

AWS D14.9/D14.9M:2013
An American National Standard

Specification for the Welding of Hydraulic Cylinders



American Welding Society®



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An American National Standard

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Specification for the Welding of Hydraulic Cylinders

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Prepared by the
American Welding Society (AWS) D14 Committee on Machinery and Equipment

Under the Direction of the
AWS Technical Activities Committee

Approved by the
AWS Board of Directors

Abstract

This specification provides standards for the design and manufacture of pressure containing welded joints and structural welded joints used in the manufacture of hydraulic cylinders. Manufacturer's responsibilities are presented as they relate to the welding practices that have been proven successful within the industry in the production of hydraulic cylinders. Included are sections defining welding procedure qualification, welding performance qualification, workmanship and quality requirements as well as inspection requirements and repair requirements.



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Foreword

This foreword is not part of AWS D14.9/D14.9M:2013, *Specification for the Welding of Hydraulic Cylinders*, but is included for informational purposes only.

This specification reflects the welding processes and practices employed by manufacturers within the industry and it incorporates various methods which have been proven successful by individual manufacturers. No restrictions are placed on the use of any welding process or procedure, provided the weld produced meets the qualification requirements of this specification. No attempt is made to limit or restrict technological progress in the welding of hydraulic cylinders, nor should any such limitation be inferred.

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Specification for the Welding of Hydraulic Cylinders

1. Scope and General Provisions

1.1 Scope

1.1.1 This specification provides requirements for the design and manufacture of welded joints of hydraulic cylinders. When specified in the purchasing documents, compliance with all the requirements shall be required. This specification does not apply to the manufacture of welded tubing used for hydraulic cylinders which is covered under ASTM and other recognized specifications. This specification does not specify load determination, design assumptions, safety factors, or calculation methods for non-weld related areas of the hydraulic cylinder.

1.1.2 The Manufacturer's adherence to this specification shall include responsibility for the following:

- (1) welding, as defined in 1.1.1, in accordance with this specification;
- (2) producing welds as designated on drawings by appropriate symbols and notes, with sufficient detail to show joint preparation compatible with applied processes;
- (3) providing written welding procedure specifications (WPSs);
- (4) recording and maintaining results of all welding procedure and welder performance qualification tests;
- (5) controlling use of designated base metals and welding consumables;
- (6) inspecting the welds to the requirements of this specification;
- (7) having a welding quality program in place. The requirements of AWS B5.17, *Specification for the Qualification of Welding Fabricators* may be used as a guide in establishing this welding quality program. Accreditation of quality systems of welding fabricators may be obtained through the AWS Certified Welding Fabricator (CWF) or equivalent programs.

1.2 Units of Measure. This specification makes use of both U.S. Customary Units and the International System of Units (SI). The measurements may not be exact equivalents; therefore each system must be used independently of the other without combining them in any way. The specification with the designation D14.9 uses U.S. Customary Units. The specification D14.9M uses SI Units. The latter are shown in appropriate columns in tables and figures or within brackets [] when used in the text. Detailed dimensions on figures are in inches. A separate tabular form that relates the U.S. Customary Units with SI units may be used in tables and figures.

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

American Welding Society:

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

Material or Equipment Manufacturers:

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

Applicable Regulatory Agencies

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

1.4 Symbols. Welding symbols shown on drawings shall be compatible with those shown in AWS A2.4, *Standard Symbols for Welding, Brazing, and Nondestructive Examination*. In addition, welding symbols not conforming to the requirements of AWS A2.4, but conforming to the requirements of this specification may be allowed on drawings. Special conditions or deviations shall be fully explained by added notes, details, or definitions on the drawings.

2. Normative References

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

2.1 AWS Standards¹

- (1) ANSI Z49.1, *Safety in Welding, Cutting, and Allied Processes*
- (2) AWS A2.4, *Standard Symbols for Welding, Brazing, and Nondestructive Examination*
- (3) AWS A3.0M/A3.0, *Standard Welding Terms and Definitions*
- (4) AWS A5.01M/A5.01 (ISO 14344 MOD), *Procurement Guidelines for Consumables—Welding and Allied Processes—Flux and Gas Shielded Electrical Welding*
- (5) AWS A5.32M/A5.32 (ISO 14175 MOD), *Welding Consumables—Gases and Gas Mixtures for Fusion Welding and Allied Processes*
- (6) AWS B2.1/B2.1M, *Specification for Welding Procedure and Performance Qualification*
- (7) AWS B4.0, *Standard Methods for Mechanical Testing of Welds (US Customary Units)*
- (8) AWS B4.0M, *Standard Methods for Mechanical Testing of Welds (Metric Customary Units)*
- (9) AWS C1.4/C1.4M, *Specification for Resistance Welding of Carbon and Low-Alloy Steels*
- (10) AWS C4.1, *Criteria for Describing Oxygen-Cut Surfaces and Oxygen Cutting Surface Roughness Gage*
- (11) AWS C6.2/C6.2M, *Specification for Friction Welding of Metals*
- (12) AWS D14.4/D14.4M, *Specification for the Design of Welded Joints in Machinery and Equipment*
- (13) AWS QC1, *Standard for Certification of Welding Inspectors*

2.2 CSA Standards²

- (1) CSA W178.2, *Certification of Welding Inspectors*

3. Terms and Definitions

Terms used in this specification shall be in accordance with AWS A3.0M/A3.0, *Standard Welding Terms and Definitions*. Additional terms specific to this standard are defined in this section.

¹ AWS standards are published by the American Welding Society, 8669 Doral Blvd., Suite 130, Doral, FL 33166.

² CSA Standards are published by the Canadian Welding Bureau, (CWB), 7250 West Credit Avenue, Mississauga, ON L5N 5N1.

Engineer. The responsible technical authority.

Groove Width. The opening between groove faces in a groove joint. See Figure 2 (the z dimension) for combination joints.

High Cycle Cylinder. A cylinder designed for an expected life to exceed one million cycles.

Low Cycle Cylinder. A cylinder designed for an expected life of under one million cycles.

Manufacturer. The organization responsible for the performance of the work covered by this specification.

Operator of Automatic Welding Equipment. Personnel who operate equipment that requires only occasional or no observation and no manual adjustment of the controls.

Owner. The person, company or agency that purchases the hydraulic cylinders.

Performance Qualification Variables. One of a set of requirements that define the limits of qualification of welders and welding operators. A change beyond the limits used in qualification requires requalification.

Procedure Qualification Variable. One of a set of elements that define the limits of use of a Welding Procedure Specification. A change beyond the limits used in qualification requires requalification.

Qualification Variable. See performance qualification variable and procedure qualification variable. (Q) is used as the designator.

Toughness Variable. A qualification variable for toughness applications. (T) is used as the designator.

Welding Consumables. Filler metals, consumable inserts, fluxes, and shielding gases used in the welding process.

Welding Operator. One who operates adaptive control, automatic, mechanized, or robotic welding equipment.

Welding Variable. Any controllable detail of a welding procedure which is required to be addressed on the WPS.

WPS Data Variable. A welding variable that if changed, does not require requalification. However, a revised WPS or new WPS shall be prepared. (D) is used as the designator.

4. Base Materials

4.1 Ferrous and Nonferrous Metals. Rolled steels, steel castings and forgings, and nonferrous metals used in the weldments for hydraulic cylinder applications shall be identified by a specification. Specifications developed by the Manufacturer or commonly used industry-wide specifications developed by organizations such as the American Society for Testing and Materials (ASTM), American Iron and Steel Institute (AISI), Society of Automotive Engineers (SAE), and American Foundrymen's Society (AFS) may be used.

4.2 Properties. Base metal specifications shall designate the chemical composition of the material to be used and shall include the mechanical properties and/or heat treatment of the material when required for proper identification. Base metals are expected to be compatible with the welding process and consumables recommended in this specification. It is not intended that base metal selection be restricted, but to assure weldability factors have been considered.

5. Welding Consumables

5.1 Shielding Gases

5.1.1 When a gas or gas mixture is used for shielding in any gas shielded welding process, it shall conform to the requirements of AWS A5.32M/A5.32 (ISO 14175 MOD), *Welding Consumables—Gases and Gas Mixtures for Fusion Welding and Allied Processes*.

5.1.2 When requested by the Engineer or Owner, the Manufacturer shall furnish the gas manufacturers certification(s) that the gas or gas mixture constituents conform to the purity and dew point requirements.

5.1.3 When mixed at the Manufacturer's plant, suitable meters shall be used for proportioning the gases. The percentage of constituent gases shall conform to the requirements of the WPS.

5.1.4 A calibrated monitoring gas analyzer with suitable limit range settings shall be used to verify gas mixtures where shielding gases are mixed at the Manufacturer's plant for welding applications.

5.2 Filler Metals, Consumable Inserts and Fluxes

5.2.1 Procurement of welding filler metals for hydraulic cylinder welding shall follow the method set forth in AWS A5.01M/A5.01 (ISO 14344 MOD), *Procurement Guidelines for Consumables—Welding and Allied Processes—Flux and Gas Shielded Electrical Welding*.

5.2.2 When requested by the Engineer or Owner, the Manufacturer shall furnish certification that the welding filler metals used for welding hydraulic cylinders conform to the requirements of the specification and classification in accordance with AWS A5.01M/A5.01 (ISO 14344 MOD), *Procurement Guidelines for Consumables—Welding and Allied Processes—Flux and Gas Shielded Electrical Welding* for heat, lot, testing, and certification requirements.

5.2.3 Welding consumables which are not procured following the methods set forth in AWS A5.01M/A5.01 (ISO 14344 MOD), *Procurement Guidelines for Consumables—Welding and Allied Processes—Flux and Gas Shielded Electrical Welding* shall be tested by the user to meet the requirements of the applicable AWS filler metal specification.

5.2.4 Welding filler metals shall be protected and stored so that their characteristics or welding properties are not adversely affected. The welding filler metals manufacturer's specific recommendations shall be applied. Annex C contains general practices for storage and the use of filler metals employed for application within the scope of this specification.

6. Weld Joint Design

6.1 The Engineer shall be responsible for the weld joint design. AWS D14.4/D14.4M, *Specification for the Design of Welded Joints in Machinery and Equipment* may be used to determine fatigue life. The Engineer shall ensure that the joint design will meet the requirements of this specification and the contract documents. When the Owner requests design validation, the need shall be specified in the contract documents.

6.2 For combination of weld types that progressively transition between fillet and groove welds such as port to tube welds or rod to cross tube, if the maximum groove width (as designed) does not exceed $3/32$ in [2.5 mm], the weld shall be considered a fillet and shall be depicted using a fillet weld symbol. Refer to Figure 1.

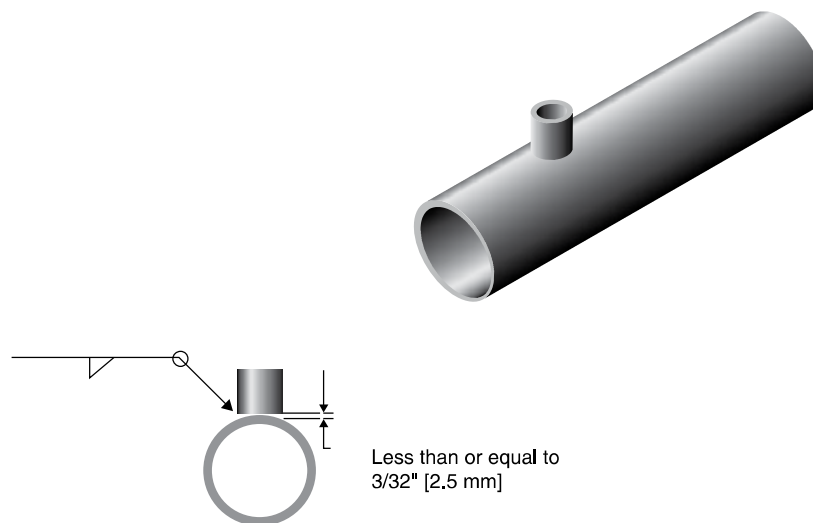


Figure 1—Fillet Weld Symbol for Groove Width Less Than or Equal to $3/32$ " [2.5 mm]

6.3 For a combination of weld types that progressively transition between fillet and groove welds such as port to tube welds or rod to cross tube, if the maximum groove width (as designed) is $3/32$ in [2.5 mm] or greater, the weld shall be considered a combination fillet and groove weld and shall be depicted using a combination weld symbol. For examples of combination groove and fillet welds and weld symbols see Figure 2.

