge metal shall provide qualification for that braze welder or braze welding operator for metals as thin as 16 gauge and thicker, up to 2t thickness, where t is the thickness of the thinner base metal qualified. (See Appendix C for Equivalents.)

(c) Braze welders qualified under (a) and (b) are also qualified to make fillet braze welds on all thicknesses of base metal.

9.3.4 The omission, but not the addition, of backing requires requalification.

9.3.5 A change in filler metal "F" number requires requalification. (See Appendix A, Table A1).

9.3.6 A change in braze welding process, including method of application requires requalification except as listed 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.

9.3.7 Changes in the type of welding current or polarity as indicated below require requalification.

(1) ac to dc or vice-versa

(2) dcen to dcep or vice-versa

9.3.8 A change in shielding gas requires requalification.

9.3.9 Requalification is required when the welding position (see Figures 5 and 6) is changed except as noted below.

(1) Qualification in the flat position shall qualify braze welder or braze welding operator only in the flat position.

(2) Qualification in the horizontal position shall qualify the braze welder or braze welding operator in both the flat and horizontal positions.

(3) Qualification in the vertical position shall qualify the braze welder or braze welding operator in the flat, horizontal, and vertical positions.

(4) Qualification in the overhead position shall qualify the braze welder or braze welding operator in all positions.

9.4 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).

9.4.1 Except for the first and last 0.5 in. (13 mm), 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 equals the thickness of the thinner base metal and shall not exceed 1/8 in. (3.2 mm). Root reinforcement shall not exceed 1/8 in. (3.2 mm).

(3) For fillet braze welds, the minimum effective throat shall be as specified for the application. Convexity shall not exceed 1/8 in. (3.2 mm).

(4) No more than one visible pore or inclusion in any 1 in. (25 mm) of weld. Size of any pore or inclusion shall not exceed 0.25t, where t is the thickness of the thinner member.

(5) There shall be no cracks.

9.5 Responsibility for Tests

9.5.1 The Contractor shall be responsible for the qualification of braze welders or braze welding operators in accordance with this Code.

9.5.2 Records of braze welder or braze welding operator qualification tested in accordance with this Code shall be maintained by the Contractor and shall be available for inspection as required by the Engineer. 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 Appendix F.

9.6 Duration of Qualification. Qualification of braze welders or braze welding operators tested to the requirements of this Code shall remain in effect unless one of the following apply:

(1) The braze welder or braze welding operator ceases to be employed with the Contractor's organization for which original qualification requirements were satisfied.

(2) 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.

(3) There is a specific reason to question the braze welder's or braze welding operator's ability.

10. Braze Welding Workmanship

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

10.1 Uniformity

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

10.1.2 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.

10.2 Cleanliness

10.2.1 Surfaces of, and adjacent to, a joint shall be free of loose scale, oxides, rust, grease, oil, or foreign matter.

10.2.2 Tightly adherent spatter is not a cause for rejection.

10.3 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 (see 8.3.1.9 and 9.3.1.9).

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

10.5 Inspection of Workmanship. Welds shall be inspected visually and shall meet the acceptance criteria of section 11.

11. Inspection of 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 by the proposer and approved by the Engineer.

The Contractor shall conduct inspections to assure conformance to the acceptance criteria. The Engineer, with mutual agreement between the Owner and Contractor, may also conduct inspections of the work to assure conformance to the acceptance criteria. The specified acceptance criteria for the work shall be as follows:

11.1 Bonding. Metallic bonding, adequate for the intended application shall be obtained.

11.2 Reinforcement of Braze Groove Welds in Butt Joints. Face reinforcement shall be a minimum of $0.5t$ where t equals the thickness of the thinner base metal and shall not exceed $1/8$ in. (3.2 mm). Root reinforcement shall not exceed $1/8$ in. (3.2 mm).

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

11.4 Porosity or Inclusions. Some limited porosity or inclusions are acceptable, consistent with 11.1 of this Code and limited to the following:

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

11.4.2 Three visible pores or inclusions no larger than $0.25t$ are also permitted in any 1 in. (25 mm) where t equals the thickness of the thinner member.

11.5 Cracks. There shall be no cracks.

11.6 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 frequently is observed and is not a basis for rejection.)

12. Safety and Health

Use of the welding processes and consumables described in this document, Parts A and B, should only be undertaken in accordance with the required safety precautions mandated by OSHA and recommended procedures contained in the document, ANSI/ASC Z49.1, *Safety in Welding and Cutting*, available from AWS. For the users convenience, some additional safety information is included in this document as Appendix J. The manufacturer's Operating Manual and Safety Instructions should always be carefully studied and complied with when operating welding or related equipment.

Appendix A

Recommended Filler Metals

(This Appendix is not a part of ANSI/AWS D9.1-90, *Sheet Metal Welding Code*, but is included for information purposes only.)

Table A1
F Number Grouping of Welding Electrodes and Rods

ASME* F Number	AWS Specification No.	AWS Classification
Steel and Steel Alloys		
1	A5.1 & A5.5	EXX20, EXX24, EXX27, EXX28
2	A5.1 & A5.5	EXX12, EXX13, EXX14
3	A5.1 & A5.5	EXX10, EXX11
4	A5.1 & A5.5	EXX15, EXX16, EXX18
4	A5.4 (ferritic)	EXXX-15, EXXX-16
5	A5.4 (austenitic)	EXXX-15, EXXX-16
6	A5.2	RXX
6	A5.9	ERXXX
6	A5.18	ERXXS-X
6	A5.20	EXXT-X
6	A5.22	EXXT-X
6	A5.28	ERXXS-X and EXXC-X
6	A5.29	EXXTX-X
Aluminum and Aluminum-Base Alloys		
21	A5.10	ER1100
22	A5.10	ER5554, ER5356, ER5556, ER5183
		ER5654
23	A5.10	ER4043, ER4047, ER4145
24	A5.10	RSC51A, R346.0
Copper and Copper-Base Alloys		
31	A5.6	ECu
31	A5.7	ERCu
31	A5.27	RBCu

* From American Society of Mechanical Engineers, Boiler and Pressure Vessel Code, Section IX, QW 432.

** These filler metals frequently are used for the braze welding of carbon and low alloy steels.

(continued)

Table A1 (Continued)

ASME F Number	AWS Specification No.	AWS Classification
32	A5.6	ECuSi
32	A5.7	ERCuSi-A**
32	A5.27	RBCuSi-A**
33	A5.6	ECuSn-A, ECuSn-C
33	A5.7	ERCuSn-A
34	A5.6	ECuNi
34	A5.7	ERCuNi**
35	A5.27	RBCuZn-A** RCuZn-B RBCuZn-C** RBCuZn-D**
36	A5.6	ECuAl-A2 ECuAl-B
	A5.7	ERCuAl-A1 ERCuAl-A2** ERCuAl-A3
37	A5.6	ECuNiAl ECuMnNiAl
	A5.7	ERCuNiAl ERCuMnNiAl
Nickel and Nickel-Base Alloys		
41	A5.11	ENi-1
41	A5.14	ErNi-1
42	A5.11	ENiCu-7
42	A5.14	ERNiCu-7
43	A5.11	ENiCrFe-1
43	A5.11	ENiCrFe-2
43	A5.11	ENiCrFe-3
43	A5.11	ENiCrFe-4
43	A5.11	ENiCrMo-2
43	A5.11	ENiCrMo-3
43	A5.14	ERNiCr-3

** These filler metals frequently are used for the braze welding of carbon and low alloy steels.

Table A1 (Continued)

ASME F Number	AWS Specification No.	AWS Classification
43	A5.14	ERNiCrFe-5
43	A5.14	ERNiCrFe-6
43	A5.14	ERNiCrMo-2
43	A5.14	ERNiCrMo-3
44	A5.11	ENiMo-1
44	A5.11	ENiMo-3
44	A5.11	ENiCrMo-4
44	A5.11	ENiCrMo-5
44	A5.14	ENiMo-1
44	A5.14	ERNiMo-2
44	A5.14	ERNiMo-7
44	A5.14	ERNiCrMo-4
44	A5.14	ERNiCrMo-5
44	A5.14	ERNiCrMo-7
45	A5.11	ENiCrMo-1
45	A5.14	ERNiCrMo-1
45	A5.14	ERNiFeCr-1
45	A5.14	ERNiCrMo-8

Appendix B

Terms and Definitions

(This Appendix is not a part of ANSI/AWS D9.1-90, *Sheet Metal Welding Code*, but is included for information purposes only.)

