AWS D15.1/D15.1M:2019
An American National Standard

Railroad Welding Specification for Cars and Locomotives

American Welding Society®

AWS D15.1/D15.1M:2019
An American National Standard

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Railroad Welding Specification for Cars and Locomotives

6th Edition

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Prepared by the
American Welding Society (AWS) D15 Committee on Railroad Welding

Under the Direction of the
AWS Technical Activities Committee

Approved by the
AWS Board of Directors

Abstract

This specification establishes minimum welding standards for the manufacture and maintenance of railcars, locomotives, and their components, intended for North American railroad service. Clauses 4 through 17 cover the general requirements for welding in the railroad industry. Clauses 18 through 23 cover specific requirements for the welding of base metals thinner than 1/8 in [3 mm].

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Foreword

This foreword is not part of this standard but is included for information purposes only.

This specification establishes minimum welding standards for the manufacture and maintenance of railcars, locomotives, and their components, intended for North American railroad service. It was developed and is maintained by the D15 Committee on Railroad Welding of the American Welding Society.

Welding of railroad components is vital to the industry. An investigating committee was formed in 1982 which recommended a Railroad Welding Committee be formed to establish minimum welding standards for the industry. This recommendation was made because of confusion and incompleteness of the existing welding specifications and guides as applied to the railroad industry needs. The committee is made up of individuals from all segments of the railroad industry: both users and suppliers, the general public, and representatives of the Association of American Railroads.

The purpose of this specification is to provide a single comprehensive document of welding data that will be used throughout the railroad industry. Also, it should contribute to improvements in welding quality and performance.

AWS D15.1-86 was titled simply *Railroad Welding Specification*. For the 1993 revision, the suffix *Cars and Locomotives* was added because the locomotive section had been introduced. A later revision was published in 2001, AWS D15.1:2001. The welding of rail is addressed in AWS D15.2/D15.2M, *Recommended Practice for the Welding of Rails and Related Rail Components for Use by Rail Vehicles*.

Several significant modifications have been made in AWS D15.1/D15.1M:2019. A vertical line in the margin or underlined text in clauses, tables, or figures indicates an editorial or technical change from the 2012 edition. Limitations of essential variables for welding procedure qualification and welder performance qualification have been set up in table format (Tables 10.1 and 11.1, respectively). Friction stir welding has been included in the list of approved welding processes. Additional prequalified joint details for FCAW and GMAW have been added (see Figures 7.1G and 7.2A). Table 17.1 (Weld Crater Limitations) has been added. Clause 18 (Welding of Sheet Metal) has been revised.

Comments and suggestions for the improvement of this standard are welcome. They should be sent to the Secretary of the AWS D15 Committee on Railroad Welding, American Welding Society, 8669 NW 36 St, # 130, Miami, FL 33166.

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1. General Requirements

1.1 Scope. This specification covers the minimum welding requirements applicable to railcars, locomotives, and their components, intended for North American railroad service. For welding tank car tanks, refer to Association of American Railroads (AAR) *Manual of Standards and Recommended Practices*, *Section C-III, Specifications for Tank Cars, Specification M-1002*.

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

1.3 Safety. Safety and health issues and concerns are beyond the scope of this standard; some safety and health information is provided, but such issues are not fully addressed herein.

Safety and health information is available from the following sources:

American Welding Society:

(1) ANSI Z49.1, *Safety in Welding, Cutting, and Allied Processes*

(2) AWS Safety and Health Fact Sheets

(3) Other safety and health information on the AWS website

Material or Equipment Manufacturers:

(1) Safety Data Sheets supplied by materials manufacturers

(2) Operating Manuals supplied by equipment manufacturers

Applicable Regulatory Agencies:

(1) Federal Railroad Administration

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

2. Normative References

The documents listed below are referenced within this publication and are mandatory to the extent specified herein. For undated references, the latest edition of the referenced standard shall apply. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply.