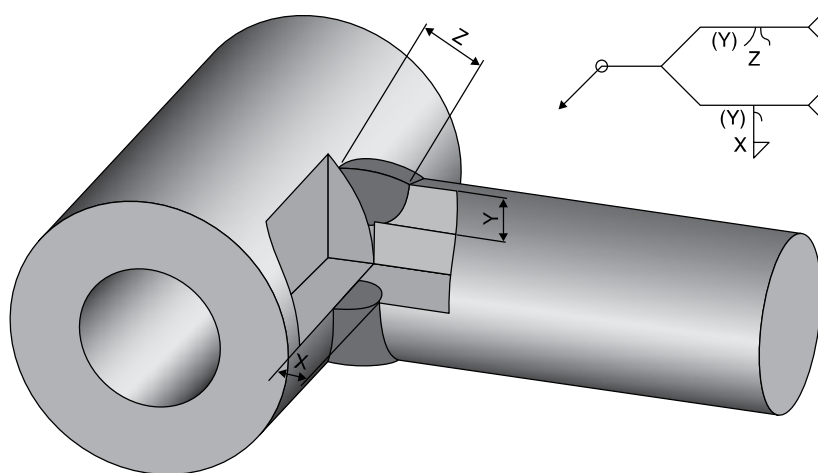


Figure 2(a)—Non-Standard Welding Symbol for Combination Weld Types: Example 1

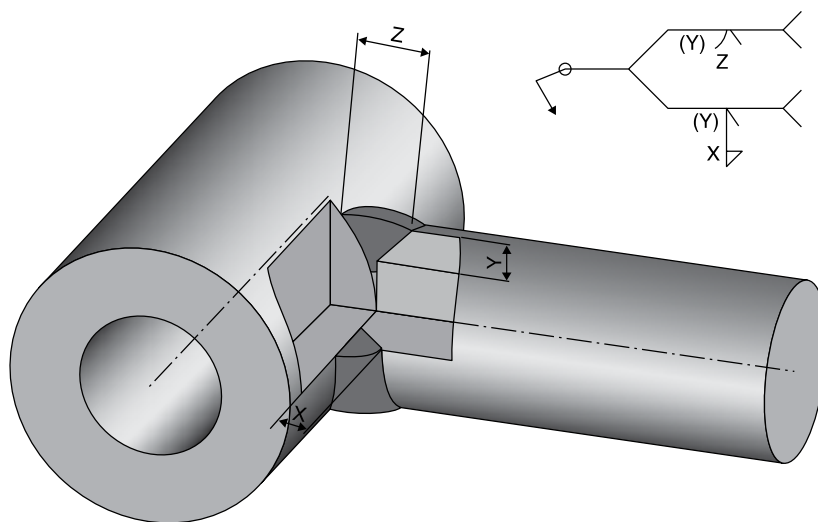


Figure 2(b)—Non-Standard Welding Symbol for Combination Weld Types: Example 2

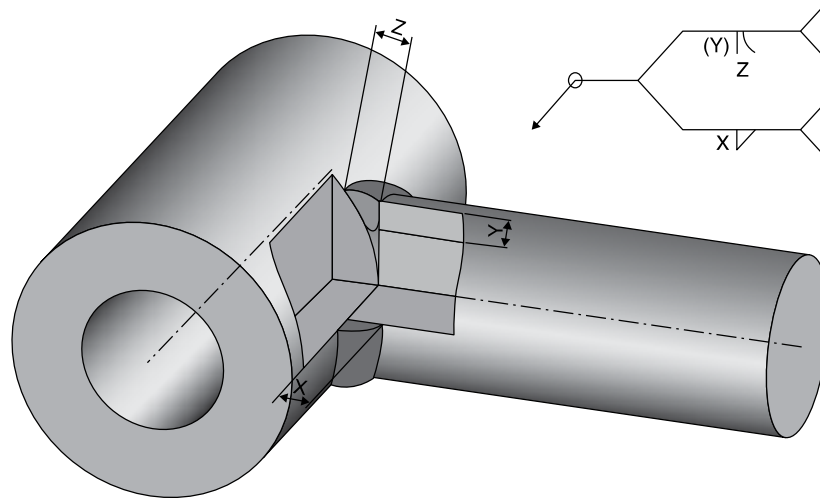


Figure 2(c)—Non-Standard Welding Symbol for Combination Weld Types: Example 3

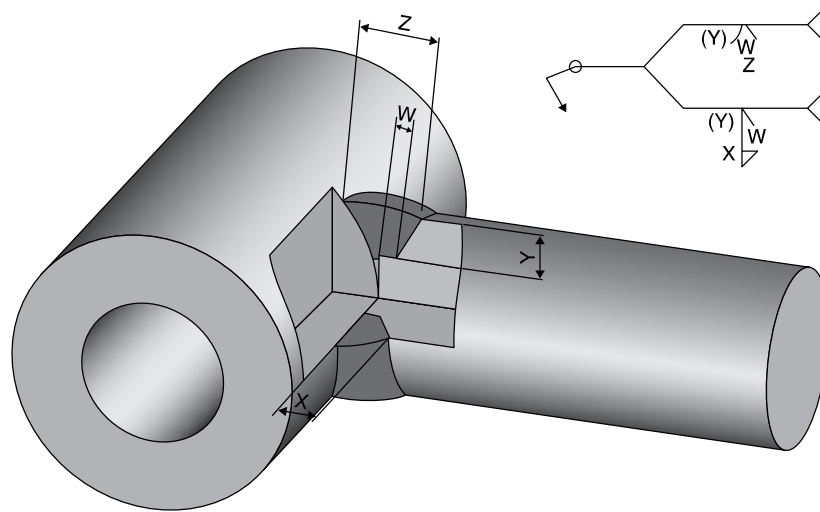


Figure 2(d)—Non-Standard Welding Symbol for Combination Weld Types: Example 4

6.4 Combination J and Single Bevel Grooves. End cap welds may be made with fillet welds or various groove types including a combination of two different groove faces as shown in Figure 3. The break in the arrow of this non-standard welding symbol is used to designate edge preparation. The broken arrow always points to the member with the beveled edge preparation.

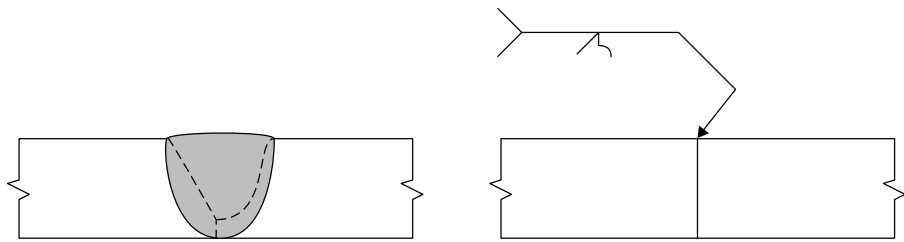


Figure 3—Non-Standard Welding Symbol for Combination J and Single Bevel Groove

6.5 Effective Size for Flare-Groove Welds. The effective weld size for flare groove welds, when filled flush to the surface of a bar, or 90 degree bend in a formed section, or a rectangular tube, shall be as shown in Table 1.

- (1) When required by the Engineer, cross-section tests shall be used to verify that the effective weld size is consistently obtained.
- (2) For a given set of procedural conditions, if the Manufacturer has demonstrated consistent production of larger effective weld sizes than those shown in Table 1, the Manufacturer may establish such larger effective weld sizes by validations.

Table 1 Effective Weld Sizes of Flare Groove Welds	
Flare-Bevel-Groove Welds	Flare-V-Groove Welds
0.312R ^a	0.5R ^(a, b)

^a R = radius of outside surface.
^b Use 0.375R for GMAW (except short circuiting transfer) process when R is 0.5 in [13 mm] or greater.

- (3) Validation required by 6.5(2) shall consist of sectioning the radiused member, normal to its axis, at mid length and at the ends of the weld. Such sectioning shall be made on a number of combinations of material sizes representative of the range used by the Manufacturer in construction or as required by the Engineer.

7. Welding Process Controls

7.1 Welding Procedure Qualification

7.1.1 General Requirements

- 7.1.1.1** A written qualified Welding Procedure Specification (WPS) shall be followed for each weld on hydraulic cylinder applications. The welding procedure specification may be in any convenient format provided all the welding variables of 7.1.7, Welding Variables, are recorded.
- 7.1.1.2** The welding variables required to be addressed for each procedure shall be those specified in 7.1.7.
- 7.1.1.3** This specification does not allow the use of prequalified welding procedures for any welding process.
- 7.1.1.4** The evaluation of procedure qualification test weldments shall be as listed in 7.1.2.1 through 7.1.2.4. Procedure qualification test weldments shall be visually examined on all surfaces. The actual welding variables used during the qualification tests shall be recorded, in addition to the results of the destructive tests and visual examination. The Welding Procedure Qualification Record (WPQR) may be in any convenient format provided all the welding variables of 7.1.7, Welding Variables, and the results of all tests are recorded.
- 7.1.1.5** If any procedure qualification test fails, the procedure fails, and a new welding procedure qualification test shall be conducted.

7.1.1.6 Welding procedures using the SMAW process or other processes not listed in this specification may be used if qualified using one of the methods in 7.1.2 and with the approval of the Engineer or Owner. In addition, the weld quality acceptance criteria of 7.1.3 shall apply.

7.1.2 Alternative Welding Procedure Qualification Methods. Each Manufacturer shall be responsible for the choice of qualifying method.

7.1.2.1 Method I – Standard Welding Procedure Specifications (SWPS). Standard Welding Procedure Specifications published by the AWS B2 committee on Procedure and Performance Qualification are considered to be qualified in accordance with this specification within the limits of 7.1.7.

7.1.2.2 Method II – Standard Tests.

(a) For the GMAW, FCAW, GTAW, PAW, SAW, and SW processes, welding procedure qualification shall be by standard test weldment as required in AWS B2.1/B2.1M, *Specification for Welding Procedure and Performance Qualification*, except that the qualification and WPS data variables of 7.1.7 shall apply.

(b) For the Friction Welding (FRW) process, welding procedure qualification shall be by standard test weldment as required in AWS C6.2/C6.2M, *Specification for Friction Welding of Metals*.

(c) For Projection Welding (PW), welding procedure qualification shall be by standard test weldment as required in AWS C1.4/C1.4M, *Specification for Resistance Welding of Carbon and Low-Alloy Steels*.

(d) For all other processes, the procedure qualification and WPS data variables of B2.1/B2.1M, *Specification for Welding Procedure and Performance Qualification* shall apply.

7.1.2.3 Method III – Weld Sectioning and Micro-Hardness. As an alternative to welding procedure qualification by standard test as given in AWS B2.1/B2.1M, welding procedures may be qualified by visual examination of a minimum of two cross-sections of the completed weld and a minimum of two micro-hardness tests of the completed weld. One cross-section and Micro-Hardness test shall be taken as close as possible to the initial start where the weld achieves full size.

7.1.2.4 Method IV – Prototype. As an alternative to welding procedure qualification by standard test as given in AWS B2.1/B2.1M, welding procedures may be qualified by prototype testing such as accelerated life testing as agreed upon by the Owner and the Manufacturer. Prototype testing shall include documentation of testing performed, validation of acceptance through nondestructive examination, and cross-section examination of welds for visual and micro-hardness testing.

7.1.3 Weld Quality Acceptance Criteria of Procedure Qualification Test Welds for GMAW, FCAW, GTAW, PAW, and SAW

7.1.3.1 All qualification test welds shall be visually examined. Visual examination may be conducted with or without magnification. The results of visual examination shall meet the acceptance criteria of Clause 8, Workmanship and Quality Requirements.

7.1.3.2 Qualification test welds qualified to AWS B2.1/B2.1M. After visual examination, two transverse tensile specimens, two root and two face bend or four side bend specimens based on the material thickness shall be tested in accordance with AWS B2.1/B2.1M, *Specification for Welding Procedure and Performance Qualification*.

7.1.3.3 Each tensile specimen shall have a tensile strength not less than at least one of the following:

(1) If the specimen breaks in the base metal outside of the weld or weld interface, the test shall be accepted, provided the strength is not more than 5% below the specified minimum tensile strength of the base metal.

(2) If the specimen breaks in the weld or weld interface, the test specimen shall have tensile strength not less than the minimum specified tensile strength of the base metal, or the weaker of the two base metals if metals of different minimum tensile strengths are used.

(3) The specified minimum tensile strength of the weld metal when the Engineer allows for the use of weld metal having a lower tensile strength than the base metal.

(4) If the base metal has no specified minimum tensile strength, then failure in the base metal shall be acceptable.

7.1.3.4 Bend specimens shall be bent in one of the guided bend test fixtures shown in AWS B2.1/B2.1M. For transverse specimens, the weld metal and heat-affected zone (HAZ) shall be completely within the bent portion of the specimen after bending. There shall be no open discontinuity exceeding 1/8 in [3 mm], measured in any direction on the

convex surface of the specimen after bending. Cracks occurring on the corners of the specimen during bending shall not be considered, unless there is definite evidence that they result from weld discontinuities. For test weldments less than 1/16 in [1.5 mm] in thickness, the specimen shall be acceptable if there are no discontinuities evident in the base metal or weld metal exceeding 1/16 in [1.5 mm] after bending.

7.1.3.5 Cross-Sectioning Welds: Test welds that require sectioning for qualification shall be cross-sectioned as follows:

- (a) End cap welds at the start/stop of the weld and at approximately 180 degrees opposite. A minimum of two cross-sections required. See Figure 4.
- (b) Rod end welds with a groove width that varies less than 3/32" [2.5 mm] at the start/stop of the weld and at approximately 180 degrees opposite. A minimum of two cross-sections required. See Figure 5.
- (c) Rod end welds with a groove width that varies 3/32" [2.5 mm] or greater at the start/stop of the weld and at the minimum groove width and at the maximum groove width. A minimum of three cross-sections required. See Figure 6.
- (d) Port welds and hydraulic line welds at the start/stop of the weld and at approximately 90 degrees. A minimum of two cross-sections required. See Figure 7.
- (e) Welds not defined above shall be cross-sectioned as required by the Engineer.

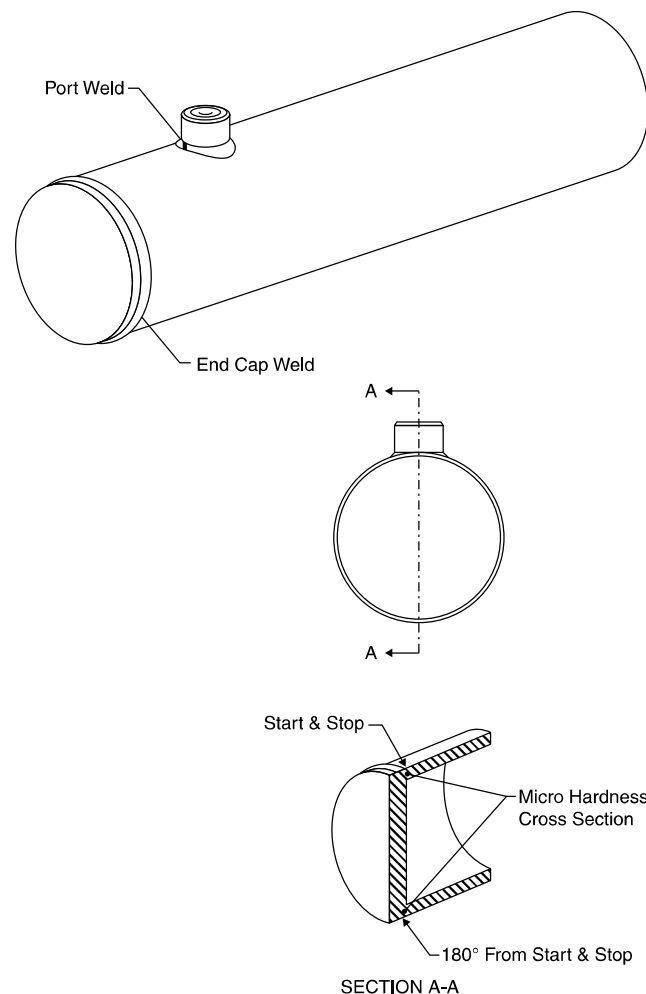
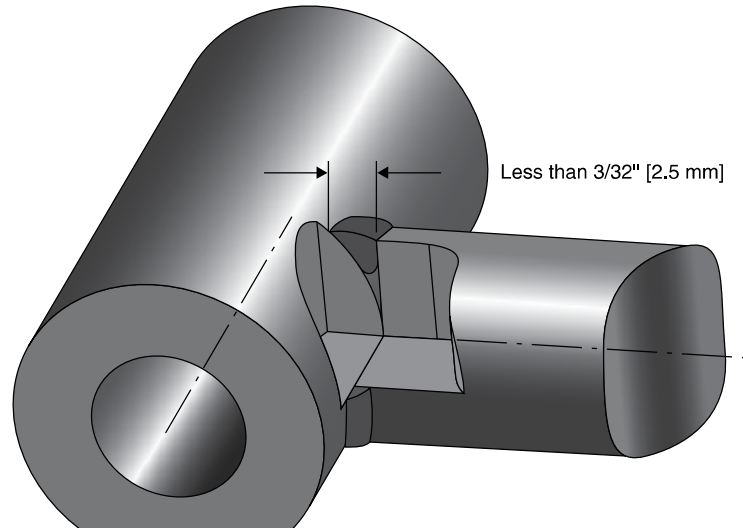


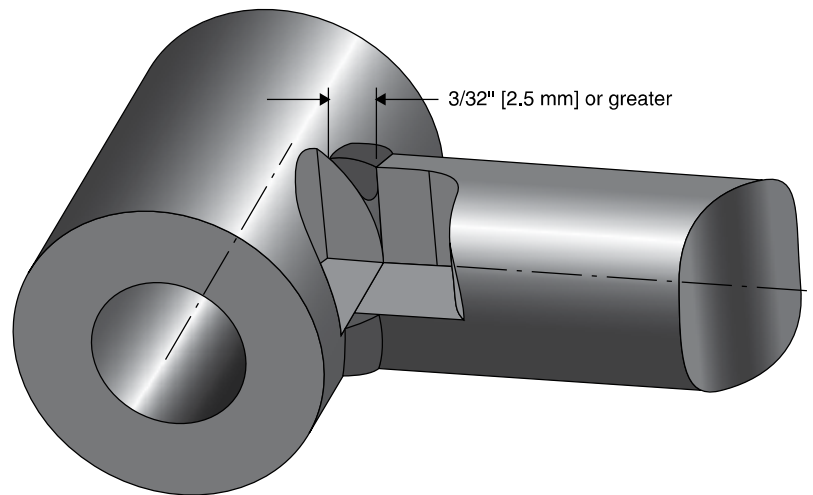
Figure 4—Typical Location for Cross-Sections in an End Cap Weld



Notes:

1. Two cross-sections required.
2. One cross-section shall be removed from the area of the start/stop.
3. One cross-section shall be removed from the area 180 degrees opposite the start/stop.