The terms and definitions in this Appendix are divided into two categories: (1) General welding terms compiled by the AWS Committee on Definitions and Symbols in A3.0-89, and (2) other terms, preceded by asterisks, which are defined as they relate to this Code.

A

abrasive blasting. A method of cleaning or surface roughening by a forcibly projected stream of abrasive particles.

acceptable weld. A weld that meets all the requirements and the acceptance criteria prescribed by the welding specifications.

arc plasma. A gas that has been heated by an electric arc to at least a partially ionized condition, enabling it to conduct an electric current.

arc seam weld. A seam weld made by an arc welding process.

arc spot weld. A spot weld made by an arc welding process.

arc time. The time during which an arc is maintained in making an arc weld.

arc voltage. The voltage across the welding arc.

arc welding (AW). A group of welding processes that produces coalescence of workpieces by heating them with an arc. The processes are used with or without the application of pressure and with or without filler metal.

autogeneous weld. A fusion weld made without filler metal.

automatic welding. Welding with equipment that requires only occasional or no observation of the welding, and no manual adjustment of the equipment controls.

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

B

backhand welding. A welding technique in which the welding torch or gun is directed opposite the progress of welding.

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

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

***backing strip.** Backing in the form of a strip.

backing weld. Backing in the form of a weld.

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

***base metal specification.** The recognized specification (usually ASTM) designating the composition or properties, or both, of the selected base metal.

brazing. A welding process variation that uses a filler metal with a liquidus above 450°C (840°F) and below the solidus of the base metal. The base metal is not melted. Unlike brazing, in braze welding the filler metal is not distributed in the joint by capillary action.

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

C

***carbon arc braze welding (CABW).** A braze welding process which produces coalescence of metals by heating them with an arc between a carbon electrode and the work. No shielding is used.

carbon arc welding (CAW). An arc welding process that uses an arc between a carbon electrode and the weld pool. The process is used with or without shielding and without the application of pressure.

coalescence. The growing together or growth into one body of the materials being welded.

***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.

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

complete joint penetration. Penetration of weld metal through the thickness of a joint with a groove weld.

consumable insert. Preplaced filler metal that is completely fused into the joint root and becomes part of the weld.

contact tube. A device which transfers current to a continuous electrode.

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

***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.

crack. A fracture type discontinuity characterized by a sharp tip and high ratio of length and width to opening displacement.

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

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

D

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

defective weld. A weld containing one or more defects.

deposited metal. Filler metal that has been added during welding.

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

dilution. The change in chemical composition of a welding filler metal caused by the admixture of the base metal or previous weld metal in the weld bead. It is measured by the percentage of base metal or previous weld metal in the weld bead.

dip transfer. A nonstandard term for **short circuiting transfer**.

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

drop-through. An undesirable sagging or surface irregularity, usually encountered when brazing or welding near the solidus of the base metal, caused by overheating with rapid diffusion or alloying between the filler metal and the base metal.

E

edge-flange weld. A flange weld with two members flanged at the location of welding.

edge joint. A joint between the edges of two or more parallel or nearly parallel members.

edge preparation. The surface prepared on the edge of a member for welding.

edge weld. A weld in an edge joint.

electrode. A component of the electrical circuit that terminates at the arc, molten conductive slag, or base metal.

bare electrode. A filler metal electrode that has been produced as a wire, strip, or bar with no coating or covering other than that which is incidental to its manufacture or preservation.

carbon electrode. A nonfiller metal electrode used in arc welding and cutting, consisting of a carbon or graphite rod, which may be coated with copper or other materials.

composite electrode. A generic term for multicomponent filler metal electrodes in various physical forms such as stranded wires, tubes, and covered wire.

covered electrode. A composite filler metal electrode consisting of a core of a bare electrode or metal cored electrode to which a covering sufficient to provide a slag layer on the weld metal has been applied. The covering may contain materials providing such functions as shielding from the atmosphere, deoxidation, and arc stabilization, and can serve as a source of metallic additions to the weld.

flux cored electrode. A composite tubular filler metal electrode consisting of a metal sheath and a core of various powdered materials, producing a complete slag cover on the face of a weld bead. External shielding may be required.

lightly covered electrode. A filler metal electrode consisting of a metal wire with a light coating applied subsequent to the drawing operation, primarily for stabilizing the arc.

metal cored electrodes. A composite tubular electrode consisting of a metal sheath and a core of various powdered materials, producing no more than slag islands on the face of a weld bead. External shielding may be required.

metal electrode. A filler or nonfiller metal electrode used in arc welding and cutting that consists of a metal wire or rod that has been manufactured by any method and that is either bare or covered.

stranded electrode. A composite filler metal electrode consisting of stranded wire that may mechanically enclose materials to improve properties, stabilize the arc, or provide shielding.

tungsten electrode. A nonfiller metal electrode used in arc welding, arc cutting, and plasma spraying, made principally of tungsten.

***engineer.** The duly designated person who acts for and in behalf of the owner on all matters within the scope of this Code.

F

face of weld. See **weld face**.

face reinforcement. Weld reinforcement at the side of the joint from which welding was done.

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

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

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

fillet weld. A weld of approximately triangular cross section joining two surfaces approximately at right angles to each other in a lap joint, T-joint, or corner joint.

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

flange weld. A weld made on the edges of two or more joint members, at least one of which is flanged.

flange weld size. The weld metal thickness measured at the weld root.

flaw. An undesirable discontinuity. See also **defect**.

flowability. The ability of molten filler metal to flow or spread over a metal surface.

flux. A material used to hinder or prevent the formation of oxides and other undesirable substances in molten metal and on solid metal surfaces, and to dissolve or otherwise facilitate the removal of such substances.

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

forehand welding. A welding technique in which the welding torch or gun is directed toward the progress of welding.

***fusion.** The melting together of filler metal and base metal (substrate), or of base metal only which results in coalescence.

fusion face. A surface of the base metal that will be melted during welding.

fusion welding. Any welding process that uses fusion of the base metal to make the weld.

G

gas metal arc welding (GMAW). An arc welding process which produces coalescence of metals by heating them with an arc between a continuous filler metal (consumable) electrode and the work. Shielding is obtained entirely from an externally supplied gas or gas mixture. Some variations of this process are called MIG or CO₂ welding (nonstandard terms).

gas tungsten arc welding (GTAW). An arc welding process that uses an arc between a tungsten electrode (nonconsumable) and the weld pool. The process is used with shielding gas and without the application of pressure.

globular transfer, arc welding. The transfer of molten metal in large drops from a consumable electrode across the arc.

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

I

inadequate joint penetration. Joint penetration that is less than that specified.

inclusion. Entrapped foreign solid material, such as slag, flux, tungsten, or oxide.

incomplete fusion. A weld discontinuity in which fusion did not occur between weld metal and fusion faces or adjoining weld beads.

inert gas. A gas that normally does not combine chemically with materials.

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

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

J

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

joint clearance. The distance between the faying surfaces of a joint. In brazing, this distance is referred to as that which is present before brazing, at the brazing temperature, or after brazing is completed.

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

***joint welding procedure.** The materials, detailed methods, and practices employed in the welding of a particular joint.

K

keyhole welding. A technique in which a concentrated heat source penetrates completely through a workpiece, forming a hole at the leading edge of the weld pool. As the heat source progresses, the molten metal fills in behind the hole to form the weld bead.

L

lack of fusion. A nonstandard term for **incomplete fusion**.

lack of penetration. A nonstandard term for **incomplete joint penetration**.

lap joint. A joint between two overlapping members.

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

liquidus. The lowest temperature at which a metal or an alloy is completely liquid.

M

machine welding. A nonstandard term when used for mechanized welding.

manual welding. Welding with the torch, gun, or electrode holder held and manipulated by hand. Variations of this term are manual brazing, manual soldering, manual thermal cutting, and manual thermal spraying. See also **automatic welding**, **mechanized welding**, and **semiautomatic welding**.

mechanized welding. Welding with equipment that requires manual adjustment of the equipment controls in response to visual observation of the welding, with the torch, gun, or electrode holder held by a mechanical device. Variations of this term are mechanized brazing, mechanized soldering, mechanized thermal cutting, and mechanized thermal spraying. See also **automatic welding**, **manual welding**, and **semiautomatic welding**.

metallic bond. The principal bond that holds metals together. It is a primary bond arising from the increased spatial extension of the valence electron wave functions when an aggregate of metal atoms is brought close together.

MIG welding. A nonstandard term for **gas metal arc welding** and **flux cored arc welding**.

molten weld pool. A nonstandard term for **weld pool**.

O

open circuit voltage. The voltage between the output terminals of the power source when no current is flowing to the torch or gun.

***open corner joint.** An offset corner joint with only a line of contact between the members. See Appendix G, Figure GA11.

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

oxidizing flame. An oxyfuel gas flame in which there is an excess of oxygen, resulting in an oxygen-rich zone extending around and beyond the cone.

oxyacetylene welding (OAW). An oxyfuel gas welding process that uses acetylene as the fuel gas. The process is used without the application of pressure.

oxyfuel gas welding (OFW). A group of welding processes that produces coalescence of workpieces by heating them with an oxyfuel gas flame. The processes are used with or without the application of pressure and with or without filler metal.

oxyhydrogen welding (OHW). An oxyfuel gas welding process that uses hydrogen as the fuel gas. The process is used without the application of pressure.

P

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

***pass.** See **weld pass**.

peel test. A destructive method of testing that mechanically separates a lap joint by peeling.

pilot arc. A low current arc between the electrode and the constricting nozzle of the plasma arc torch to ionize the gas and facilitate the start of the welding arc.

plasma. See **arc plasma**.

plasma arc welding (PAW). An arc welding process that uses a constricted arc between a nonconsumable electrode and the weld pool (transferred arc) or between the electrode and the constricting nozzle (nontransferred arc). Shielding is obtained from the ionized gas issuing from the torch, which may be supplemented by an auxiliary source of shielding gas. The process is used without the application of pressure.

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

***pore.** A single cavity type discontinuity.

porosity. Cavity type discontinuities formed by gas entrapment during solidification.

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

postheating. The application of heat to an assembly after welding, brazing, soldering, thermal spraying, or thermal cutting.

preheat. The heat applied to the base metal or substrate to attain and maintain preheat temperature.

preheat temperature. The temperature of the base metal or substrate in the welding, brazing, soldering, thermal spraying or thermal cutting area immediately before these operations are performed.

procedure. The detailed elements of a process or method used to produce a specific result.

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

***Procedure Qualification Record (PQR).** A document providing the actual welding variables used to produce an acceptable test weld and the results of tests conducted on the weld for the purpose of qualifying a welding procedure specification (see Appendix E).

process. A grouping of basic operational elements used in welding, thermal cutting, or thermal spraying.

pulsed gas metal arc welding (GMAW-P). A gas metal arc welding variation in which the current is pulsed. See also **pulsed power welding**.

pulsed gas tungsten arc welding (GTAW-P). A gas tungsten arc welding variation in which the current is pulsed.

pulsed power welding. Any arc welding process variation in which the power is cyclically programmed to pulse so that effective but short duration values of a parameter can be utilized. Such short duration values are significantly different from the average value of the parameter. Equivalent terms are pulsed voltage or pulsed current welding; see also **pulsed spray welding**.

pulsed spray welding. An arc welding process variation in which the current is pulsed to utilize the advantages of the spray mode of metal transfer at average currents equal to or less than the globular to spray transition current.

R

reducing flame. A gas flame having a reducing effect (excess fuel gas).

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

reverse polarity. A nonstandard term for **direct current electrode positive**.

root penetration. The distance the weld metal extends into the joint root.

root reinforcement. Reinforcement of weld at the side other than that from which welding was done.

S

seal welds. Any weld designated primarily to provide a specific degree of tightness against leakage.

seam weld. A continuous weld made between or upon overlapping members, in which coalescence may start and occur on the faying surfaces, or may have proceeded from the surface of one member. The continuous weld may consist of a single weld bead or a series of overlapping spot welds.

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

***sheet metal.** Sheet metal can be coated or uncoated, ferrous or nonferrous metal as thick as 3 gauge [0.239 in. (6.07 mm)] or as thin as 30 gauge [0.0157 in. (0.4 mm)].

shielded metal arc welding (SMAW). An arc welding process which produces coalescence of metals by heating them with an arc between a covered metal electrode and the work. Shielding is obtained from decomposition of the electrode covering. Pressure is not used and filler metal is obtained from the electrode.

short arc. A nonstandard term when used for short circuit arc.

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

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

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

spot weld. A weld made between or upon overlapping members in which coalescence may start and occur on the faying surfaces or may proceed from the outer surface of one member. The weld cross section (plan view) is approximately circular.

spray transfer (arc welding). Metal transfer in which molten metal from a consumable electrode is propelled axially across the arc in small droplets.

***stick welding.** A nonstandard term for **shielded metal arc welding**.

stitch weld. A nonstandard term for **intermittent weld**.

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

T

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

throat of a fillet weld

actual throat. The shortest distance from the root of a fillet weld to its face.

effective throat. The minimum distance minus any convexity between the weld root and the face of a fillet weld.

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

TIG welding. A nonstandard term for **gas tungsten arc welding**.

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

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.

twin carbon arc welding CAW-T. A carbon arc welding process variation that uses an arc between two carbon electrodes and no shielding.

U

underbead crack. A crack in the heat-affected zone generally not extending to the surface of the base metal.

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

underfill. A depression on the face of the weld or root surface extending below the surface of the adjacent base metal.

W

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

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

weld bead. A weld resulting from a pass.

weld crack. A crack located in the weld metal or heat-affected zone.

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

weld metal. The portion of a fusion weld that has been completely melted during welding.

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

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

weld reinforcement. Weld metal in excess of the quantity required to fill a joint. See also **face reinforcement** and **root reinforcement**.

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

welder. One who performs manual or semiautomatic welding.

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

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

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

welding operator. One who operates machine or automatic welding equipment.

welding procedure. The detailed methods and practices

including all welding procedure specifications involved in the production of a weldment. See **welding procedure specification**.

welding procedure specification (WPS). A document providing in detail the required variables for a specific application to assure repeatability by properly trained welders and welding operators. (See Appendix D)

***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.

welding rod. A form of welding filler metal, normally packaged in straight lengths, that does not conduct the welding current.

welding technique. The details of a welding procedure which are controlled by the welder or welding operator.

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

Appendix C

Gauge Numbers and Equivalent Thicknesses in U.S. Customary Units (Standard) and S.I. Units

(This Appendix is not a part of ANSI/AWS D9.1-90, *Sheet Metal Welding Code*, but is for information purposes only.)

Table C1
Hot-Rolled and Cold-Rolled Steel Sheet

Manufacturer's Standard Gauge No.	Thickness	
	in.	mm
3	0.2391	6.07
4	0.2242	5.70
5	0.2092	5.31
6	0.1943	4.94
7	0.1793	4.55
8	0.1644	4.18
9	0.1495	3.80
10	0.1345	3.42
11	0.1196	3.04
12	0.1046	2.66
13	0.0897	2.28
14	0.0747	1.90
15	0.0673	1.71
16	0.0598	1.52
17	0.0538	1.37
18	0.0478	1.21
19	0.0418	1.06
20	0.0359	0.91
21	0.0329	0.84
22	0.0299	0.76
23	0.0269	0.68
24	0.0239	0.61
25	0.0209	0.53
26	0.0179	0.46
27	0.0164	0.42
28	0.0149	0.38

*For materials or gauges other than those listed in Appendix C, consult the producer.