Figure 5—Typical Location of Cross-Sections for Rod Welds with Groove Width Less than 3/32" [2.5 mm]



Notes:

1. Three cross-sections required.
2. One cross-section shall be removed from the area of the start/stop.
3. One cross-section shall be removed from the area with the largest groove width.
4. One cross-section shall be removed from the area with the minimum groove width.

Figure 6—Typical Location of Cross-Sections for Rod Welds with Groove Width 3/32" [2.5 mm] and Greater

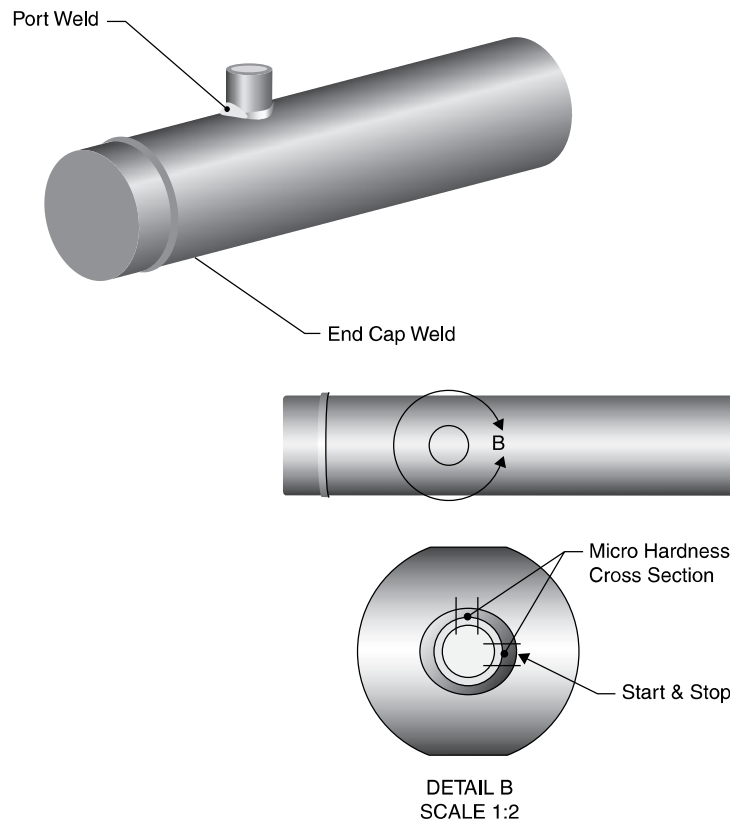


Figure 7—Typical Location for Cross-Sections in a Port Weld

7.1.3.6 Cross-Section Methodology. Cross-sectioned welds shall be prepared and etched with a suitable solution to give a clear definition of the weld and heat affected zones. Visual examination of the cross-sectioned welds may be conducted with magnification up to 10× or without magnification. The results of visual examination shall meet the acceptance requirements of Clause 8, Workmanship and Quality Requirements.

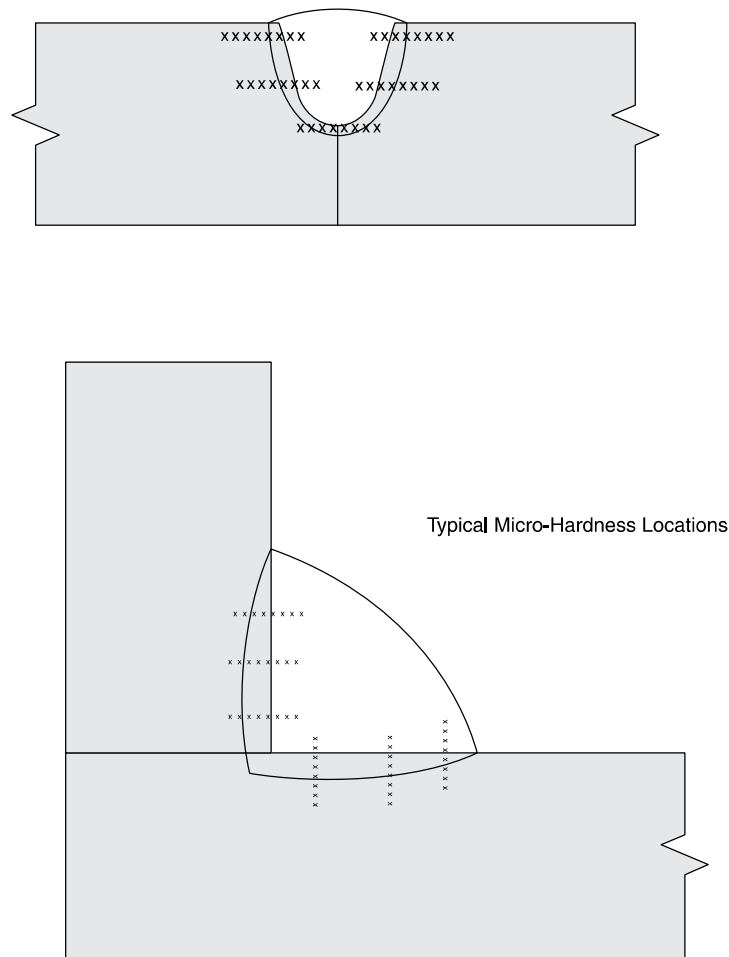
7.1.3.7 Micro-Hardness Acceptance Criteria. The hardness of the HAZ shall be evaluated. Hardness measurement shall be taken in the area of the root and surface of the weld as shown in Figure 8. Acceptable HAZ hardness values shall be as follows:

- (a) HAZ hardnesses that are less than 410 Vickers (42 HRC converted) shall be acceptable.
- (b) With the Engineer's permission, the hardness may exceed 410 Vickers but shall not exceed 445 Vickers (45 HRC converted).
- (c) The maximum HAZ hardness shall not exceed 445 Vickers (45 HRC converted).

7.1.4 Weld Quality Acceptance Criteria of Procedure Qualification Test Welds for Friction Welding (FRW).

7.1.4.1 Welds shall be visually examined. Visual examination may be conducted with or without magnification. The results of visual examination shall meet the acceptance criteria of AWS C6.2/C6.2M, *Specification for Friction Welding of Metal*.

7.1.4.2 After visual examination, two metallurgical specimens shall be tested in accordance with AWS C6.2/C6.2M, *Specification for Friction Welding of Metal*.



Note: Figure 8 provides recommended zones to take micro hardness readings. The actual locations and number of readings shall be determined by the manufacturer.

Figure 8—Micro-Hardness Locations

7.1.4.3 The hardness of the HAZ shall be evaluated. Hardness measurements shall be taken in the area of the root and surface of the weld as shown in Figure 8. Acceptable HAZ hardness values shall be as follows:

- (a) HAZ hardnesses that are less than 410 Vickers (42 HRC converted) shall be acceptable.
- (b) With the Engineer's permission, the hardness may exceed 410 Vickers but shall not exceed 445 Vickers (45 HRC converted).
- (c) The maximum HAZ hardness shall not exceed 445 Vickers (45 HRC converted).

7.1.5 Weld Quality Acceptance Criteria of Procedure Qualification Test Welds for Stud Welding (SW).

7.1.5.1 Welds shall be visually examined. Visual examination may be conducted with or without magnification. The results of visual examination shall meet the acceptance criteria of Clause 8, Workmanship and Quality Requirements.

7.1.5.2 After visual examination, the bend and tensile load tests shall meet the acceptance criteria specified by AWS B2.1/B2.1M, *Specification for Welding Procedure and Performance Qualification*.

7.1.6 Weld Quality Acceptance Criteria of Procedure Qualification Test Welds for Projection Welding (PW)

7.1.6.1 Welds shall be visually examined. Visual examination may be conducted with or without magnification. The results of visual examination shall meet the acceptance criteria of AWS C1.4M/C1.4, *Specification for Resistance Welding of Carbon and Low-Alloy Steels*.

7.1.6.2 After visual examination, two metallurgical specimens and two threaded direct tension specimens shall be tested in accordance with AWS C1.4M/C1.4, *Specification for Resistance Welding of Carbon and Low-Alloy Steels*.

7.1.6.3 The hardness of the HAZ shall be evaluated. Hardness measurement shall be taken in the area of the root and surface of the weld as shown in Figure 8. Acceptable HAZ hardness values shall be as follows:

- (a) HAZ hardnesses that are less than 410 Vickers (42 HRC converted) shall be acceptable.
- (b) With the Engineer's permission, the hardness may exceed 410 Vickers but shall not exceed 445 Vickers (45 HRC converted).
- (c) The maximum HAZ hardness shall not exceed 445 Vickers (45 HRC converted).

7.1.6.4 Acceptability of the threaded direct tension tests shall be determined by the Engineer.

7.1.7 Welding Variables. Table 2 lists the matrix of welding variables required to be addressed on both the welding procedure qualification record (WPQR) and welding procedure specification (WPS). The types of welding variables found in this matrix are qualification (Q), WPS data (D), and fracture toughness (T), as defined in Clause 3. A change in a qualification variable beyond that allowed in Table 2 requires requalification of the WPS. If fracture toughness is required, a change in a toughness (T) variable beyond that allowed in Table 2 requires requalification of the WPS. If fracture toughness is not required, all variables noted as toughness (T) variables shall be treated as a WPS data variable. A change in a WPS data variable may be made without requalification, but a revised WPS or new WPS shall be prepared.

7.2 Welding Performance Qualification

7.2.1 For GMAW, FCAW, GTAW, PAW, and SAW processes, welding performance qualification shall be by standard test in accordance with AWS B2.1/B2.1M. The welder or welding operator performance qualification shall be documented and may be in any convenient format provided all the welding variables of 7.2.10, Welding Performance Qualification Variables, and the results of all tests are recorded.

7.2.1.1 For processes not listed in 7.2, qualification of welding performance shall be in conformance with B2.1/B2.1M, *Specification for Procedure and Performance Qualification*.

7.2.2 Visual examination of standard test weldments shall meet the acceptance criteria of Clause 8, Workmanship and Quality Requirements.

7.2.3 Bend specimens shall be bent in one of the guided bend test fixtures shown in AWS B2.1/B2.1M. For transverse specimens, the weld metal and heat-affected zone shall be completely within the bent portion of the specimen after bending. Bend test specimens shall be examined visually. Bend specimens shall have no openings greater than 1/8 in [3 mm] or 1/2 T, whichever is less, where T equals the base metal thickness qualified.

7.2.4 As an alternate to 7.2.3, radiography may be performed for evaluation of performance qualification test welds. The radiographic procedure shall be as listed in AWS B2.1/B2.1M, Annex E. For acceptance, the weld shall have no discontinuities exceeding 1/8 in [3 mm] or 1/2 T, whichever is less. Oxide islands shall not be considered relevant indications for this test.

7.2.5 If workmanship samples are required as additional qualification, they shall be specified in contract documents.

7.2.6 The performance qualification of a welder or welding operator shall be affected when one of the following conditions occur:

Table 2
Qualification and WPS Data for Welding Procedure Qualification

WELDING VARIABLES

This matrix lists the welding variables required to be addressed on both the Welding Procedure Qualification Record and Welding Procedure Specification. The three types of variables found in this matrix are Toughness (T), Qualification (Q) and WPS Data (D) variables as defined in Section 3. If no type of variable is listed, the variable is not applicable for the process and does not need to be addressed.

Section Paragraph		WELDING PROCESSES						
		GMAW	FCAW	GTAW	PAW	SAW	PW	SW
Joint Design								
7.1.7.1	(1) A change in groove type that restricts access to the root of the joint (from U-groove to single bevel, etc.)	Q	Q	Q	Q	Q		
	(2) Any change in the joint details (e.g., angle, groove, radius, root face, etc.)	D	D	D	D	D		
	(3) Any change in treatment of backside, method, or gouging/preparation	D	D	D	D	D		
	(4) A change from a fillet to a groove weld	Q	Q	Q	Q	Q		
	(5) A decrease in the root opening beyond that used in the qualification test outside the design tolerance	Q	Q	Q	Q	Q		
	(6) An increase in root face outside the design tolerance	Q	Q	Q	Q	Q		
	(7) A decrease in groove angle outside the design tolerance	Q	Q	Q	Q	Q		
	(8) A change in the size, shape, ferrule/flux type							D
	(9) A change in the backing material M-number as listed in B2.1	Q	Q	Q	Q	Q		
Section Paragraph		WELDING PROCESSES						
		GMAW	FCAW	GTAW	PAW	SAW	PW	SW
Base Metal								
7.1.7.2	(1) Any changes outside of the limitations listed in B2.1.	Q	Q	Q	Q	Q		D
	(2) A change from one M-number to another M-number or to a combination of M-number base metals listed in B2.1.	Q	Q	Q	Q	Q		Q
	(3) For unlisted base metals, a change in the specified chemistry or specified mechanical properties.	Q	Q	Q	Q	Q		Q

Table 2 (Continued)
Qualification and WPS Data for Welding Procedure Qualification

Section Paragraph		WELDING PROCESSES						
		GMAW	FCAW	GTAW	PAW	SAW	PW	SW
Base Metal								
	(4) A change from one M-Number Group Number to any other M-Number Group Number with the following exception. If the WPS for welding the combination of base metals specifies the same qualification variables including electrode or filler metal, as both WPS's for welding each base metal to itself, such that the base metal is the only change, then the WPS for welding the combination of base metals is also qualified.	T	T	T	T	T		Q
	(5) A change from one M-5 Group (A, B, etc.) to any other. A change from M-9A to M-9B, but not vice versa. A change from one M-10 or M-11 group (A, B, etc.) to any other group.	Q	Q	Q	Q	Q		Q
Section Paragraph		WELDING PROCESSES						
		GMAW	FCAW	GTAW	PAW	SAW	PW	SW
Filler Metal								
7.1.7.3	(1) The addition or deletion of filler metal			Q	Q			
	(2) For ferrous materials, a change in the filler metal A-Number	Q	Q	Q	Q	Q		
	(3) A change in the filler metal diameter	Q	Q	Q	Q	Q		
	(4) A change from one F-Number to any other F-Number or to any filler metal not listed in AWS B2.1/B2.1M	Q	Q	Q	Q	Q		
	(5) If the weld metal alloy content is largely dependent upon the composition of the flux, any change in the welding procedure which would result in the important weld metal alloying elements being outside the specified chemical composition range of the WPS					D		
	(6) A change in filler metal AWS specification and classification	T	T	T	T	T		
	(7) A change from one of the following filler metal product forms to another: (a) flux cored (b) bare (solid) or metal cored (c) flux covered (d) any filler metal not covered	Q	Q	Q	Q	Q		

Table 2 (Continued)
Qualification and WPS Data for Welding Procedure Qualification

Section Paragraph		WELDING PROCESSES						
		GMAW	FCAW	GTAW	PAW	SAW	PW	SW
Filler Metal								
	(8) A change in the number of electrodes	Q	Q	Q	Q	Q		
	(9) A change in flux type or a change from AWS electrode-flux classification listed to another electrode-flux classification						Q	
Section Paragraph		WELDING PROCESSES						
		GMAW	FCAW	GTAW	PAW	SAW	PW	SW
Shielding								
7.1.7.4	(1) A change in the specified nominal head or torch shielding gas composition	Q	Q	Q	Q			Q
	(2) A change in the specified nominal backing (purge) gas composition	Q	Q	Q	Q			Q
	(3) An omission or deletion of torch shielding gas	Q	Q	Q	Q			Q
	(4) The addition or deletion of a trailing gas	D		D	D			
	(5) A change in shielding as a result of an addition or deletion of flux or a change in the flux type	Q	Q	Q	Q			
	(6) A change in the shielding gas flow rate greater than $\pm 25\%$ from that qualified	Q	Q	Q	Q			Q
	(7) A change in the backing (purge) gas flow rate greater than $\pm 10\%$ from that qualified	D	D	D	D			D
	(8) Deletion of backing (purge) gas	Q	Q	Q	Q			Q
	(9) A change in shielding as a result of a change in ferrule or flux type							Q
Section Paragraph		WELDING PROCESSES						
		GMAW	FCAW	GTAW	PAW	SAW	PW	SW
Electrical Characteristics								
7.1.7.5	(1) The addition or deletion of pulsing current	Q	Q	D	Q	Q	Q	
	(2) Any change in pulsing parameters range.	D	D	D	D	D		
	(3) A change in the current type or polarity	Q	Q	Q	Q	Q		Q
	(4) A change in the current range greater than $\pm 10\%$ from that qualified	Q	Q	D	D	Q		Q