Table C2
Galvanized Steel Sheet

Galvanized Sheet Gauge No.	Thickness	
	in.	mm
8	0.1681	4.27
9	0.1532	3.89
10	0.1382	3.51
11	0.1233	3.13
12	0.1084	2.75
13	0.0934	2.37
14	0.0785	1.99
15	0.0710	1.80
16	0.0635	1.61
17	0.0575	1.46
18	0.0516	1.31
19	0.0456	1.56
20	0.0396	1.01
21	0.0366	0.93
22	0.0336	0.85
23	0.0306	0.78
24	0.0276	0.70
25	0.0247	0.63
26	0.0217	0.55
27	0.0202	0.51
28	0.0187	0.48
29	0.0172	0.44
30	0.0157	0.40
31	0.0142	0.36
32	0.0134	0.34

Table C3
Stainless Steel Sheet

Manufacturers' Standard Gauge No.	Thickness	
	in.	mm
8	0.1719	4.37
9	0.1563	3.97
10	0.1406	3.57
11	0.1250	3.18
12	0.1094	2.78
13	0.0938	2.39
14	0.0781	1.98
15	0.0703	1.79
16	0.0625	1.59
17	0.0563	1.43
18	0.0500	1.27
19	0.0438	1.11
20	0.0375	0.95
21	0.0344	0.87
22	0.0313	0.79
23	0.0281	0.71
24	0.0250	0.64
25	0.0219	0.56
26	0.0188	0.48
27	0.0172	0.44
28	0.0156	0.40
29	0.0141	0.36
30	0.0125	0.32
31	0.0109	0.28

Table C4
Aluminum and Aluminum Alloy Sheet

Browne and Sharp Gauge No.	Thickness	
	in.	mm
8	0.1285	3.26
9	0.1144	2.91
10	0.1019	2.59
11	0.0907	2.30
12	0.0808	2.05
13	0.0720	1.83
14	0.0641	1.63
15	0.0571	1.45
16	0.0508	1.29
17	0.0453	1.15
18	0.0403	1.02
19	0.0359	0.91
20	0.0320	0.81
21	0.0285	0.72
22	0.0253	0.64
23	0.0226	0.57
24	0.0201	0.51
25	0.0179	0.46
26	0.0159	0.40
27	0.0142	0.36
28	0.0126	0.32
29	0.0113	0.29
30	0.0100	0.25
31	0.0089	0.23

Table C5
Copper and Copper Alloy Sheet

Weight per Square Foot oz.	Thickness	
	in.	mm
48	0.0645	1.64
32	0.0431	1.09
24	0.0323	0.82
20	0.0270	0.69
16	0.0216	0.55
12	0.0161	0.41
8	0.0108	0.27

Appendix D

(This Appendix is not a part of ANSI/AWS D9.1-90, *Sheet Metal Welding Code*, but is included for information purposes only.)

Welding Procedure Specification (WPS)

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 _____
Electrical characteristics _____ ac _____ dcep _____ dcen _____
Mode of transfer _____
Shielding gas/combination _____
Gas flow (CFH) _____

*See Definitions

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 ANSI/AWS D9.1 Sheet Metal Welding Code.

Manufacturer or Contractor _____

Authorized by _____

Date _____

Appendix E

(This Appendix is not a part of ANSI/AWS D9.1-90, *Sheet Metal Welding Code*, but is included for information purposes only.)

Procedure Qualification Test Record (PQR)

Variables

Base metal _____
 Metal thickness _____
 Coating _____
 Joint preparation _____
 Backing _____
 Position of welding _____
 Welding process _____
 Manual, semiautomatic, or automatic _____
 *Filler metal spec. _____
 *Filler metal class _____
 *Weld metal grade _____
 Electrical characteristics _____ ac _____ dcep _____ dcen _____
 Mode of transfer _____
 Shielding gas/combination _____
 Gas flow (CFH) _____
 Welder's name _____
 Welder's ID no. _____

PQR Number _____
 WPS Number _____

Weld in butt joint visual exam results
 (see 3.4.1 or 8.4.1) _____
 Fusion _____
 Penetration _____
 Reinforcement _____
 Porosity _____
 Undercut _____
 Cracks _____
 Fillet weld visual exam results
 (see 3.4.2 or 8.4.2) _____
 Fusion _____
 Effective throat _____
 Convexity _____
 Porosity _____
 Undercut _____
 Cracks _____

*See Definitions

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 ANSI/AWS D9.1, *Sheet Metal Welding Code*.

Manufacturer or Contractor _____

Authorized by _____

Date _____

Appendix F

(This Appendix is not a part of ANSI/AWS D9.1-90, *Sheet Metal Welding Code*, but is included for information purposes only.)

Welder and Welding Operator Qualification Test Record

Qualification Test Performed

Name _____
I.D. no. _____
Date of test _____

WPS number _____
Square groove (butt joint) _____
Fillet _____
Weld test _____
Braze weld test _____

Essential Variables Qualified by Test

Type of base metal _____

Coating material on sheet _____ Yes _____ No
Backing material _____
Filler metal F number _____

Welding process _____
Method of application _____
_____ Manual _____ Semiautomatic _____ Automatic
Mode of transfer (GMAW) _____
Welding current _____ ac _____ dcen _____ dcep
Shield gas used _____
Position welded _____ Flat _____ Horizontal _____ Vertical
Overhead

Visual Inspection Results

Square groove (butt joint) weld

Acceptance criteria

Weld Braze Weld

Yes	No	Yes	No
		NA	NA
		NA	NA

Joint fusion (metallic bond)

Required joint penetration

Face reinforcement

More than one pore or inclusion
than 0.25t

Undercut exceeding 0.15t, or
0.25t

Cracks

Fillet Weld

Acceptance criteria

Weld Braze Weld

Yes	No	Yes	No
		NA	NA

Joint fusion (metallic bond)

Required minimum effective throat

Required maximum convexity

Pore or inclusion over 0.25t

Undercut exceeding 0.15t, or
0.25t

Cracks

Thickness range qualified _____

Inspection performed by _____

Positions qualified _____

Name of inspector _____

Types of joints qualified _____

Signature _____

Date _____

Appendix G Joint Design and Details

(This Appendix is not a part of ANSI/AWS D9.1-90, *Sheet Metal Welding Code*, but is included for information 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

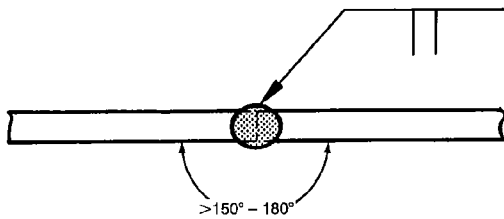


Figure GA1 — Square-Groove Weld

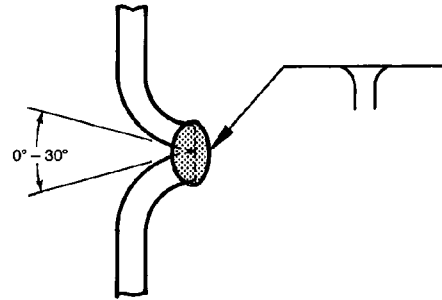


Figure GA4 — Edge Flange Weld

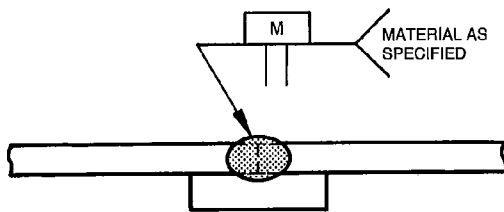


Figure GA2 — Square-Groove Weld with Backing

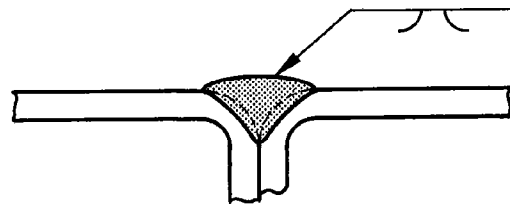


Figure GA5 — Flare-V-Groove Weld

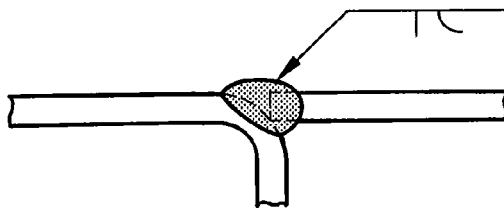
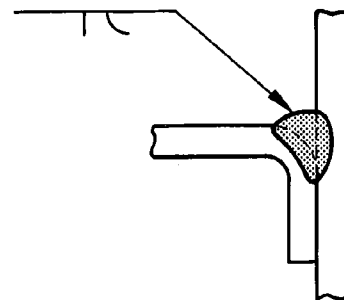


Figure GA3 — Flare-Bevel-Groove Weld



**Figure GA6 — Flare-Bevel-Groove Weld
(in T-joint or Inside Corner Joint)**

Part A — Arc Welding

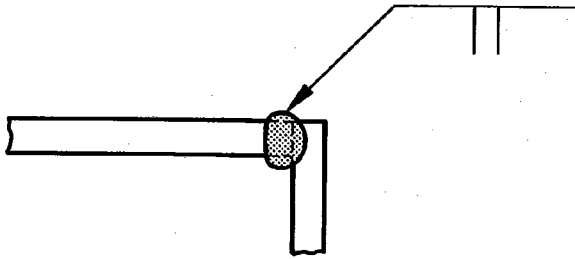


Figure GA7 — Square-Groove Corner Weld

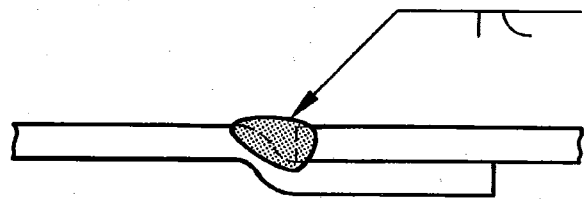


Figure GA8 — Flare-Bevel Weld in an Offset Lap Joint

Fillet Welds

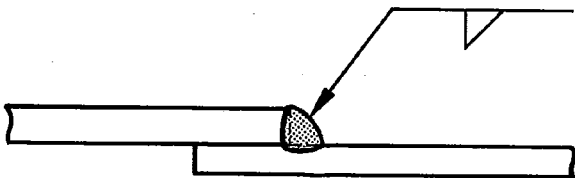


Figure GA9 — Plain Lap Joint Fillet Weld

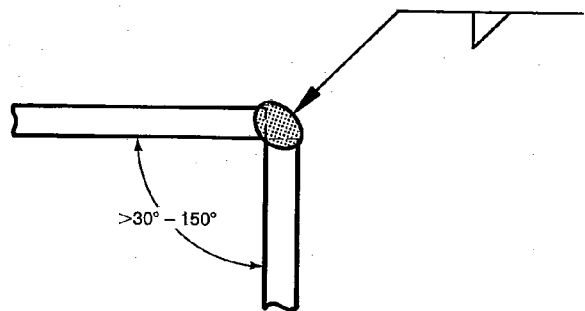


Figure GA11 — Fillet Weld in Open (Offset) Corner Joint (Angle May Vary from 90°)

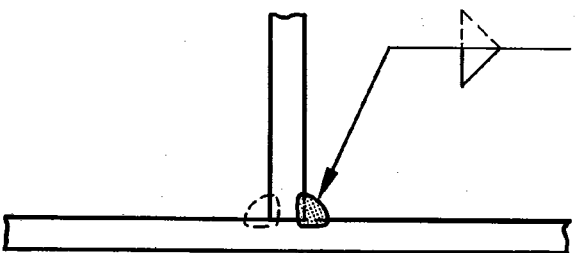


Figure GA10 — Fillet Weld in T-joint (One or Both Sides)

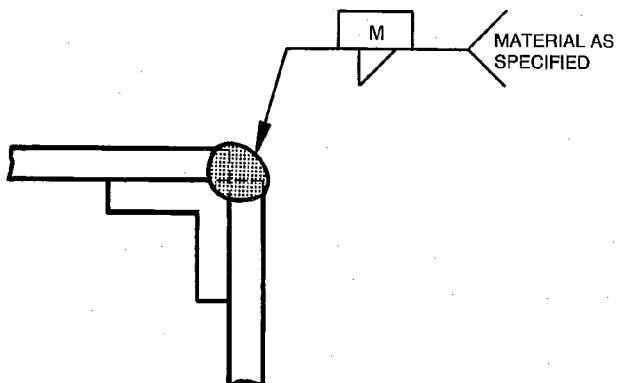
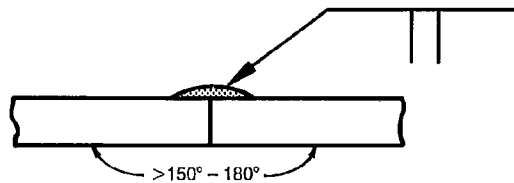
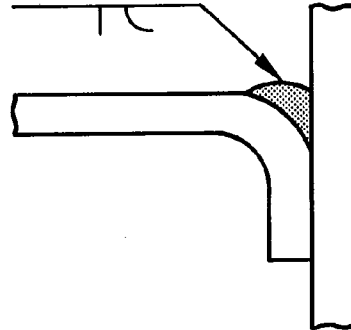
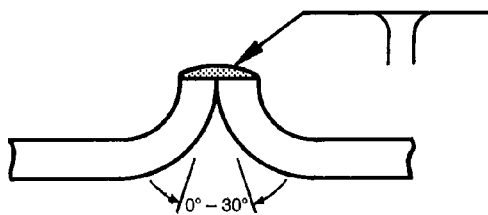
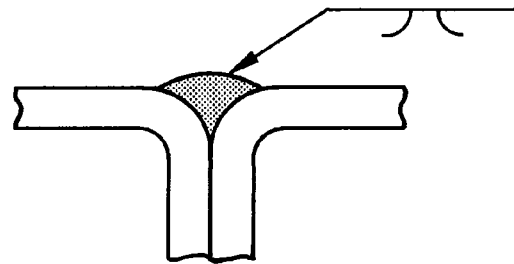
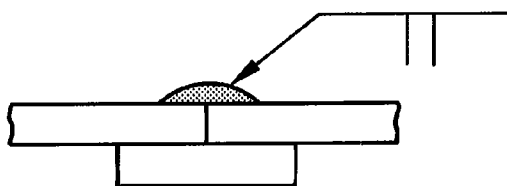
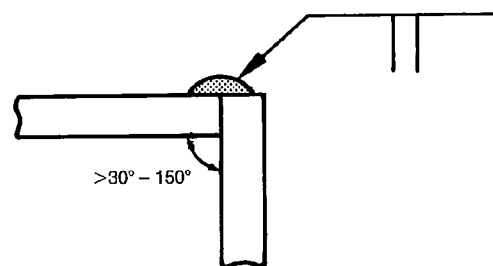


Figure GA12 — Corner Weld with Backing

Part A — Arc Welding (Continued)

Groove Braze Welds**Figure GB1 — Square-Groove Braze Weld****Figure GB4 — Flare-Bevel-Groove Braze Weld (in T-joint or Inside Corner Joint)****Figure GB2 — Edge Flange Braze Weld****Figure GB5 — Flare V-Groove Braze Weld****Figure GB3 — Square-Groove Braze Weld with Backing****Figure GB6 — Square-Groove Corner Braze Weld****Part B — Braze Welding**

Fillet Braze Welds

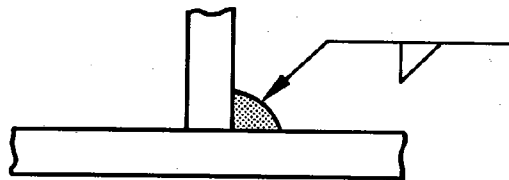


Figure GB7 — Fillet Braze Weld T-Joint

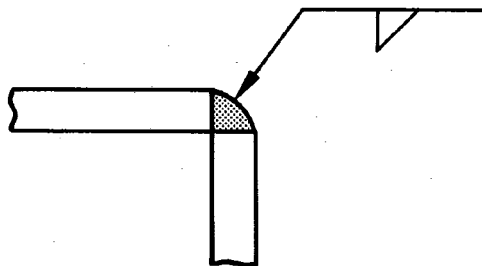


Figure GB8 — Fillet Braze Weld in Open (Offset) Corner Joint (Angle May Vary from 90°)

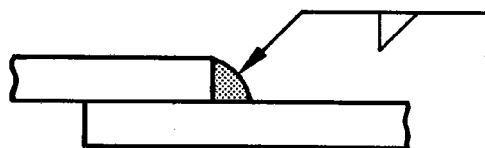


Figure GB9 — Plain Lap Joint Fillet Braze Weld

Part B — Braze Welding (continued)

Appendix H

Recommended Arc Welding Practices

(This Appendix is not a part of ANSI/AWS D9.1-90, *Sheet Metal Welding Code*, but is included for information purposes only.)