Table 2 (Continued)
Qualification and WPS Data for Welding Procedure Qualification

Section Paragraph		WELDING PROCESSES						
		GMAW	FCAW	GTAW	PAW	SAW	PW	SW
Electrical Characteristics								
	(5) A change in the wire feed speed range greater than $\pm 10\%$ from that qualified	D	D	D	D	D		
	(6) A change in tungsten type			D	D			
	(7) A change in tungsten size			D	D			
	(8) A change exceeding $\pm 7\%$ in the voltage from that qualified	Q	Q	D	D	Q		
	(9) A change in the mode of metal transfer	Q	Q					
	(10) A change in the type of power source, or a change in the arc timing exceeding 1/10 second, or a change in amperage exceeding $\pm 10\%$ from that qualified							Q
Section Paragraph		WELDING PROCESSES						
		GMAW	FCAW	GTAW	PAW	SAW	PW	SW
Other Variables								
7.1.7.6	(1) A change in the welding process	Q	Q	Q	Q	Q		Q
	(2) A change in the cup size or nozzle size	D	D	D	D	D		
	(3) A change in the cleaning method	D	D	D	D	D		D
	(4) A change in the type of welding (manual, semiautomatic, mechanized, or automatic)	D	D	D	D	D		D
	(5) A change exceeding $\pm 10\%$ in travel speed for mechanized or automatic welding	D	D	D	D	D		
	(6) A change in the nominal size or shape of the stud at the section to be welded							Q
	(7) A change in the stud gun model, or a change exceeding 1/32 in [1mm] in the nominal lift							Q
	(8) A change in position	D	D	D	D	D		Q
	(9) A change in vertical progression	Q	Q	D	D			
	(10) A change in electrode extension $\pm 1/8$ " [3 mm].					Q		
	(11) A change in electrode extension	D	D					
	(12) A change from stringer to weave or vice versa	Q	Q	Q	Q			

Table 2 (Continued)
Qualification and WPS Data for Welding Procedure Qualification

Section Paragraph		WELDING PROCESSES						
		GMAW	FCAW	GTAW	PAW	SAW	PW	SW
Other Variables								
	(13) A change in weave oscillation width greater than five times the wire diameter	Q	Q	Q	Q			
	(14) For mechanized or automated circumferential welding in a singular plane a change in torch angle and/or work angle	D	D	D	D	D		
Preheat and Interpass Temperature								
7.1.7.7	(1) A decrease in preheat of more than 100F [55C] from that qualified	Q	Q	Q	Q	Q		Q
Section Paragraph		WELDING PROCESSES						
		GMAW	FCAW	GTAW	PAW	SAW	PW	SW
Postweld Heat Treatment								
7.1.7.8	(1) For the following M-Numbers 1, 2, 3, 4, 5, 6, 7, 9, 10, 11, and 12, a change to any other requires requalification: (a) No PWHT (b) PWHT below the lower transformation temperature. (c) PWHT with the transformation temperature range. (d) PWHT above the upper transformation temperature. (e) PWHT above the upper transformation temperature, followed by treatment below the lower transformation temperature.	Q	Q	Q	Q	Q		Q
	(2) For all materials not covered above, a separate PQR is required for no PWHT and PWHT	Q	Q	Q	Q	Q		Q

(1) When he/she has not welded with a process during a period of 6 months or more, his/her qualifications for that process shall expire.

(2) Requalification as a result of (1) is permitted by having the welder or welding operator make one test weldment using the same process. If the test weldment meets the requirements of this specification, then all of the welder's or welding operator's previous qualifications for that process, for materials, thicknesses, product forms, and other variables are reinstated.

(3) When there is a specific reason to question his/her ability to make welds that meet the specification, the qualifications which support the welding he/she is doing shall be revoked. All other qualifications not questioned remain in effect.

(4) Requalification as a result of (3) is permitted by having the welder or welding operator successfully complete performance qualification test(s) that support the qualification(s) questioned.

7.2.7 For Friction Welding (FRW), welding operator qualification shall be in accordance with AWS C6.2/C6.2M, *Specification for Friction Welding of Metals*.

7.2.8 For Stud Welding (SW), the pre-production test required by 7.3.2, if successful, shall also serve to qualify the stud welding operator. Before any production studs are welded by an operator not involved in the pre-production set-up of 7.3.2, the first two studs welded by the operator shall have been tested in conformance with the provisions of 7.3.2.3 and 7.3.2.4. When the two welded studs are found satisfactory, the operator may then weld production studs. Operator qualification for stud welding is required for the first two studs in each day's production or any change in the set-up such as changing of any one of the following: stud gun, timer, power source, stud diameter, gun lift and plunge, total welding lead length, or changes greater than 5% in current and time.

7.2.9 For Projection Welding (PW), the pre-production test required by 7.3.3, if successful, shall also serve to qualify the projection welding operator. Before any production projection welds are welded by an operator not involved in the pre-production set-up of 7.3.3, the first two projection welds welded by the operator shall have been tested in conformance with the provisions of 7.3.3 and shall be visually inspected in accordance with 7.1.6.1 and destructive testing as agreed upon between the owner and the manufacturer. When two projection welds are found satisfactory, the operator may then weld production. Operator qualification for projection welding is required for the first two welds in each day's production or any change in the set-up such as listed in AWS C1.4M/C1.4, *Specification for Resistance Welding of Carbon and Low Alloy Steels*.

7.2.10 Performance Qualification Variables for GMAW, FCAW, GTAW, PAW, and SAW. Qualification with one WPS will also qualify for welding with any other WPS within the limits given in the following performance qualification variables shown in Table 3.

7.2.11 Operators of Automatic Welding Equipment The manufacturer shall be responsible for determining the qualification requirements of operators of automatic welding equipment.

7.2.12 Records. Documentation of the test results shall be maintained by the Manufacturer. Documentation should be maintained that shows the qualified welder, tack welder, or welding operator has maintained their qualification by welding within a 6 month period of time.

7.2.13 Qualification of Tack Welders

7.2.13.1 Limitation of Variables. The following rules (in addition to those found in Table 3) shall apply for the qualification of a tack welder.

(1) For fillet welds, a tack welder shall be qualified by one test plate (See Figure 9) made in each position in which the tack welder is to tack weld (flat, horizontal, vertical up, vertical down, and overhead).

(2) For groove welds, a tack welder shall be qualified by one test plate (See Figure 11) made in each position in which the tack welder is to tack weld (flat, horizontal, vertical up, vertical down, and overhead).

(3) A tack welder qualified in the vertical up position for a particular process shall also be considered qualified in the flat and horizontal positions for that process.

7.2.13.2 Test Specimens—Number, Type, and Preparation.

(1) **Fillet.** The tack welder shall make a 1/4 in [6 mm] maximum-size weld approximately 2 in [50 mm] long on the fillet weld break specimen as shown in Figure 9.

(2) **Groove.** The tack welder shall make a 3/16 in [5 mm] maximum-size weld approximately 3 in [75 mm] long on the flare bevel groove weld break specimen as shown in Figure 11.

7.2.13.3 Method of Testing Tack Weld Specimen.

(1) **Fillet Weld.** A force shall be applied to the specimen as shown in Figure 10 until rupture occurs. The force may be applied by any convenient means.

(2) **Groove Weld.** Prior to fracture, the groove weld test specimen shall be cross-sectioned for macro examination at approximately 1 in [25mm] from one end of the tack weld. A force shall be applied to the fracture specimen as shown in Figure 12 until rupture occurs. The force may be applied by any convenient means.

Table 3
Qualification Variables for Welding Performance Qualification

WELDING VARIABLES

A change in any variable listed below from that which was used in the welder's, tack welder's, or welding operator's qualification test will require requalification of the welder, tack welder, or welding operator

Section	Paragraph	WELDING PROCESSES				
		GMAW	FCAW	GTAW	PAW	SAW
Welders and Tack Welders						
7.2.10.1	(1) A change in the welding process	Q	Q	Q	Q	Q
	(2) The deletion of backing	Q	Q	Q	Q	Q
	(3) A change in the filler metal F-Number except as permitted by AWS B2.1/B2.1M	Q	Q	Q	Q	Q
	(4) A change in the base metal except as permitted in AWS B2.1/B2.1M	Q	Q	Q	Q	Q
	(5) A change from alternating to direct current or vice versa, or a change in polarity			Q		
	(6) A change in position from that qualified except as permitted in AWS B2.1/B2.1M	Q	Q	Q	Q	Q
	(7) A change in vertical weld progression from uphill to downhill, or vice versa for any pass except root passes that are completely removed by back gouging or final passes used to dress the final weld surface	Q	Q	Q	Q	
	(8) A change from spray transfer, globular transfer, or pulsed spray transfer to short-circuiting transfer, or vice versa	Q	Q			
	(9) The omission or addition of consumable inserts, or the deletion of root shielding gas except for double welded butt joints, partial penetration groove, and fillet welds	Q	Q	Q	Q	Q
	(10) A change in thickness or diameter from that tested except as permitted in AWS B2.1/B2.1M	Q	Q	Q	Q	Q
	(11) A change in the maximum size fillet weld made in one pass exceeding 3/8 in [10 mm] for the flat position and 5/16 in [8 mm] for the horizontal position.	Q	Q			Q

Table 3 (Continued)
Qualification Variables for Welding Performance Qualification

Section	Paragraph	WELDING PROCESSES				
		GMAW	FCAW	GTAW	PAW	SAW
Welding Operators						
7.2.10.2	(1) A change in the welding process	Q	Q	Q	Q	Q
	(2) A change from direct visual to remote visual control or vice versa	Q	Q	Q	Q	Q
	(3) A change in base metal except as permitted in AWS B2.1/B2.1M	Q	Q	Q	Q	Q
	(4) A change in position from that qualified except as permitted in AWS B2.1/B2.1M	Q	Q	Q	Q	Q
	(5) A change from spray transfer, globular transfer, or pulsed spray transfer to short-circuiting transfer, or vice versa.	Q	Q			
	(6) The deletion of consumable inserts	Q	Q	Q	Q	Q

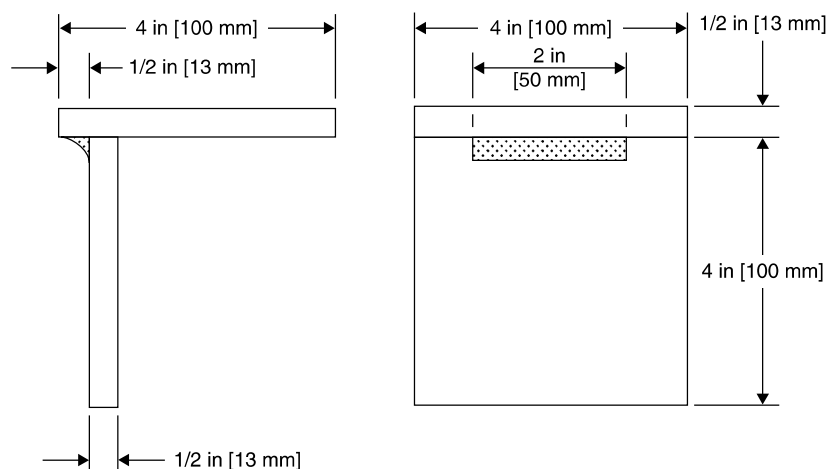


Figure 9—Fillet Weld Break Specimen—Tack Welder Qualification

7.2.13.4 Test Results Required

Fillet and Groove

(1) The tack weld shall present a reasonably uniform appearance and shall be free of cracks, undercut and shall have an acceptable profile per Figure 16. There shall be no porosity visible on the surface of the weld.

Fillet Only

(2) The fractured surface of the fillet tack weld shall show fusion to the root, but not necessarily beyond, and shall exhibit complete fusion to the base metal without any inclusions or porosity larger than 3/32 in [2 mm] in the greatest dimension or the sum of the greatest dimensions shall not exceed 3/16 in [5 mm].

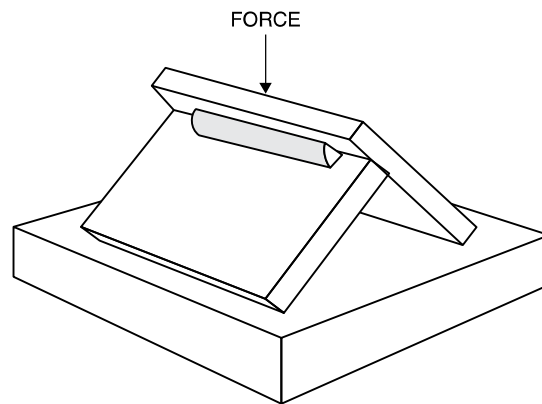
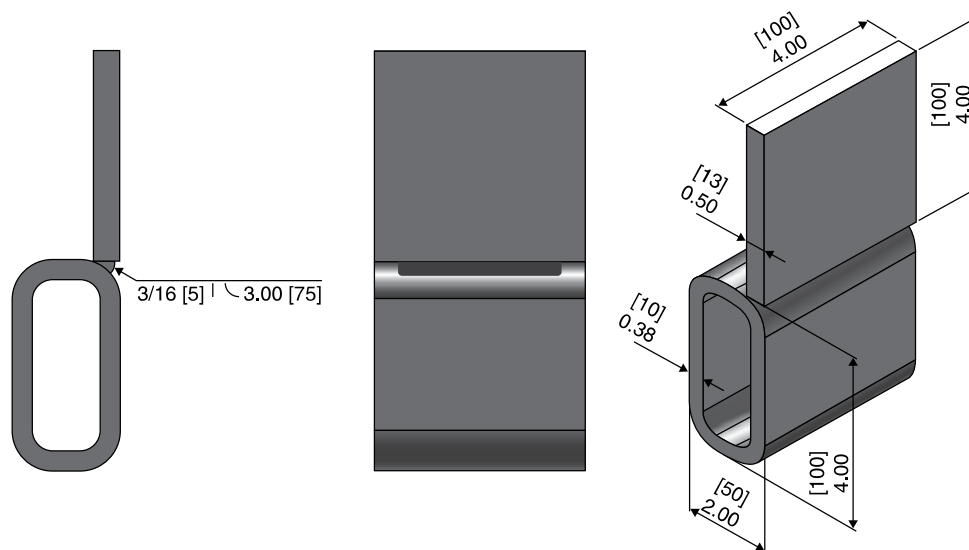


Figure 10—Method for Rupturing Specimen—Tack Welder Qualification



Note: Plate thickness = 1/2" [13 mm], Tubing wall thickness = 3/8" [10 mm].

Figure 11—Groove Weld Break Specimen—Tack Welder

(3) A tack welder who passes the fillet weld break test shall be eligible to tack weld all types of fillet welds for the process and in the positions in which the tack welder has qualified.

Grooves Only

(4) The fractured surface of the groove tack weld shall show a minimum depth of joint penetration of 3/16 in [5 mm] without any inclusions or porosity larger than 3/32 in [2 mm] in the greatest dimension or the sum of the greatest dimensions shall not exceed 3/16 in [5 mm].

(5) The groove qualification cross-section test specimens shall be prepared and etched with a suitable solution to give a clear definition of the weld and shall be visually examined for defects with the acceptance criteria of 7.2.13.4(4).

(6) A tack welder who passes the groove weld break test and groove weld cross-section shall be eligible to tack weld all groove and fillet types for the process and in the positions in which the tack welder has qualified.

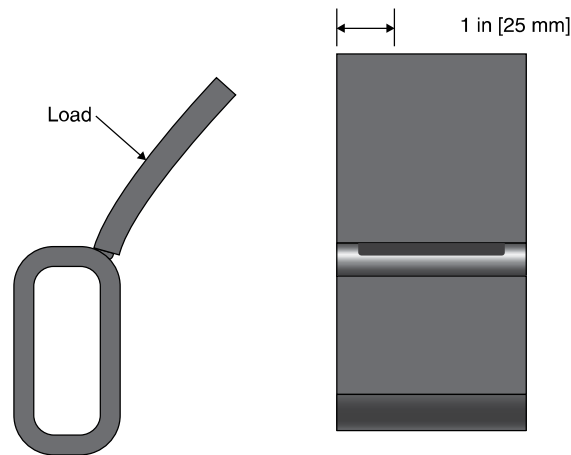


Figure 12—Method of Evaluating Tack Welder Qualification for Grooves

7.2.13.5 Retests. The tack welder may make one retest without additional training in case of failure to pass the above test.

7.2.13.6 Period of Effectiveness. The tack welder qualification shall remain in effect indefinitely in the position and with the processes for which the tack welder is qualified unless there is some specific reason to question the tack welder's ability. In such case, the tack welder shall be required to demonstrate the ability to make sound tack welds by again passing the prescribed tack welding test.

7.2.13.7 Records. Documentation of the test results shall be maintained by the Manufacturer.

7.3 Welding Equipment Qualification

7.3.1 Friction Welding (FW).

7.3.1.1 Equipment for friction welding shall meet the requirements of AWS C6.2/C6.2M, *Specification for Friction Welding of Metals*.

7.3.1.2 A welded assembly or test specimen shall be tested periodically during production as specified by the manufacturer's quality plan per AWS C6.2/C6.2M, *Specification for Friction Welding of Metals*. The category of initial inspection shall be agreed upon by the owner and manufacturer. The process parameters for each weld must be measured and compared to established limits having been proven to be indicative of the required product weld quality. When the process parameters can be correlated with the applicable test results and a level of confidence commensurate with the welding application is achieved, the process control system may be substituted in place of the periodic production testing requirements.

7.3.1.3 The machine shall be set-up and verified to be in conformance with the WPS by the appropriately trained personnel as determined by the Engineer.

7.3.1.4 To maintain acceptable production quality assurance the following shall apply:

- (1) Welds shall be made by a qualified machine operator to the requirements of the WPS.
- (2) When machines are equipped with monitors, they shall be set and used in accordance with the WPS.
- (3) Sampling of production welds shall be used for quality assurance in accordance with the WPS. In the absence of other contractual quality-assurance requirements, one (1) metallurgical specimen shall be cross-sectioned and visually examined for complete soundness at the beginning of each shift or after the machine has been idle for 8 or more hours.
- (4) Statistical process control may be applied to measure physical dimensions of the weldment, upset length, or other process variables.
- (5) Documentation shall be maintained by the manufacturer.

7.3.2 Stud Welding (SW).

7.3.2.1 Before production welding with a particular set-up and with a given size and type of stud, and at the beginning of each day's or shift's production, testing shall be performed on the first two studs that are welded. The stud technique may be developed on a piece of material similar to the production member in thickness and properties. If actual production thickness is not available, the thickness may vary $\pm 25\%$. All test studs shall be welded in the same general position as required on the production member (flat, vertical, or overhead).

7.3.2.2 Instead of being welded to separate material, the test studs may be welded on the production member, except when separate plates are required by 7.3.2.5.

7.3.2.3 The test studs shall be visually examined. They shall exhibit full 360° flash with no evidence of undercut into the stud base.

7.3.2.4 In addition to visual examination, the test shall consist of bending the studs after they are allowed to cool, to an angle of approximately 30° from their original axes by either striking the studs with a hammer on the unwelded end or placing a pipe or other suitable hollow device over the stud and manually or mechanically bending the stud. At temperatures below 50°F [10°C], bending shall preferably be done by continuous slow application of load. For threaded studs, the torque test as described in AWS B2.1/B2.1M shall be substituted for the bend test.

7.3.2.5 If on visual examination the test studs do not exhibit 360° flash, or if on testing, failure occurs in the weld zone of either stud, the procedure shall be corrected, and two more studs shall be welded to separate material or on the production member and tested in conformance with the provisions of 7.3.2.3 and 7.3.2.4. If either of the second two studs fails, additional welding shall be continued on separate plates until two consecutive studs are tested and found to be satisfactory before any more production studs are welded to the member.

7.3.2.6 Once production welding has begun, any changes made to the welding setup, as determined in 7.3.2, shall require that the testing in 7.3.2.3 and 7.3.2.4 be performed prior to resuming production welding.

7.3.2.7 In production, studs on which a full 360° flash is not obtained may be repaired by adding the minimum fillet weld as required by Table 4 in place of the missing flash. The repair weld shall extend at least $3/8$ in [10 mm] beyond each end of the discontinuity being repaired.

7.3.3 Projection Welding (PW). Welding equipment requirements and process validation for projection welding shall meet the requirements of AWS C1.4M/C1.4, *Specification for Resistance Welding of Carbon and Low Alloy Steels*.

7.4 Welding Process Audits

7.4.1 To ensure that welding operations conducted at the manufacturer are in compliance with the welding quality requirements of this standard, periodic welding process audits shall be conducted on each production welder, welding operator and tack welder at least 2 times per year. Operators of automatic welding equipment are excluded from the welding process audit requirements.

7.4.2 The welding process audits include observation of welding practices and visual inspection of welds produced by each welder, welding operator and tack welder.

7.4.3 In addition to examining one or more parts welded by the welder, welding operator or tack welder, the welding auditor shall evaluate the welder, welding operator or tack welder, for compliance to the requirements of the applicable WPS and the limitations of performance qualification. Other items such as the use of personal protective equipment

Table 4
Minimum Fillet Weld Size for Small Diameter Studs

Stud Diameter		Minimum Size Fillet	
in	mm	in	mm
$1/4$ thru $7/16$	6 thru 11	$3/16$	5
$1/2$	12	$1/4$	6
$5/8$, $3/4$, $7/8$	16, 20, 22	$5/16$	8
1	25	$3/8$	10

(PPE) and the condition of welding equipment and fixturing may also be evaluated during the welding practice observation portion of the audit.

7.4.4 The visual inspection of welds, inspected during the welding process audit, shall include an inspection for defects that are commonly found with the welding process or processes used to produce the weld being inspected.

8. Workmanship and Quality Requirements

8.1 Scope. This section presents quality and workmanship levels, which may be expected to be normally attainable within this industry. General or specific applications and designs may allow levels different than those listed here. Such differences, when specified and documented, may be applied.

8.2 General Requirements

8.2.1 All requirements of this section shall be satisfied in the production and inspection of welded assemblies covered under this specification.

8.2.2 Welding shall not be performed when the temperature of the part to be welded is lower than specified on the engineering drawing or welding procedure specification, nor shall welding be performed when the weldment is exposed to high winds, drafts, moisture. The temperature of the part, when not specified, shall not be lower than 50°F [10°C]. Winds and drafts must be limited to avoid adversely affecting the weld process. During welding, wind velocity shall not exceed a maximum of 5 miles per hour [8 kilometers per hour]. In addition, winds and drafts shall also be limited to avoid excessive cooling rates, which may affect properties of the weld and heat-affected zones.

8.3 Equipment

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

8.4 Preparation of Materials

8.4.1 Joints for pressure containing welds require thorough cleanliness. Joint surfaces and edges shall be uniform and free from fins, notches, tears, cracks, and other irregularities that will adversely affect the quality or strength of the weld or member. The welding surface and surfaces adjacent to a weld shall also be free from loose or thick scale, slag, rust or oxidation, moisture, paint, grease, or other foreign material that will adversely affect the quality or strength of the weld or produce hazardous fumes. Thin rust-inhibitive coating, or anti spatter compound applied per the manufacturer's specification (that will not adversely affect welding) need not be removed. Any plating, coating, or cladding that has been determined to be detrimental to the weld by the Engineer shall be removed to the extent of the weld area.

8.4.2 Surfaces within 1.0 in [25mm] of any weld location shall be free from material that will adversely affect welding.

8.4.3 Mechanical or thermal processes may be used for weld joint preparation provided the weld joint meets the required dimensions and surface conditions of the engineering drawing or specification. The resulting surfaces shall be reasonably smooth for welding. The roughness of cut surfaces shall not be greater than sample No. 2 of AWS C4.1, *Surface roughness Guide for Oxygen Cut Surfaces*, for material thickness up to 2 in [50mm], and sample No. 1 for materials 2 in [50mm] to 8 in [200mm] thick. Surfaces exceeding these values shall not be used unless removed by machining, or grinding, or approved by the Engineer.

8.4.4 Backgouging or the removal of unacceptable work or material may be carried out by any appropriate means such as chipping, grinding, carbon arc, plasma arc, or oxyfuel gas gouging. Caution shall be taken when oxyfuel gas cutting or gouging is used on any structural weldment where stresses due to adverse heating conditions may be considered detrimental to the end product. One exception is that oxygen gouging shall not be used on quenched and tempered steels. The gouged or cut surfaces may require grinding to remove a carburized layer resulting from these operations. Exercising care in the use of the gouging or cutting process may produce surfaces which are usable without subsequent preparation.

8.5 Assembly

8.5.1 Tack Welds. Tack welds shall be made using a qualified welding procedure, by a qualified tack welder, and subject to the same quality requirements as the final weld. Tack welds which are to be incorporated into the final weld

shall be cleaned thoroughly (except for the GMAW, PAW, GTAW processes) before incorporation. Tack welds not incorporated in the final weld and not shown on the drawing shall be removed.

8.5.2 Fillet Welds

8.5.2.1 The parts to be joined by fillet welds shall be brought into as close contact as practicable. The root opening between parts shall not exceed $1/8$ in [3mm] without approval from the Engineer. For material thicknesses less than $1/2$ in [13 mm], the fillet weld shall have the leg size increased by the amount of root opening in excess of $1/32$ in [1 mm]. For material thicknesses $1/2$ in [13 mm] or greater, the fillet weld shall have the leg size increased by the amount of root opening in excess of $1/16$ in [1.5 mm].

8.5.2.2 Port Welds. For ports joined to tubes by fillet welds, as defined by 6.2, the groove width between the port and tube shall not exceed $3/32$ in [2.5 mm] without the approval from the Engineer. The fillet weld shall have the leg size increased by the amount of the groove width in excess of $1/32$ in [1 mm]. For port joints where the base of the port is flat welded to a tube radius (see Figure 13) the groove width is measured at the maximum opening. Alternative port designs that can be used to minimize groove width between the port and the cylinder tube are shown in Figure 14 and Figure 15.

8.5.3 Groove Welds

8.5.3.1 Dimensions of the cross-section of groove joints shall not vary from those shown on the detail drawing.

8.5.4 Faying Surfaces. The separation between faying surfaces of lap joints, plug and slot welds, and of butt joints with backing shall not exceed $1/16$ in [1.5 mm].

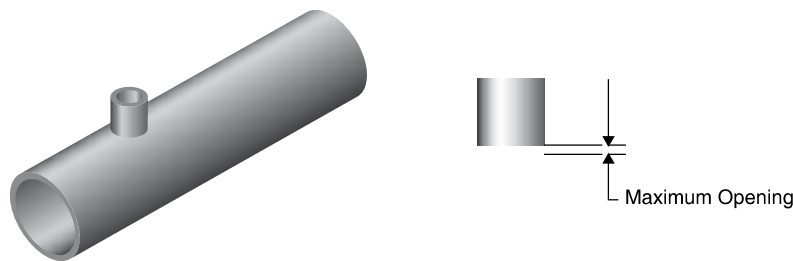


Figure 13—Flat Based Port Design on Round Tube

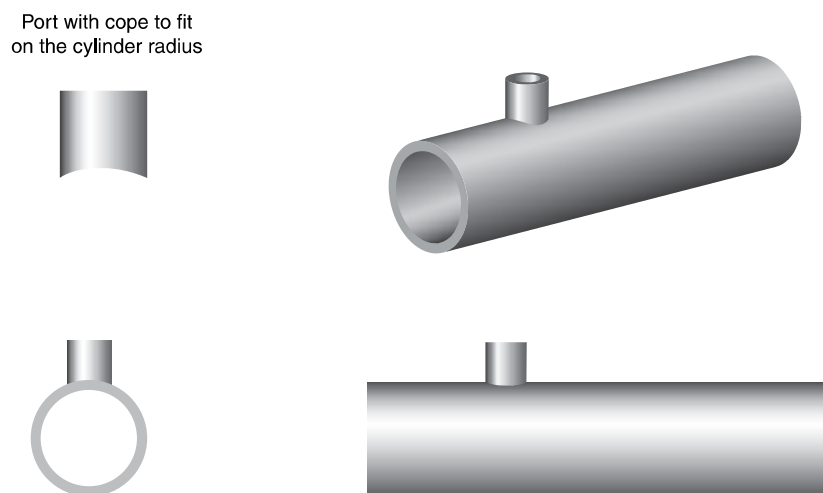
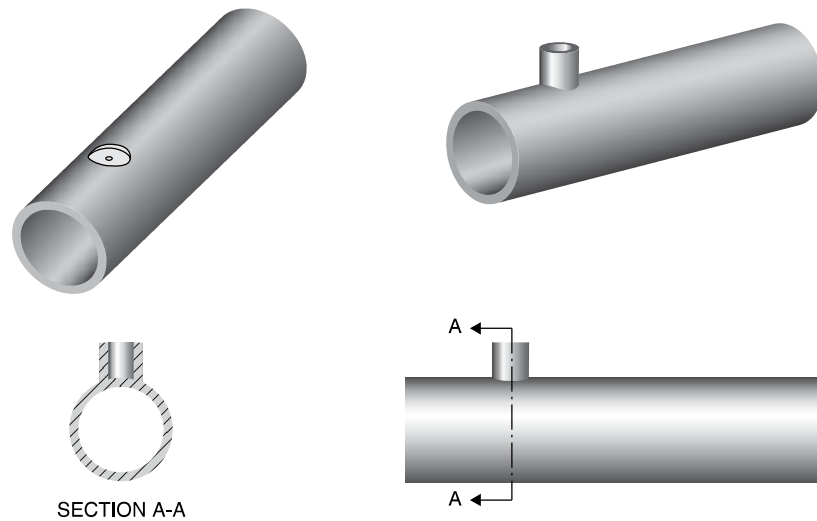


Figure 14—Coped Port Design

Cylinder showing spotfaced area

**Figure 15—Spot Faced Port Design**

8.5.5 Butt Joint Alignment. Parts to be joined at butt joints shall be carefully aligned. Where the parts are effectively restrained against bending due to eccentricity in alignment, an offset not exceeding 10% of the thickness of the thinner part joined, but in no case more than 1/8 in [3mm], shall be permitted as a departure from the theoretical alignment. In correcting misalignment in such cases, the parts shall not be drawn into a greater slope than 1/2 in in 12 in [13 mm in 300 mm]. Measurement of offset shall be based on the centerline of parts unless otherwise shown on the drawings.

8.5.6 Slugging. Slugging is prohibited.

8.6 Preheat

8.6.1 Preheat requirements shall be as stated on the WPS. Preheating and interpass temperature control shall ensure that the full thickness of the weld joint preparation and adjacent base metal for a distance at least equal to the thickness of the thickest welded part (but not less than 3 in [75 mm]) in all directions from the point of welding are within the temperature specified. Refer to Annex B for additional information on preheat.