H1. Introduction

These recommended practices have been prepared by the AWS Committee on Welding, Brazing, and Soldering of Sheet Metal. It has long been recognized that the welding of sheet metal has its own peculiar 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, Seventh Edition, *Welding Handbook*, and the latest editions of ANSI/AWS C5.1, *Plasma Arc Welding* and ANSI/AWS C5.6, *Gas Metal Arc Welding*.

H2. Brief History of Sheet Metal Arc Welding

The term *sheet metal* is usually associated with very thin galvanized sheet steel. Actually, the term *sheet metal* can mean a coated or uncoated ferrous or nonferrous metal as thick as 3 gauge, 0.239 in. (6.1 mm), and as thin as 32 gauge 0.0134 in. (0.34 mm).

For many years after welding had become everyday practice in structural steel 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, welding became a practical method of joining sheet metal components. As the equipment and proc-

esses became more versatile, the practice of arc 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 application; food and beverage dispensing systems; food processing equipment; air pollution and "airveyor" systems; 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 handcutting 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 2 in. (51 mm) 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 1/8 in. (3.2 mm) increases as the thickness of metal decreases. Special electrodes are produced in 5/64 in. (2.0 mm) and 1/16 in. (1.6 mm) diameter which may be used with currents as low as 20 amps. Table H1 presents suggested current ranges for welding sheet metal of various gauges.

Table H1
Suggested Covered Electrode Size for Various Currents
and Gauges

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

*Irrespective of polarity.

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 E6012 and E6013 (the latest edition of AWS specification A5.1, *Specification for Covered Carbon Steel Arc Welding Electrodes*). The E6012 electrodes operate on ac and dc straight polarity (electrode negative). The E6013 electrodes operate on ac and dc, either straight or reverse polarity. Reverse polarity (electrode positive), however, is not normally used for sheet metal welding because of the deeper penetrating characteristics of the arc using that polarity. The 3/32 in. (2.4 mm) 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 gauge [0.063 in. (1.6 mm)]. Table H1 presents sug-

gested current ranges for welding sheet metal of various gauges.

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 H2 gives typical storage conditions for various AWS electrode classifications. Some of these are seldom used for sheet metal welding because of their deeply penetrating 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 for sensitive applications.

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 1/16 in. (1.6 mm) in all compositions (see the latest edition of ANSI/AWS specification A5.4, *Specification for Corrosion-Resisting Chromium and Chromium-Nickel Steel Covered Electrodes*). Classification -15 is used only with deep. Classification -16 is used with ac or deep.

The electrode classification should be chosen to match the composition of the base metal. There are more than 30 different compositions in ANSI/AWS A5.4 to provide the correct composition and properties to match a variety of sheet metal weldments. In general, a match type is used: for example, Type 410 stainless steel is welded with E410-15 or -16 electrodes; Types 302 and 304 are welded with E308-15 or -16 electrodes, or E308L -15 or -16 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.

Table H2
Typical Storage and Drying Conditions for Arc Welding Electrodes

AWS Classification	Storage Conditions		
	Standard	Holding Ovens	Drying*
E6010, E6011	Ambient temperature	Not recommended	Not Recommended
E6012, E6013, E6020, E6022, E6027, E7014, E7024	80 ± 20°F (30 ± 10°C) 50% max. relative humidity	20°F (11°C) to 40°F (22°C) above ambient temperature	275 ± 25°F (135 ± 15°C) 1 hr. at temperature
E7015, E7016, E7018, E7028	80 ± 20°F (30 ± 10°C) 50% max. relative humidity	50°F (28°C) to 250°F (139°C) above ambient temperature	475 ± 25°F (245 ± 15°C) 2 hr. at temperature

*Because of inherent differences in manufacture, the suppliers of these electrodes should be consulted for the exact drying conditions.

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 power welding), gas tungsten arc, and plasma arc welding.

H4.1.6 Welding Copper-Base Sheet Metals. As in welding aluminum sheet metal, better results can be obtained using gas metal arc (pulsed power 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. 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 H3.

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.

(7) The pulsed power 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 gauge metal.

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 power variation requires argon-rich gas mixtures; the short circuiting arc variation generally uses carbon dioxide, alone or in gas mixtures.

(1) **Pulsed Power 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 pulse power welding process is used frequently to weld thin sections in all positions.

Table H3
Suggested Welding Conditions for Ferrous Sheet Metal

GMAW Process Variation	Wire Diameter		Operating Current Range, A	Operating Voltage Range	Thickness of Metal to be Welded		Shielding Gas	Gauge
	in.	mm			in.	mm		
Pulsed power	0.035	0.9	60-200	15-23	0.039 to 0.125	1.0 to 3.2	Argon or 75% He + 25% A	20 to 11
	0.045	1.2	90-300	17-28	0.062 to 0.187	1.6 to 4.8		16 to 7
	1/16	1.6	110-300	18-30	0.187 and over	4.8 and over		7 and over
Spray transfer	0.035	0.9	125-300	20-28	0.039 to 0.125	1.0 to 3.2	Argon or 75% He + 25% A	20 to 11
	0.045	1.2	155-450	22-32	0.062 to 0.187	1.6 to 4.8		16 to 7
	1/16	1.6	210-500	24-34	0.187 and over	4.8 and over		7 and over
Short circuiting (dip) transfer	0.035	0.9	55-200	15-23	0.039 to 0.125	1.0 to 3.2	Argon or 75% He + 25% A	20 to 11
	0.045	1.2	75-200	16-24	0.062 to 0.187	1.6 to 4.8		16 to 7

Note: Ranges subject to change due to variances in welding conditions.

(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
- (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 varia-

tion is easy to master for use in all positions. The pulsed power 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 very easy.

A reasonable amount of preventive maintenance is required to assure 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 easily.

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
- (2) Helium
- (3) CO₂
- (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 0.030 in. (0.8 mm) to 1/16 in. (1.6 mm). 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.

Table H4
Suggested Welding Conditions for Aluminum Sheet Metal

Process	Wire Diameter		Operation Current Range, A	Operation Voltage Range	Thickness of Metal to be Welded		Shielding Gas
	in.	mm			in.	mm	
Pulsed Power	0.030	0.8	25-90	16-20	0.032 to 0.102	0.81	Argon or 75%
	3/64	1.2	40-150	17-23	0.051 to 0.187	1.29	He + 25% A
	1/16	1.6	45-300	17-28	0.102 and over	2.59	
	3/32	2.4	100-300	19-29			
Spray transfer	0.030	0.8	90-200	18-27	0.032 to 0.102	0.81	Argon or 75%
	3/64	1.2	130-300	21-32	0.051 to 0.187	1.29	He + 25% A
	1/16	1.6	155-400	22-35	0.102 and over	2.59	
	3/32	2.4	200-450	23-35			

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 1/4 in. (6 mm) and with square butt joint designs. The pulsed arc is used to weld sheet as thin as 18 gauge, 0.0478 in. (1.22 mm) in all positions.

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

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. Although the shielding gas used is normally argon, a mixture of argon + helium + CO₂ can, in some cases, be used to advantage.

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 deep (current) and argon shielding gas, it is possible to weld thin aluminum of approximately 0.050 in. (1.23 mm). Electrode wire sizes of 0.030 to 1/16 in. (0.8 to 1.6 mm) are commonly used. With these diameter wires, base metal melt-through and spatter are both minimized. Pulsed arc variation of GMAW produces good results when welding aluminum sheet metal. Table H4 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 produce their own protective environment and do not require an external source of gas. By controlling the ionizable materials in the core, the process can employ either reverse polarity [direct current electrode positive-(dcep)] or straight polarity [direct current electrode negative-(dcen)]. The self-shielded FCAW process is commercially available in mild steel, austenitic stainless steel, and nickel-iron filler metals. This process is currently being little used in the sheet metal industry.

In general, the GMAW and FCAW processes are cost effective. The deposition efficiencies are particularly high, approaching 95 to 100 percent with solid electrode (depending upon the shielding gas), 85 to 90 percent with gas-shielded cored electrodes, and 80 to 85 percent 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 and magnesium and their alloys and some grades of stainless steels. Dcen is preferred for welding carbon steel. Dcep is not used because the tungsten electrode overheats and evaporates 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 re-ignition 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. Welders can be trained more quickly, and all-position welding is easier.

A variety of tungsten electrodes is used with the process. The thoriated and zirconiated tungsten electrodes have higher current-carrying capacity and electron emission characteristics than pure tungsten, making them most 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 and magnesium 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.

Gas tungsten arc welding is generally more expensive than SMAW due to the cost of the inert gas, and is

only 10 to 20 percent as fast as GMAW. However, GTAW will provide the optimum weld quality while accommodating a wider range of thicknesses, positions, and geometries than either SMAW or GMAW.

H4.5 Plasma Arc Welding (PAW). The PAW process has had limited acceptance in the sheet metal industry to date. The equipment includes a control circuit, power supply, torch, work clamp 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 0.062 in. (1.5 mm)]; 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 7000 to 9000°F (3900 to 5000°C), 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 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 "everdure", has achieved a high degree of usage in the sheet metal industry for joining light gage galvanized fittings. These are 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.

Appendix I

Recommended Braze Welding Practices

(This Appendix is not a part of ANSI/AWS D9.1-90, *Sheet Metal Welding Code*, but is included for information purposes only.)

I1. Introduction

These recommended braze welding practices are designed to be of a general nature. There are many variations of braze welding in the sheet metal industry; the recommendations of this appendix are proposed as general guidelines. More detailed information may be found in the latest edition of ANSI/AWS A5.7, *Specification for Copper and Copper Alloy Bare Welding Rods and Electrodes*, AWS *Brazing Manual*, and Volume 2, Chapter 11, 7th Edition, of the *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, the term *sheet metal* can mean a coated or uncoated ferrous or nonferrous metal as thick as 3 gauge, 0.239 in. (6.07 mm), and as thin as 30 gauge, 0.0157 (0.4 mm).

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 equip-

ment; 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 (liquidus temperature) of the base metal and requires by definition, to distinguish from soldering, a filler metal having a melting (liquidus) temperature above 840°F (450°C). 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"), the gas metal arc (GMAW), and the gas tungsten arc (GTAW) welding processes.

I4. Fit-up

Stringent fit-up 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 Appendix 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 840°F (450°C) 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.

17. 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.

18. 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.

19. 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.

110. 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.

Appendix J

Safety and Health

(This Appendix is not a part of ANSI/AWS D9.1-90, *Sheet Metal Welding Code*, but it is included for information purposes only.)

J1. General

The following pages present information on nine Safety and Health topics which appeared in the *Welding Journal* during the period from August 1982 through January 1984.

Also included is a list of reference material from which further detailed information may be obtained.

J1.1 Fumes and Gases. Many welding, cutting and allied processes produce fumes and gases which may be harmful to health. Fumes are solid particles which originate from welding consumables, the base metal, and any coatings present on the base metal. In addition to shielding gases that may be used, gases are produced during the welding process or may be produced by the effects of process radiation on the surrounding environment. You — the reader — should acquaint yourself with the effects of these fumes and gases. The amount and composition of these fumes and gases depend upon the composition of the filler metal and base material, welding process, current level, arc length and other factors.

The possible effects of over-exposure range from irritation of eyes, skin, and respiratory system to more severe complications. Effects may occur immediately or at some later time. Fumes can cause symptoms such as nausea, headaches, dizziness, and metal fume fever. The possibility of more serious health effects exists when especially toxic materials are involved. In confined spaces, gases might displace breathing air and cause asphyxiation.

Keep your head out of the fumes. Use enough ventilation, exhaust at the arc, or both, to keep fumes and gases from your breathing zone and general area. In some cases, natural air movement will provide enough ventilation. Where ventilation is inadequate, corrective measures should be applied. See References 4, 5, and 6.

J1.2 Radiation. Welding, cutting and allied operations may produce radiant energy (radiation) harmful to health. You should acquaint yourself with the effects of this radiant energy.

Radiant energy may be ionizing (such as x-rays) or nonionizing (such as ultraviolet, visible light, or infrared). Radiation can produce a variety of effects such as skin burns and eye damage, depending on the radiant energy's wavelength and intensity, if excessive exposure occurs.

Ionizing Radiation

Ionizing radiation is produced by the electron beam welding process. It is ordinarily controlled within acceptable limits by use of suitable shielding enclosing the welding area.

Nonionizing Radiation

The intensity and wavelengths of nonionizing radiant energy produced depend on many factors such as the process, welding parameters, electrode and base metal composition, fluxes, and any coating or plating on the base material.

Some processes such as resistance welding and cold pressure welding ordinarily produce negligible quantities of radiant energy. However, most arc welding and cutting processes (except submerged arc when used properly), laser welding and torch welding, cutting, brazing, or soldering can produce quantities of nonionizing radiation such that precautionary measures are necessary.

Safety glasses with UV protective side shields have been shown to provide some beneficial protection from ultraviolet radiation produced by welding arcs. See References 15, 16, and 17.

J1.3 Noise

Excessive noise is a known health hazard. Exposure to excessive noise can cause a loss of hearing. The loss of hearing can be either full or partial, and temporary or permanent. In welding, cutting, and allied operations, noise may result from the process, the power source, or other equipment. Air-carbon arc cutting and plasma arc cutting are examples of processes which are frequently noisy. Engines of engine-driven generators may also be quite noisy.

Excessive noise adversely affects hearing capability. This adverse effect in hearing capability may be a temporary threshold shift from which the ears may recover if removed from the noise source. However, if a person is exposed to this same noise level for a longer time, then the loss of hearing may become permanent. The time required to develop permanent hearing loss depends upon factors such as individual susceptibility, noise level, and exposure duration. In addition, there is evidence that excessive noise affects other bodily functions and behavior.

A direct method to protect against excessive noise is to reduce the intensity of the source. Another method is to shield the source, but this has limitations. The acoustical characteristics of a room will also affect the level of noise. When engineering control methods fail to reduce the noise, personal protective devices such as ear muffs or ear plugs may be employed. Generally, these devices are only accepted when engineering controls are not fully effective. See References 4, 5, and 7.

J1.4 Electrical Hazards. Electric shock can kill. However, it can be avoided. Do not touch live electrical parts. Read and understand the manufacturer's instructions and recommended safe practices. Faulty installation, improper grounding, and incorrect operation and maintenance of electrical equipment are all sources of danger.

Ground all electrical equipment and the workpiece. The work lead is not a ground lead. It is used only to complete the welding circuit. A separate connection is required to ground the workpiece. Do not mistake the work lead for a ground connection.

Use the correct cable size, since sustained overloading will cause cable failure and result in possible electric shock or fire hazard. Make sure all electrical connections are tight, clean and dry. Poor connections can overheat and even melt. Further, they can produce dangerous arcs and sparks. Do not allow water, grease, or dirt to accumulate on plugs, sockets or electrical units. Moisture can conduct electricity. To prevent shock, keep the work area, equipment, and clothing dry at all times. Wear dry gloves, rubber soled shoes, or stand on a dry board or insulated platform.

Keep cables and connectors in good condition. Improper or worn electrical connections may set up conditions that could cause electrical shock or short circuits. Do not use worn, damaged or bare cables. Avoid open circuit voltage.

When several welders are working with arcs of different polarities, or when a number of alternating current machines are being used, the open circuit voltages can be additive. The added voltages increase the severity of the shock hazard.