8.6.2 Prior to welding the preheat temperature shall be verified by a device that will verify the correct temperature has been met. One method of verification for through thickness preheat is to delay the measurement of temperature for 20 seconds per inch thickness of the thicker member.

8.7 Arc Strikes

8.7.1 Arc strikes outside the area of permanent welds shall not be permitted. Cracks or blemishes caused by arc strikes shall be removed and ground to a smooth contour and inspected to ensure soundness.

8.7.2 Arc strikes on quenched and tempered steels, which have been removed, shall be visually inspected with or without magnification. Additional inspection shall be performed as specified by the Engineer.

8.7.3 The reduction of thickness resulting from the removal of arc strikes shall not exceed the design base metal tolerance without the Engineer's approval.

8.8 Cleaning of Welds

8.8.1 Before welding over previously deposited weld metal, all detrimental slag (including silica) shall be removed and the weld and adjacent base metal shall be clean. This requirement shall apply not only to successive layers but also to successive beads and to the crater area when welding is resumed after any interruption. The weld and adjacent base metal shall be cleaned by brushing or other suitable means.

8.9 Peening

8.9.1 Peening may be used on intermediate weld layers for control of shrinkage stresses to prevent cracking. No such peening shall be done on the root pass or surface layer of the weld or the base metal at the edges of the weld.

8.10 Stress Relief

8.10.1 When the Owner requires weldments to be stress relieved, it shall be specified in contract documents.

8.10.2 All stress relief shall be by thermal heat treatment. Refer to Annex B for additional information on postweld heat treatment.

8.11 Quality of Welds

8.11.1 General Requirements. Acceptance criteria for workmanship and quality requirements shall conform to contract documents. In the absence of contract documents, then the requirements of Clause 8 shall apply.

8.11.2 Nondestructive Examination. All welds shall be visually inspected unless this requirement is exempted by contract documents. If additional nondestructive examination is required by the Owner, the process and extent of examination shall be specified in the contract documents. When nondestructive examination (NDE) is required, it shall be performed in accordance with AWS D14.4/D14.4M, *Specification for the Design of Welded Joints in Machinery and Equipment*, methods developed by the manufacturer, or as specified by contract documents.

8.11.2.1 When specified, the acceptance criteria for magnetic particle testing and liquid penetrant testing shall be those specified in 8.11.3.

8.11.2.2 When specified, the acceptance criteria for radiographic and ultrasonic examination shall be those specified in 8.11.4.

8.11.3 Surface Requirements.

8.11.3.1 All welds shall be cleaned prior to inspection. Cleaned is defined as the removal of soot, spatter, arc strikes, slag (including silica) or any other foreign material that will interfere with inspection.

8.11.3.2 Weld metal and base metal cracks shall not be permitted.

8.11.3.3 Incomplete fusion between weld metal and base metal and between successive layers of weld metal shall not be permitted.

8.11.3.4 Spatter shall not be permitted in areas where it would interfere with the function or corrosion protection of the member or as specified by the owner.

8.11.3.5 For high cycle cylinders, surface porosity is not permitted.

8.11.3.6 For low cycle cylinders, all pressure containing welds shall be free from surface porosity. Unless otherwise specified by the Owner, all other welds, the sum of diameters of visual or surface porosity, including piping porosity, shall not exceed 1/8 in [3 mm] in any 4 in [100 mm] length of weld and shall not exceed 3/8 in [10 mm] in any 12 in [300 mm] length of weld, with no single void exceeding 3/64 in [2.4 mm] in diameter.

8.11.3.7 Weld overlap shall not be permitted (see Figure 16).

8.11.3.8 For high cycle cylinders, undercut is not permitted.

8.11.3.9 For low cycle cylinders, undercut exceeding the following shall not be permitted:

- (1) 0.010 in [0.25 mm] deep up to 10% of weld length for material thicknesses equal to or less than 1/8 in [3 mm].
- (2) 0.020 in [0.5 mm] deep up to 10% of the weld length for material thicknesses greater than 1/8 in [3 mm] and less than 1/4 in [6 mm].
- (3) 0.030 in [0.75 mm] deep up to 10% of the weld length for material thicknesses 1/4 in [6 mm] and greater.

NOTE 1: Regardless of depth up to the limits of (1), (2), and (3), undercut greater than 25% of the weld length is not permitted.

NOTE 2: Undercut less than 0.005 in [0.13 mm] is considered nonrelevant regardless of length.

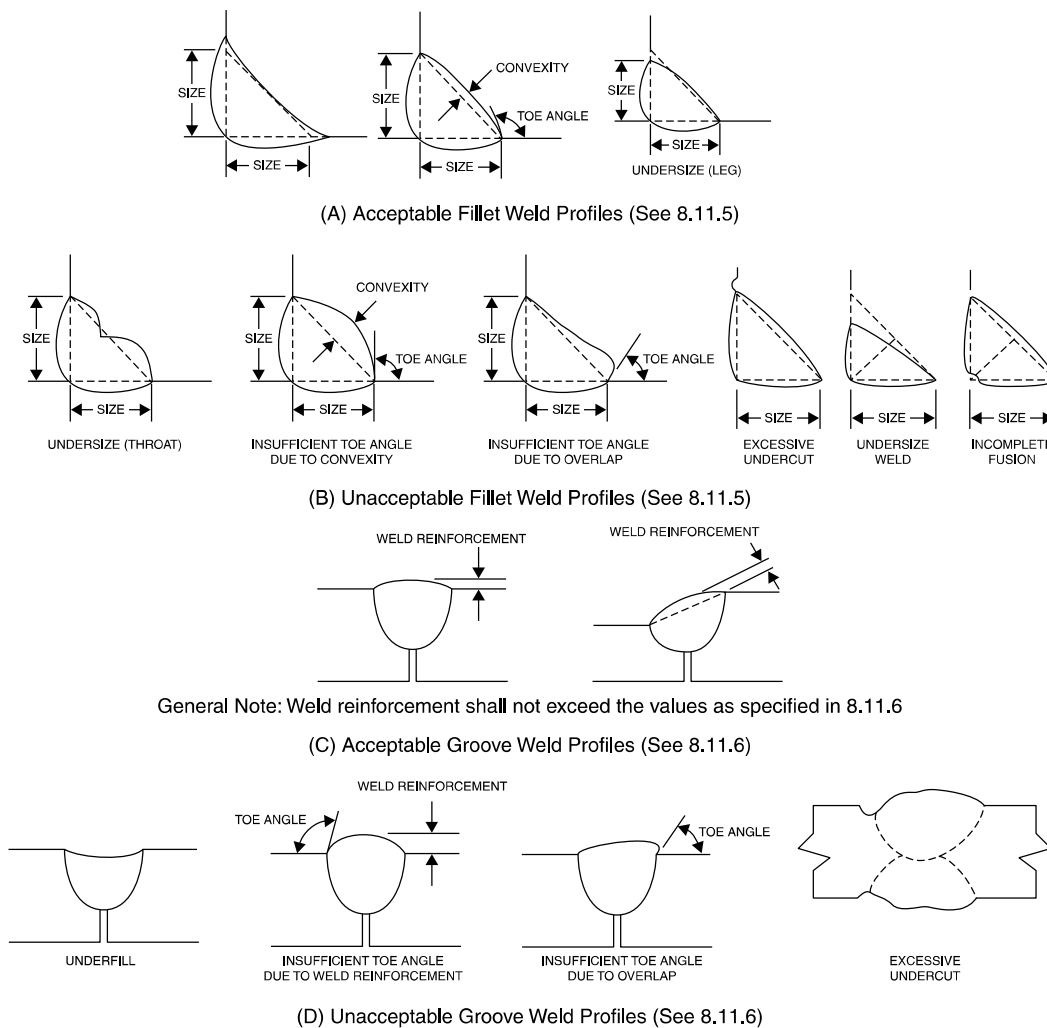


Figure 16—Acceptable and Unacceptable Weld Profiles

8.11.4 Subsurface Requirements. The subsurface quality of the welds as determined by radiographic examination, ultrasonic examination, or destructive sectioning and testing shall meet the following minimum acceptance criteria:

8.11.4.1 Cracks are not permitted.

8.11.4.2 For high cycle cylinders, incomplete penetration to the root, three-dimensional-type discontinuities (porosity), and/or planar-type discontinuities (lack of fusion, slag inclusions, or fissures) are not permitted.

8.11.4.3 For pressure containing welds for low cycle cylinders, incomplete penetration to the root, and/or planar-type discontinuities (lack of fusion, slag inclusions, or fissures) are not permitted.

8.11.4.4 For nonpressure containing welds for low cycle cylinders, planar-type discontinuities (lack of fusion, slag inclusions, or fissures) are permissible to 10% of specified weld size, or less than 10% of joint penetration in height or width. The length of an individual discontinuity, or the sum of the discontinuities, shall not exceed 10% of the weld length.

8.11.4.5 For low cycle cylinders, three-dimensional-type discontinuities (porosity) are permissible in discontinuous distribution, provided the largest dimension of any single discontinuity does not exceed 10% of the weld size.

NOTE: The sum of the discontinuities at their largest dimension shall not exceed 1/8 in [3 mm] in any linear inch [25 mm] of weld, nor 10% of the weld length.

8.11.5 Fillet Weld Size and Profiles (see Figure 16)

8.11.5.1 All craters shall be filled to at least 85% of the full cross-section of the welds and shall terminate where required by the drawing.

8.11.5.2 All fillet welds shall have an acceptable profile as shown in Figure 16.

8.11.5.3 For low cycle cylinders, the reentrant angle at the weld toe (toe angle) shall be no less than 90 degrees. Toe angle requirement may be increased based on load conditions as agreed upon by the Owner and the Manufacturer and as specified on the drawing.

8.11.5.4 For high cycle cylinders, the reentrant angle at the weld toe (toe angle) shall be no less than 110 degrees. Toe angle requirement may be increased based on load conditions as agreed upon by the Owner and the Manufacturer and as specified on the drawing.

8.11.5.5 All weld lengths and sizes shall conform to the requirements shown on the drawing.

8.11.5.6 Fillet weld leg size shall conform to the following tolerances based on a measurement of fused leg length:

- (1) Weld sizes less than 3/8 in [10 mm]:

+1/8 in [3 mm]

−1/32 in [1 mm]

- (2) Weld sizes 3/8 in [10 mm] and over:

+1/8 in [3 mm]

−1/16 in. [1.6 mm]

The average weld size of a given length of weld shall not be less than the weld size specified on the engineering drawing. The average weld size is determined by the average of leg length measurements obtained at 3 in [75 mm] intervals along the weld length. For welds under 3 in [75 mm] in length, the above tolerances are applied directly. For welds exceeding these tolerances, see 8.12.6 and 8.12.7.

8.11.6 Groove Weld Size and Profiles (see Figure 16)

8.11.6.1 All weld lengths and sizes shall conform to the requirements shown on the drawing.

8.11.6.2 All craters shall be filled to at least 85% of the full cross-section of the welds and shall terminate where required by the drawing.

8.11.6.3 Groove welds shall be made with slight reinforcement, unless otherwise specified, and shall have no defects such as those shown in Figure 16. The reinforcement for the specified groove weld size shall not exceed the following:

- (1) Up to 1/2 in [13 mm] thick inclusive, the maximum reinforcement is 3/32 in [2.5 mm];
- (2) Over 1/2 in to 1 in [13 mm to 25 mm] thick inclusive, the maximum reinforcement is 1/8 in [3 mm];
- (3) Over 1 in [25 mm] thick, the maximum reinforcement is 5/32 in [4 mm].

8.11.6.4 Weld reinforcement shall have a gradual transition to the plane of the base metal surface with reentrant angles at the weld toes greater than or equal to 110 degrees. Toe angle requirement may be increased based on load conditions as agreed upon by the Owner and the Manufacturer and as specified on the drawing.

8.11.6.5 Underfill greater than or equal to 5% of the thickness of the thinner member is not permitted regardless of length. Underfill less than 5% of the thickness of the thinner member is permissible up to 10% of the weld length with the approval of the Engineer.

8.12 Repair of Weld Defects

8.12.1 All repair welding shall be performed in conformance to the welding requirements of this specification and the WPS for the welded joint involved.

8.12.2 Underfilled Craters. Underfilled craters shall be rewelded and filled to the requirements of 8.11.5 and 8.11.6.

8.12.3 Cracks, Porosity, and Planar Discontinuities. Cracks, porosity, and planar-type discontinuities deemed to be unacceptable in accordance with the established acceptance criteria (see 8.11) shall be completely removed by appropriate means. The areas from which these discontinuities are removed shall be inspected by an approved NDE method, such as magnetic particle, penetrant testing or visual testing to assure complete removal of the discontinuity prior to repair welding. The area removed shall be rewelded with the original welding procedure or a qualified repair procedure.

8.12.4 Undercut. Undercut may be repaired by grinding and blending or by welding using a qualified welding procedure or a repair procedure.

8.12.4.1 Blending shall be done with a slope not to exceed 1 in 2.5. The blending operation shall not reduce the base material below the specified minimum mill tolerance of the base material thickness. Repair of undercut areas by grinding and blending in excess of this amount may be permitted with approval of the Engineer.

8.12.4.2 When undercut is to be repaired by welding, the surfaces shall be prepared and then additional weld metal shall be deposited using the original welding procedure or a repair procedure.

8.12.5 Overlap. Overlap shall be removed by appropriate means. Additional weld metal may be added after removal of the overlap condition in order to restore the specified weld size and profile using the original welding procedure or a repair procedure.

8.12.6 Undersize Welds. Undersize welds shall be repaired by depositing additional weld metal as required using the original welding procedure or a repair procedure.

8.12.7 Oversize Welds. Oversize welds shall be reduced to specified size by appropriate means only when they will cause interference with other parts, or will otherwise produce an adverse effect upon the weldment. For high cycle cylinders acceptance of oversized welds shall be approved by the Engineer.

8.12.8 The area of repaired work shall be reinspected.

9. Quality Assurance

9.1 The Manufacturer shall provide appropriate personnel to assure that all fabrication by welding is performed in accordance with this specification. Inspection practices and controlling methods shall be used which assure the following:

9.2 Welding Procedures shall comply with Section 7.1, Welding Procedure Qualification.

9.3 Welding personnel shall be qualified in accordance with Section 7.2, Welding Personnel Qualification, and they shall be observed at specified intervals as outlined in Clause 7 to make certain that the workmanship requirements of Clause 8, Workmanship and Welding Quality Requirements, are maintained.

9.4 Personnel involved in nondestructive examination and evaluation (including visual examination) shall be qualified to determine weld quality levels in compliance with Clause 8, Workmanship and Welding Quality Requirements.

9.4.1 Inspection Personnel qualification shall be according to the following:

(1) Current certification as a Certified Welding Inspector (CWI) in conformance with the provisions of AWS QC1, *Standard and Guide for Qualification and Certification of Welding Inspectors*;

(2) Current qualification by the Canadian Welding Bureau (CWB) to the requirements of the Canadian Standard Association (CSA) Standard W178.2, *Certification of Welding Inspectors*; or

(3) An engineer or technician who, by training or experience, or both, in metals fabrication, inspection and testing, is competent to perform inspection of the work.

9.5 Weld quality shall comply or be corrected to conform to the provisions of Clause 8, Workmanship and Welding Quality Requirements.

9.6 When the quality performance of welding personnel is found to be consistently below the requirements of this specification, that person shall be requalified to the requirements of Section 7.2, Welding Personnel Qualification.

10. Repair and Modification

10.1 This specification recognizes the eventual need for repairs as a result of normal wear and tear or accident. Each repair and any related modification shall be the responsibility of the equipment owner and the person or agency performing the work. The original manufacturer shall be contacted, if possible, to ensure any repair or modification maintains the original design requirement. Modifications that change the design intent of the equipment without documented consent from the original manufacturer shall be the responsibility of the owner and the person or agency performing the work.

A modification or repair can also be a change or correction by the Manufacturer to a new or existing model after shipment. In this case, the Manufacturer shall furnish drawings, procedures, or instructions necessary for the modification or repair.

The Owner, Manufacturer, or Manufacturer's representative should appoint an Engineer who is responsible for the execution of the repair or modification.

10.2 Specific instruction provided shall indicate (by outline diagrams or other means) those areas and materials which require specific welding procedures and techniques necessary to assure weldability (e.g., preheat, postheat, filler metals, etc.).

10.3 All repair welding shall be performed by personnel qualified to perform welding in the basic welding positions as may be necessary.

10.4 All repair welding shall be performed with welding procedures qualified to the requirements of this specification.

10.5 A recommended resource for understanding weldability for repair on existing structures is AWS D1.7/D1.7M, *Guide for Strengthening and Repairing Existing Structures*.

Annex A (Informative)

Commonly Used Welding Processes and Hydraulic Cylinder Component Nomenclature

This annex is not part of AWS D14.9/D14.9M:2013, *Specification for the Welding of Hydraulic Cylinders*, but is included for informational purposes only

A1. GMAW and GMAW-P³

A1.1 Definitions. Gas Metal Arc Welding (GMAW) is an arc welding process that uses an arc between a continuous filler metal electrode and the weld pool. The process is used with shielding from an externally supplied gas and without the application of pressure. Pulsed Gas Metal Arc Welding (GMAW-P) is a gas metal arc welding process variation in which the current is pulsed.

A1.2 Typical applications for GMAW and GMAW-P for use in hydraulic cylinders are the following (Component Nomenclature shown in Figure A.1):

- (1) end cap welds
- (2) hydraulic lines
- (3) port welds
- (4) rod end welds
- (5) tang welds
- (6) cross tube
- (7) trunnion

A2. FCAW³

A2.1 Definition. Flux Cored Arc Welding (FCAW) is 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.

A2.2 Typical applications for FCAW for use in hydraulic cylinders are the following (Component Nomenclature shown in Figure A.1):

- (1) end cap welds
- (2) hydraulic lines
- (3) port welds
- (4) rod end welds
- (5) tang welds

³ AWS A3.0M/A3.0, *Standard Welding Terms and Definitions*, American Welding Society

- (6) cross tube
- (7) trunnion

A3. SAW³

A3.1 Definition. Submerged Arc Welding (SAW) is an arc welding process that uses an arc or arcs between a bare metal electrode or electrodes and the weld pool. The arc and molten metal are shielded by a blanket of granular flux on the workpieces. The process is used without pressure and with filler metal from the electrode and sometimes from a supplemental source (welding rod, flux, or metal granules).

A3.2 Typical applications for SAW for use in hydraulic cylinders are the following (Component Nomenclature shown in Figure A.1):

- (1) end cap welds

A4. GTAW³

A4.1 Definition. Gas Tungsten Arc Welding (GTAW) is an arc welding process that uses an arc between a tungsten electrode (non-consumable) and the weld pool. The process is used with shielding gas and without the application of pressure.

A4.2 Typical applications for GTAW for use in hydraulic cylinders are the following (Component Nomenclature shown in Figure A.1):

- (1) end cap welds
- (2) port welds
- (3) rod end welds
- (4) tang welds
- (5) repair welding

A5. PAW³

A5.1 Definition. Plasma Arc Welding (PAW) is an arc welding process that uses a constricted arc between a non-consumable electrode and the weld pool (transferred arc) or between the electrode and the constricted nozzle (non-transferred 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.

A5.2 Typical applications for PAW for use in hydraulic cylinders are the following (Component Nomenclature shown in Figure A.1):

- (1) end cap welds
- (2) port welds
- (3) rod end welds
- (4) tang welds
- (5) repair welding

³ AWS A3.0M/A3.0, *Standard Welding Terms and Definitions*, American Welding Society

A6. SW³

A6.1 Definition. Arc Stud Welding (SW) is an arc welding process that uses an arc between a metal stud, or similar part, and the other workpiece. The process is used without filler metal, with or without shielding gas or flux, with or without partial shield from a ceramic or graphite ferrule surrounding the stud, and with the application of pressure after the faying surfaces are sufficiently heated.

A6.2 Typical applications for SW for use in hydraulic cylinders are the following (Component Nomenclature shown in Figure A.1):

- (1) port welds
- (2) spacers

A7. FRW^{3,4,5}

A7.1 Definition. Friction Welding (FRW) is a solid-state welding process that produces a weld under the compressive force contact of workpieces rotating or moving relative to one another to produce heat and plastically displaced material from the faying surfaces.

A7.2 Typical applications for FRW for use in hydraulic cylinders are the following (Component Nomenclature shown in Figure A.1):

- (1) rod end welds

References. C6.1, *Recommend Practice for Friction Welding* (latest edition) and C6.2/C6.2M, *Specification for Friction Welding of Metals* (latest edition).

A8. PW^{3,6,7}

A8.1 Definition. Projection Welding (PW) is a resistance welding process in which heat localization occurs at predetermined points by projections, embossments, or intersections.

A8.2 Specific design and process conditions for annular projection welding are not uniformly established. Use and process control of annular projection welding in the application of hydraulic cylinders shall be by agreement between the owner and the manufacturer (Component Nomenclature shown in Figure A.1).

References. A3.0M/A3.0, *Standard Welding Terms and Definitions*. C1.1, *Recommend Practice for Resistance Welding* (latest edition) and C1.4/C1.4M, *Specification for Resistance Welding of Carbon and Low-Alloy Steels* (latest edition).

³ AWS A3.0M/A3.0, *Standard Welding Terms and Definitions*, American Welding Society

⁴ C6.1, *Recommended Practices for Friction Welding* (latest edition)

⁵ C6.2/C6.2M, *Specification for Friction Welding of Metals* (latest edition)

⁶ C1.1M/C1.1, *Recommended Practices for Resistance Welding* (latest edition)

⁷ C1.4M/C1.4, *Specification for Resistance Welding of Carbon and Low-Alloy Steels* (latest edition)

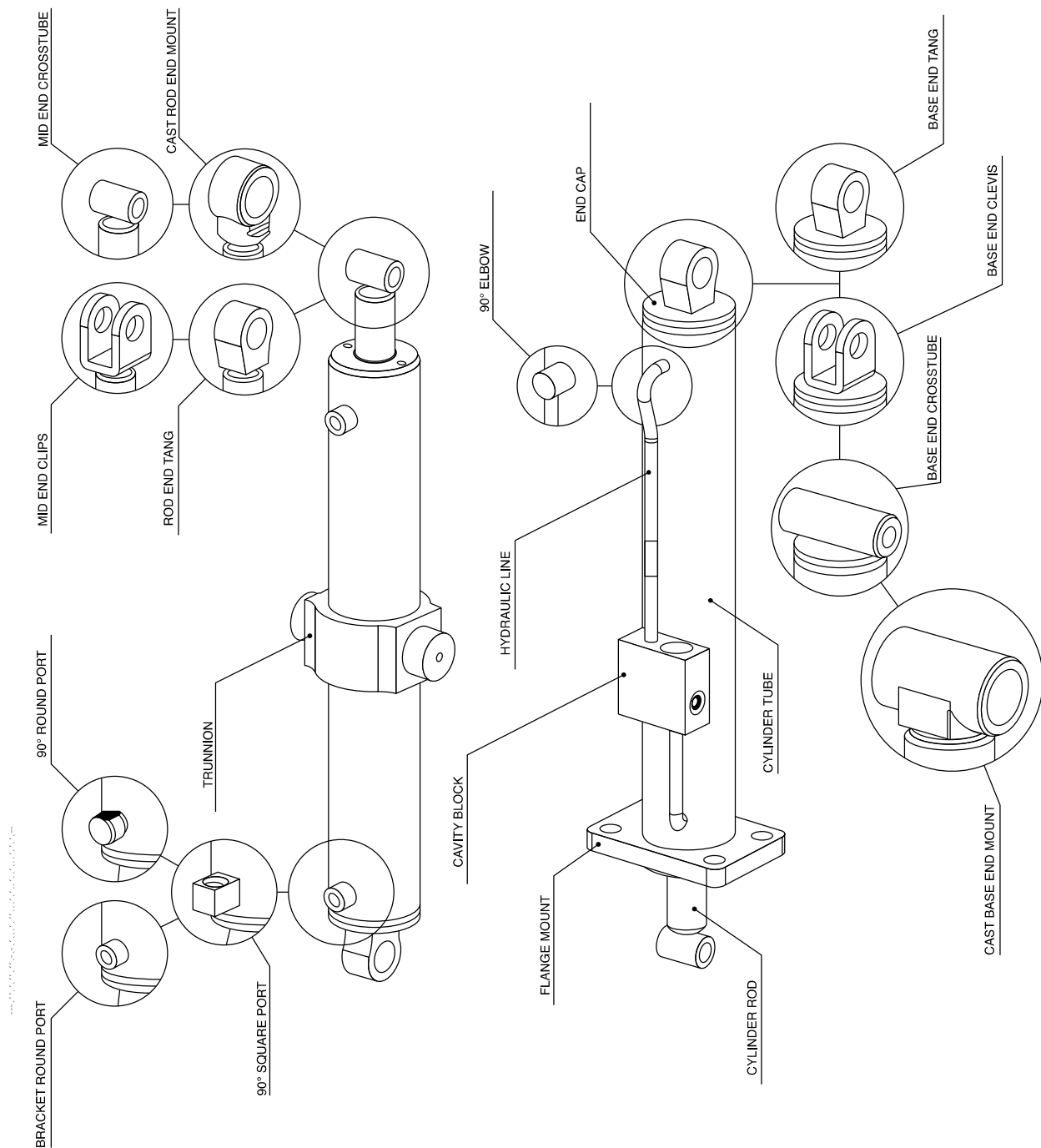


Figure A.1—Hydraulic Cylinder Component Nomenclature

Annex B (Informative)

Preheat and Postweld Heat Treatment Recommendations

This annex is not part of AWS D14.9/D14.9M:2013, *Specification for the Welding of Hydraulic Cylinders*, but is included for informational purposes only.

B1. For the heat treatment of all material M-Numbers listed in this section, the furnace air temperature should not exceed 600°F [315°C] at the time of loading of the parts.

B2. Above 600°F [315°C], the rate of increase in temperature of the furnace should not exceed 400°F/hr [220°C/hr] divided by the maximum metal thickness of the part in inches, but in no case more than 400°F/hr [220°C/hr]. During the heating period, there should not be a greater variation in temperature than 250°F [120°C] throughout the part being heat treated.

B3. Above 600°F [315°C], cooling should be done in a closed furnace or cooling chamber at a rate not greater than 500°F/hr [280°C/hr] divided by the maximum metal thickness of the part in inches, but in no case more than 500°F/hr [280°C/hr]. Below 600°F [315°C], the part may be cooled in still air. During the cooling period, there should not be a greater variation in temperature than 200°F [110°C] throughout the part being heat treated.

B4. The temperature of the part during heat treating should be measured with thermocouples attached to the part.

B5. M-1 Materials. For M-1 material,³ the following minimum preheat and interpass temperatures are recommended:

- | | |
|--|---------------|
| (1) ≤ 1 1/2 in [38 mm] | 50°F [10°C] |
| (2) > 1 1/2 in [38 mm] to ≤ 2 1/2 in [63 mm] | 150°F [65°C] |
| (3) > 2 1/2 in [63 mm] | 225°F [105°C] |

The postweld heat treatment (PWHT) of M-1 materials is neither mandatory nor prohibited under this specification. If PWHT is specified, it should be accomplished at a temperature from 1100°F [595°C] to 1200°F [650°C] and should be at temperature for 1 hour per 1 in [25 mm] of thickness, plus 15 minutes for each 1 in [25 mm] over 2 in [50 mm].

B6. M-3, M-4, and M-5 Materials

B6.1 For M-3, M-4, and M-5 materials, preheat is recommended for thicknesses over 1/2 in [13 mm]. The following minimum preheat and interpass temperatures should be used.

³ The temperatures herein are consistent with the use of low-hydrogen filler materials only. For filler materials not falling into this category, it is suggested that higher minimum preheat and interpass temperatures may be required.

- (1) Preheat for M-3 material 200°F [95°C]
- (2) Preheat for M-4 and M-5, Group 1 materials 300°F [150°C]
- (3) Preheat for M-5, Group 2 materials 400°F [205°C]

B6.2 For M-3, M-4, and M-5 Group 1 materials over 1/2 in [13 mm] thick and all M-5 Group 2 materials, PWHT is recommended. The following PWHT temperatures within the ranges shown are recommended for these materials.

- (1) M-3: 1100°F to 1250°F [595°C to 675°C]
- (2) M-4 and all M-5: 1250°F to 1350°F [675°C to 730°C]

B6.3 The time at temperature should be based on the HAZ hardness as determined on the procedure qualification test plate. The maximum acceptable hardness should be 22 Rockwell “C” scale.

B7. M-6 and M-7 Materials

B7.1 For M-6 and M-7 Group 1 materials, a minimum preheat and interpass temperature of 400°F [205°C] is recommended.

B7.2 A PWHT of these materials at 1400°F [760°C] is recommended when austenitic stainless steel filler metal is not used.

B7.3 The time at temperature should be based on the HAZ hardness as determined on the procedure qualification test plate. The maximum acceptable hardness should be 22 Rockwell “C” scale.

B7.4 The PWHT of M-7 Group 2 materials is neither mandatory nor prohibited.

B8. M-8 Materials. Preheat and PWHT of M-8 materials are neither mandatory nor prohibited. The maximum interpass temperature of M-8 materials should be 350°F [175°C], except during hard surfacing.

B9. M-9 Materials

B9.1 Minimum preheat and interpass temperatures should be as follows:

- (1) Preheat for M-9A materials 250°F [120°C]
- (2) Preheat for M-9B materials 300°F [150°C]

B9.2 The PWHT of M-9 materials is neither mandatory nor prohibited.

B10. M-10 Materials

B10.1 M-10A materials should be preheated and interpass temperatures maintained in conformance to the following:

- (1) $\leq 3/4$ in [20 mm] 50°F [10°C]
- (2) $> 3/4$ in [20 mm] to $\leq 1\ 1/2$ in [38 mm] 150°F [65°C]
- (3) $> 1\ 1/2$ in [38 mm] to $\leq 2\ 1/2$ in [63 mm] 250°F [120°C]
- (4) $> 2\ 1/2$ in [63 mm] 300°F [150°C]

B10.2 M-10A material over 1 in [25 mm] thick should be PWHT at 1050°F [565°C] $\pm 50^\circ\text{F}$ [30°C] for one hour per 1 in [25 mm] of thickness.

B10.3 M-10B materials should be preheated and PWHT same as M-4 materials.

B10.4 M-10C materials should be preheated and PWHT same as M-10A materials.

B10.5 M-10E materials should be preheated at 300°F [150°C] and should maintain an interpass temperature of 350°F to 450°F [175°C to 230°C]. PWHT is neither mandatory nor prohibited. However, if these materials are PWHT, the cooling from 1200°F [650°C] $\pm$ 50°F [30°C] should be sufficiently rapid to prevent embrittlement.

B10.6 M-10F materials should be preheated and PWHT same as M-3 materials.

B10.7 For M-10H materials, preheat and PWHT are neither mandatory nor prohibited. If PWHT is done, check Manufacturer, Fabricator, or Repair Organization's literature for proper holding temperatures and cooling rates.

B10.8 For M-10I materials, preheat is not mandatory. PWHT at 1300°F to 1400°F [705°C to 760°C] for 1 hour per 1 in [25 mm] of thickness is recommended for thicknesses in excess of 1/2 in [13 mm]. This material should be rapidly cooled from the PWHT temperature.