In case of electric shock, turn off the power. If the rescuer must resort to pulling the victim from the live contact, use nonconducting materials. If the victim is not breathing, administer cardiopulmonary resuscitation (CPR) as soon as contact with the electrical source is broken. Call a physician and continue CPR until breathing has been restored, or until a physician has arrived. Treat electrical burns as thermal burns; that is, apply clean, cold (iced) compresses. Prevent contamination and cover with a clean, dry dressing. Call a physician. See References 1, 2, and 3.

J1.5 Fire and Explosion Prevention. Molten metal, sparks, slag, and hot work surfaces are produced by welding, cutting, and allied processes. These can cause fire or explosion if precautionary measures are not used.

Many of the fires associated with welding, cutting, and allied processes have been caused by sparks which can travel up to 35 feet in a horizontal direction from the work area. Sparks can pass through or become lodged in cracks, clothing, pipe holes, and other small openings in floors or partitions. (Note: Sparks and molten metal can travel greater distances when falling.)

Typical combustible materials commonly involved in fires are floors, partitions, roofs, and building contents such as wood, paper, clothing, plastics, chemicals and flammable liquids and gases. Outdoors, the combustible materials involved are dry leaves, grass and brush. Explosions have occurred where welding or cutting have been performed in spaces containing flammable gases, vapors, liquids or dusts.

Remove any combustible material from the work area. Where possible, move the work to a location well away from combustible materials. If neither action is possible, protect combustibles with a cover of fire resistant material. Remove or make safe all combustible materials for a radius of 35 feet around the work area. All open doorways, windows, cracks and other openings should be covered or blocked with fire resistant material. If possible, enclose the work area with portable fire resistant screens. Protect combustible walls, ceilings, etc. from sparks and heat with fire resistant covers.

If work is to be performed on a metal wall, ceiling, etc. prevent ignition of combustibles on the other side by moving the combustibles to a safe location. If this cannot be done, designate someone to serve as a fire watch, equipped with a fire extinguisher during the welding operation and for one-half hour after welding is completed. Welding or cutting should not be performed on material having a combustible coating or combustible internal structure, as in walls or ceilings, without an approved method for eliminating the hazard. Do not dispose of hot slag in containers holding combustible material. Keep fire extinguisher nearby. Make a thorough

examination for evidence of fire. Remember that easily visible smoke or flame may not be present for some time after the fire has started.

Be sure the work cable is connected to the work as close to the welding area as practical. Work cables connected to the building framework or other locations some distance from the welding area increase the possibility of the welding current passing through lifting chains, crane cables or other alternate circuits. This can create fire hazards or overheat lifting chains or cables until they fail.

Do not weld or cut in atmospheres containing dangerously reactive or flammable gases, vapors, liquids, or dust. Do not apply heat to a container that has held an unknown substance or a combustible material whose contents when heated can produce flammable or explosive vapors. Heat should not be applied to a workpiece covered by an unknown substance or whose coating can produce flammable, toxic or reactive vapors when heated. Adequate procedures should be developed and proper equipment used to do the job safely. Provide adequate ventilation in work area to prevent accumulation of flammable gases, vapors or dusts. Clean and purge containers before applying heat.

Closed containers, including castings, should be vented before preheating, welding or cutting. Venting will prevent the buildup of pressure and possible explosion due to the heating and the resultant expansion of gases. See References 1, 3, 4, 10, and 11.

J1.6 Burn Protection. Molten metal, sparks, slag, and hot work surfaces are produced by the welding, cutting, and allied processes. These can cause burns if precautionary measures are not used.

Workers should wear protective clothing made of fire resistant material. Do not wear pant cuffs or have open pockets or other places on clothing that can catch and retain molten metal or sparks. Wear high top shoes or leather leggings and fire resistant gloves. Pant legs should be worn over the outside of high top boots. Use helmets or hand shields that provide protection for the face, neck, and ears, and wear a head covering to protect the head.

In addition, appropriate eye protection should be used. When welding overhead or in confined spaces, wear ear plugs to prevent weld spatter from entering the ear canal and goggles or equivalent to give added eye protection. Keep clothing free of grease and oil. Do not carry combustible materials in pockets. If any combustible substance has been spilled on clothing, change to clean fire resistant clothing before working with open arcs or flame.

Use aprons, cape-sleeves, leggings, and shoulder covers and bibs designed for welding service. Where usually heavy welding or cutting is involved, sheet metal shields

should be used for extra protection. Mechanization of highly hazardous processes or jobs should be considered.

Other personnel in the work area should be protected by the use of noncombustible screens or by the use of appropriate protection as described in the previous paragraph. Before leaving a work area, mark hot work pieces to alert other persons of this hazard. Do not attempt to repair or disconnect electrical equipment under load. Disconnecting under load produces arcing of the contacts and may cause burns and/or shocks. (Note: Burns can be caused by touching hot equipment such as electrode holders, tips and nozzles. Therefore, insulated gloves should be worn when these items are handled unless an adequate cooling period has been allowed before touching.) See References 1, 4, 8, and 9.

J1.7 Mechanical Hazards. The use of, or the proximity to, mechanical equipment can present hazards to the welder. A knowledge of the proper use of power tools, such as grinders, chippers, drills and various hand tools, is important to welder safety. Know and understand the safe limits and proper use of cranes, positioners, and other material handling equipment, and use the appropriate guards and personal protective equipment.

(1) Adhere to grinding wheel speed limitations. Don't grind on the side of a wheel not designed for such service. When starting a new wheel, stand to the side until it reaches speed and correct any abnormalities noted. Be sure guards are in place and used.

(2) Wear proper eye and hand protection. Use face shields, safety glasses and goggles as appropriate. Watch out for sharp objects, pinch points, and moving objects.

(3) Avoid wearing items that can be caught in machinery such as rings, necklaces, bracelets, long hair, loose clothing, etc.

(4) Use the right tool for the job. Keep a firm grip on tools to prevent their slipping away. Do not overload or force a tool beyond its expected capabilities. Foresee results of unexpected occurrences such as tools getting away, binding, or coming loose from their handles. Any tool that has become jammed or otherwise overstressed should be checked for damage before reuse. Anticipate the reactive force from tools. See References 1, 4, and 12.

J1.8 Tripping and Falling. Trips and falls are a frequent cause of occupational injury and can result in serious injury or death. Welding, cutting and heating can take place in a variety of locations. Therefore, welders are exposed to the same tripping and falling hazards as those in other occupations. Proper precautions should be observed. Be alert to the conditions in the work area. Good housekeeping is essential to minimize tripping and falling. Actions to prevent falls include the use of safety

belts and harnesses that are tied off, secured ladders, guardrails, proper scaffolding, and nets. Scaffolds and other climbing and elevating equipment must be installed and used properly. Do not carry items which obstruct your view. Proper protective wear, such as skid resistant soles on shoes, should be used when conditions warrant. Electrical equipment should be grounded and other precautions taken to prevent shock. Shock can cause a fall due to involuntary movements.

An alert, professional approach needs to be taken at all times. Do not tolerate horseplay, tossing tools to each other, bumping someone in a precarious position, or other distractions such as shouting when there is no reason to shout. All these acts can contribute to tripping and falling. See References 1 and 4.

J1.9 Confined Spaces. Welding, cutting and heating operations can take place in a variety of locations. Some of these locations may be considered "confined spaces" having characteristics such as:

- (1) limited space, entry or exit, or

- (2) unfavorable ventilation which could contain or trap hazardous air contaminants and/or prevent replenishment of safe breathing air, or both.

Typical confined spaces include small rooms, storage tanks, compartments of ships, process vessels, pits, silos, vats, degreasers, reactor vessels, boilers, ventilation and exhaust ducts, sewers, tunnels, underground utility vaults, and pipelines. They can also include even the unventilated corner of a room. Death and serious injury have resulted from welding operations in confined spaces due to fire, explosions, asphyxiation, and exposure to hazardous air contaminants.

- (1) Open all covers and secure them from closing.

- (2) Test the atmosphere of the confined space to assure

- (a) The oxygen content is suitable for breathing.
- (b) The atmosphere is not combustible or reactive.
- (c) The atmosphere is not toxic.

For detailed precautions see References 4 and 13.

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