B11. M-11 Materials

B11.1 The preheat and interpass temperatures that are used during the welding of these materials should be compatible with the heat input of the welding process. The heat input and preheat should be selected so that the as-welded mechanical properties in the HAZ are optimized.

B11.2 For M-11A Groups 1 and 2 materials, preheat and PWHT are neither mandatory nor prohibited. PWHT procedures require rapid cooling rates. Check literature for proper holding temperatures and cooling rates if PWHT is done.

B11.3 For M-11A Groups 3, 4, 5, and 6 materials, preheat should be in conformance to B10.1. PWHT should be mandatory and should be accomplished at a temperature 50°F [30°C] below the tempering temperature. The time at temperature should be a minimum of 1/2 hour per 1 in [25 mm] of thickness but not less than 1/2 hour.

B11.4 For M-11B materials, preheat and PWHT are neither mandatory nor prohibited.

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Annex C (Informative)

Recommended Practices for Storage and Treatment of Electrodes and Fluxes

This annex is not a part of AWS D14.9/D14.9M:2013, *Specification for the Welding of Hydraulic Cylinders*, but is included for informational purposes only.

NOTE: When available, the consumable manufacturer's specific requirements for storage, atmospheric exposure and reconditioning should be applied. When the consumable manufacturer's specifications are not available, the following guidelines may be used.

C1. SMAW Electrodes

C1.1 Storage Conditions

1. Low-Hydrogen Electrodes. All electrodes having low-hydrogen coverings conforming to AWS A5.1/A5.1M, *Specification for Carbon Steel Electrodes for Shielded Metal Arc Welding*, and AWS A5.5/A5.5M, *Specification for Low-Alloy Steel Electrodes for Shielded Metal Arc Welding*, should be purchased in hermetically sealed containers or should be baked by the user in accordance with C1.3 prior to use. Immediately after opening the hermetically sealed container, electrodes should be stored in ovens held at a temperature of at least 250 °F [120 °C]. Electrodes should be rebaked no more than once. Electrodes that have been wet should not be used.

2. Non-Low-Hydrogen Electrodes. Electrodes in unopened cans or cartons retain the proper moisture content indefinitely when stored in good condition. If exposed to humid air for long periods of time, electrodes from opened container may pick up enough moisture to affect operating characteristics or weld quality. If moisture appears to be a problem, discard the affected electrodes. Store electrodes from freshly opened containers in a dry environment. Cellulosic coverings for E6010 and E6011 electrodes need moisture levels of 3% to 7% for proper operation; therefore, storage or conditioning above ambient temperature may dry them too much and adversely affect their operation.

C1.2 Approved Low-Hydrogen Electrode Atmospheric Time Periods. After hermetically sealed containers are opened or after electrodes are removed from baking or storage ovens, the electrode exposure to the atmosphere should not exceed the values shown for the specific electrode classification (see Tables C.1 and C.2) with optional supplemental designators, where applicable. Electrodes exposed to the atmosphere for periods less than those shown may be returned to a holding oven maintained at 250 °F [120 °C] min; after a minimum hold period of four hours at the specified minimum temperature, the electrodes may be reissued.

C1.3 Reconditioning of Low-Hydrogen Electrodes. Electrodes exposed to the atmosphere for periods, greater than those permitted above should be reconditioned as follows:

- (1) All electrodes having low-hydrogen coverings conforming to AWS A5.1/A5.1M should be baked for at least one hour between 500 °F [260 °C] and 800 °F [430 °C], or
- (2) All electrodes having low-hydrogen coverings conforming to AWS A5.5/A5.5M should be baked for at least one hour at temperatures between 700 °F [370 °C] and 800 °F [430 °C].

C1.4 Reconditioning of Non-Low-Hydrogen Electrodes. Non-low-hydrogen electrodes should be reconditioned according to the consumable manufacturer's specifications or discarded.

Table C.1
Electrodes Covered by AWS A5.1/A5.1M, Specification for Carbon Steel Electrodes for Shielded Metal Arc Welding

Electrode Designation	Maximum Exposure Time
E70XX	4 hours
E70XXR ^a	9 hours
E70XXHZR ^a	9 hours
E7018M	9 hours

^a The optional supplemental designator, R, designates a low-hydrogen electrode which has been tested for covering moisture content after exposure to a moist environment for 9 hours and has met the maximum level permitted in AWS A5.1/A5.1M.

Table C.2
Electrodes Covered by AWS A5.5/A5.5M, Specification for Low-Alloy Steel Electrodes for Shielded Metal Arc Welding

Electrode Designation	Maximum Exposure Time
E70XX-X	4 hours
E70XX-X-R ^a	9 hours
E70XX-X-HZR ^a	9 hours
E80XX-X	2 hours
E80XX-X-R ^a	9 hours
E80XX-X-HZR ^a	9 hours
E90XX-X	1 hours
E90XX-X-R ^a	9 hours
E90XX-X-HZR ^a	9 hours
E100XX-X	1/2 hour
E100XX-X-R ^a	9 hours
E100XX-X-HZR ^a	9 hours
E110XX-X	1/2 hour
E110XX-X-R ^a	9 hours
E110XX-X-HZR ^a	9 hours

^a The optional supplemental designator, R, designates a low-hydrogen electrode which has been tested for covering moisture content after exposure to a moist environment for 9 hours and has met the maximum level permitted in AWS A5.5/A5.5M, *Specification for Low-Alloy Steel Electrodes for Shielded Metal Arc Welding*.

C2. FCAW and Metal Core Electrodes

C2.1 Electrode Packaging. Electrodes for FCAW and Metal Core welding should be received in moisture-resistant packages that are undamaged. They should be protected against contamination and injury during shipment and storage. Electrode packages should remain effectively sealed against moisture until the electrode is required for use. When removed from protective packaging and installed on machines, care should be taken to protect the electrodes and coatings, if present, from deterioration or damage. No one should modify or lubricate an electrode after manufacture for any reason except that drying may be permitted when recommended by the consumable manufacturer.

C2.2 Electrode Storage. When welding is to be suspended for more than 24 hours, electrode spools or coils should be removed from the machines and stored in airtight coverings or placed in a storage or drying oven maintained at a temperature of 250°F [120°C] to 300°F [150°C] or as recommended by the consumable manufacturer. Electrodes on spools or coils not consumed within 48 hours of accumulated exposure outside sealed or heated storage should be redried as described in C2.3. Electrodes should be identified to facilitate monitoring of total atmospheric exposure time.

C2.3 Drying Temperatures. Only when approved by the consumable manufacturer, FCAW and Metal Core electrodes on metal supports may be baked once as specified by the consumable manufacturer to restore their condition. If the electrode or the electrode support is damaged by baking, the electrode should not be used. For electrodes in bulk storage packaging, follow the consumable manufacturer's recommendations for exposure and storage.

C3. Solid Wire Electrodes

C3.1 Electrode Care and Storage. Wire should be kept clean and care should be taken to keep wire from being contaminated with rust, oil, moisture, grinding dust, or other materials present in the work environment. When idle, the wire should be kept in its original plastic wrapping and/or shipping container. When a spool of wire is in place on a wire feeder, it should be covered with a protective covering when not used for prolonged periods of time.

C4. Submerged Arc Welding Flux

C4.1 Condition of Flux. Flux used for SAW should be dry and free of contamination from dirt, mill scale, or other foreign material. All flux should be purchased in packages that can be stored, under normal conditions, for at least six months without such storage affecting its welding characteristics or weld properties. Flux from damaged packages should be reconditioned according to consumable manufacturer's specifications or discarded. Flux should be placed in the dispensing system immediately upon opening a package, or if used from an opened package, the top 1 inch [25 mm] should be discarded. Flux that has been wet should not be used.

C4.2 Flux Reclamation. SAW flux that has not been melted during the welding operation may be reused after recovery by vacuuming, catch pans, sweeping or other means. The welding fabricator should have a system for collecting unmelted flux, adding new flux, and welding with the mixture of these two, such that the flux composition and particle size distribution at the weld puddle are relatively constant.

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Annex D (Informative)

Magnetism, a cause of Arc Blow

This annex is not part of AWS D14.9/D14.9M:2013, *Specification for the Welding of Hydraulic Cylinders*, but is included for informational purposes only.

The manufacturing of hydraulic cylinders can inherently cause magnetic arc blow problems.

It is not uncommon to use alloy materials like AISI 4340, magnets for material handling, procedures requiring DC welding, deep V groove joints and inspecting welds by means of magnetic particle inspection, all of which aid to the magnetic arc blow phenomenon.

During arc welding, a beam of electrons flow through an ionized column of gas between two electrodes, or in this case the electrode and the work piece. The arc travels the shortest path between the electrode and the work piece.

When this flow is influenced by an unbalanced magnetic field the arc will not follow the shortest path, but is deflected forward, backward, or sideways. This phenomenon is called magnetic arc blow. Unless controlled, arc blow can be the cause of difficulties controlling the molten pool and slag, cause excessive spatter, incomplete fusion, porosity or slows down the welding speed.

Welding handbooks usually identify forward and backward deflection of the arc common in longitudinal welds. When there is a current flow, magnetic fields are set up as circular force planes perpendicular to the current flow in the conductor. When these circular forces are interrupted for instance at the end of a plate or in the corner of a profile, the forces or magnetic flux lines distort, trying to stay within the boundary of the work piece and therefore having heavier concentrations at the edge of the work piece. This imbalance in magnetic flux causes the arc to deflect. As there is a current flowing from the work piece to the ground lead there is a magnetic flux set-up here as well. A concentration of this flux and the flux set-up by the electrode causes the arc to deflect away from the ground. This is called the "ground effect."

As welding of hydraulic cylinders usually involves circumferential welds more so than longitudinal the above mentioned problems do not affect us as much as sideways deflection in the groove. Most of this magnetic deflection is not caused by magnetic flux induced by the current flow, but by residual magnetic fields from other operations. (Note that materials with a relative high Carbon and Nickel content tend to retain magnetism at a higher rate.)

To reduce the effect we must demagnetize the work pieces.

If this is not feasible, try to keep the arc length as short as possible and if you are using a DC process, investigate the use of an AC process. You can also try to counteract a magnetic field by introducing another magnetic field by wrapping the ground lead around your work piece.

(This last mentioned method has to be determined by trial and error.)

The strength of a magnetic field (flux density) is usually expressed in the unit Gauss, or milli Tesla.

(1 mT = 10 Gauss)

Noticeable problems occur when Gauss levels reach and exceed 20 Gauss.

The goal is to reduce the residual magnetism to 5 Gauss or less.

(From a hydraulic cylinder manufacturer stand point it is also good to know that higher levels of magnetism affect plating processes adversely as well.)

Demagnetizing equipment for larger weldments delivers either AC or DC power to a magnetizing cable which is coiled around the weldment. The best success is usually achieved using DC demagnetizing (down cycling) which repeatedly reverses the polarity of the magnetic field and reduces the flux density.

Annex E (Informative)

Informative References

This annex is not part of AWS D14.9/D14.9M:2013, *Specification for the Welding of Hydraulic Cylinders*, but is included for informational purposes only.

- (1) AWS A5.1/A5.1M, *Specification for Carbon Steel Electrodes for Shielded Metal Arc Welding*
- (2) AWS A5.5/A5.5M, *Specification for Low-Alloy Steel Electrodes for Shielded Metal Arc Welding*
- (3) AWS A5.17/A5.17M, *Specification for Carbon Steel Electrodes and Fluxes for Submerged Arc Welding*
- (4) AWS A5.18/A5.18M, *Specification for Carbon Steel Electrodes and Rods for Gas Shielded Arc Welding*
- (5) AWS A5.23/A5.23M, *Specification for Low Alloy Steel Electrodes and Fluxes for Submerged Arc Welding*
- (6) AWS A5.28/A5.28M, *Specification for Low Alloy Steel Electrodes and Rods for Gas Shielded Arc Welding*
- (7) AWS A5.36/A5.36M, *Specification for Carbon and Low-Alloy Steel Flux Cored Electrodes for Flux Cored Arc Welding and Metal Cored Electrodes for Gas Metal Arc Welding*
- (8) AWS B5.17, *Specification for the Qualification of Welding Fabricators*
- (9) AWS C1.1/C1.1M, *Recommended Practices for Resistance Welding*
- (10) AWS C6.1, *Recommended Practices for Friction Welding*
- (11) AWS D1.7/D1.7M, *Guide for Strengthening and Repairing Existing Structures*

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Annex F (Informative)

Guidelines for the Preparation of Technical Inquiries

This annex is not part of AWS D14.9/D14.9M:2013, *Specification for the Welding of Hydraulic Cylinders*, but is included for informational purposes only.

F1. Introduction

The American Welding Society (AWS) Board of Directors has adopted a policy whereby all official interpretations of AWS standards are handled in a formal manner. Under this policy, all interpretations are made by the committee that is responsible for the standard. Official communication concerning an interpretation is directed through the AWS staff member who works with that committee. The policy requires that all requests for an interpretation be submitted in writing. Such requests will be handled as expeditiously as possible, but due to the complexity of the work and the procedures that must be followed, some interpretations may require considerable time.

F2. Procedure

All inquiries shall be directed to:

Managing Director
Technical Services Division
American Welding Society
8669 Doral Blvd., Suite 130
Doral, FL 33166

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

F2.1 Scope. Each inquiry shall address one single provision of the standard unless the point of the inquiry involves two or more interrelated provisions. The provision(s) shall be identified in the scope of the inquiry along with the edition of the standard that contains the provision(s) the inquirer is addressing.

F2.2 Purpose of the Inquiry. The purpose of the inquiry shall be stated in this portion of the inquiry. The purpose can be to obtain an interpretation of a standard's requirement or to request the revision of a particular provision in the standard.

F2.3 Content of the Inquiry. The inquiry should be concise, yet complete, to enable the committee to understand the point of the inquiry. Sketches should be used whenever appropriate, and all paragraphs, figures, and tables (or annex) that bear on the inquiry shall be cited. If the point of the inquiry is to obtain a revision of the standard, the inquiry shall provide technical justification for that revision.

F2.4 Proposed Reply. The inquirer should, as a proposed reply, state an interpretation of the provision that is the point of the inquiry or provide the wording for a proposed revision, if this is what the inquirer seeks.

F3. Interpretation of Provisions of the Standard

Interpretations of provisions of the standard are made by the relevant AWS technical committee. The secretary of the committee refers all inquiries to the chair of the particular subcommittee that has jurisdiction over the portion of the standard addressed by the inquiry. The subcommittee reviews the inquiry and the proposed reply to determine what the response to the inquiry should be. Following the subcommittee's development of the response, the inquiry and the response are presented to the entire committee for review and approval. Upon approval by the committee, the interpretation is an official interpretation of the Society, and the secretary transmits the response to the inquirer and to the *Welding Journal* for publication.

F4. Publication of Interpretations

All official interpretations will appear in the *Welding Journal* and will be posted on the AWS web site.

F5. Telephone Inquiries

Telephone inquiries to AWS Headquarters concerning AWS standards should be limited to questions of a general nature or to matters directly related to the use of the standard. The AWS *Board Policy Manual* requires that all AWS staff members respond to a telephone request for an official interpretation of any AWS standard with the information that such an interpretation can be obtained only through a written request. Headquarters staff cannot provide consulting services. However, the staff can refer a caller to any of those consultants whose names are on file at AWS Headquarters.

F6. AWS Technical Committees

The activities of AWS technical committees regarding interpretations are limited strictly to the interpretation of provisions of standards prepared by the committees or to consideration of revisions to existing provisions on the basis of new data or technology. Neither AWS staff nor the committees are in a position to offer interpretive or consulting services on (1) specific engineering problems, (2) requirements of standards applied to fabrications outside the scope of the document, or (3) points not specifically covered by the standard. In such cases, the inquirer should seek assistance from a competent engineer experienced in the particular field of interest.