American Welding Society (AWS) standards:[1]

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

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

AWS A5.01M/A5.01 (ISO 14344:2010 MOD), *Welding Consumables—Procurement of Filler Metals and Fluxes*;

AWS A5.1/A5.1M, *Specification for Carbon Steel Electrodes for Shielded Metal Arc Welding*;

AWS A5.4/A5.4M, *Specification for Stainless Steel Electrodes for Shielded Metal Arc Welding*;

AWS A5.5/A5.5M, *Specification for Low-Alloy Steel Electrodes for Shielded Metal Arc Welding*;

AWS A5.9/A5.9M, *Specification for Bare Stainless Steel Welding Electrodes and Rods*;

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

AWS A5.17/A5.17M, *Specification for Carbon Steel Electrodes and Fluxes for Submerged Arc Welding*;

AWS A5.18/A5.18M, *Specification for Carbon Steel Filler Metals for Gas Shielded Arc Welding*;

AWS A5.20/A5.20M, *Specification for Carbon Steel Electrodes for Flux Cored Arc Welding*;

AWS A5.22/A5.22M, *Specification for Stainless Steel Flux Cored and Metal Cored Welding Electrodes and Rods*;

AWS A5.23/A5.23M, *Specification for Low Alloy Steel Electrodes and Fluxes for Submerged Arc Welding*;

AWS A5.28/A5.28M, *Specification for Low-Alloy Steel Electrodes and Rods for Gas Shielded Arc Welding*;

AWS A5.29/A5.29M, *Low Alloy Steel Electrodes for Flux Cored Arc Welding*;

AWS A5.32M/A5.32 (ISO 14175: 2008 MOD), *Welding Consumables—Gases and Gas Mixtures for Fusion Welding and Allied Processes*;

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*;

AWS B1.10M/B1.10, *Guide for Nondestructive Examination of Welds*;

AWS B2.1/B2.1M, *Specification for Welding Procedure and Performance Qualification*;

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

AWS D16.4M/D16.4, *Specification for the Qualification of Robotic Arc Welding Personnel*.

American National Standards Institute (ANSI) standard:[2]

ANSI Z49.1, *Safety in Welding, Cutting, and Allied Processes*.

Association of American Railroads (AAR) standards:[3]

AAR M-1002, *Specification for Tank Cars,* Appendix W;

AAR S-137, *Standard for Coupler Shank Wear Plates and Application*;

AAR S-269, *Standard for Coupler Carrier Wear Plate*;

AAR S-306, *Standard for Center Bowl Vertical Wear Liner*;

AAR S-307, *Standard for Center Bowl Horizontal Wear Liner*;

AAR S-308, *Standard for Center Bowl Wear Liner Application*;

[1] AWS standards are published by the American Welding Society, 8669 NW 36 St, # 130, Miami, FL 33166.
[2] This ANSI standard is published by the American Welding Society, 8669 NW 36 St, # 130, Miami, FL 33166.
[3] AAR standards are published by the Association of American Railroads, TTCI, Technical Standards Publications, PO Box 11130, Pueblo, CO 81001.

AAR S-320, *Standard for the Application of Side Frame Column Friction Wear Plates*;

AAR S-327, *Standard for Side Frame Roof Repair*;

AAR *Field Manual of Interchange Rules*; and

AAR *Manual of Standards and Recommended Practices, Section C-II, Design, Fabrication and Construction of Freight Cars, M-1001*.

ASME International standards:[4]

ASME *Boiler and Pressure Vessel Code,* Section V;

ASME *Boiler and Pressure Vessel Code,* Section IX; and

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

American Society for Nondestructive Testing (ASNT) standards and practices:[5]

ASNT SNT-TC-1A, *Personnel Qualification and Certification in Nondestructive Testing*.

ASTM International Standards:[6]

ASTM A435, *Specification for Straight Beam Ultrasonic Examination of Steel Plates for Pressure Vessels*;

ASTM A488, *Practice for Steel Castings, Welding, Qualifications of Procedures and Personnel*;

ASTM B548, *Method and Specifications for Ultrasonic Inspection of Aluminum—Alloy Plate for Pressure Vessels*;

ASTM E94, *Guide for Radiographic Testing*;

ASTM E165, *Practice for Liquid Penetrant Inspection Method*;

ASTM E709, *Practice for Magnetic Particle Examination*;

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

ASTM E1032, *Standard Test Method for Radiographic Examination of Weldments*.

Canadian Standards Association:[7]

CSA W47.1, *Certification of Companies for Fusion Welding of Steel Structures*; and

CSA W47.2, *Certification of Companies for Fusion Welding of Aluminum*.

Federal Railroad Administration[8]

49 CFR Part 229 *Locomotive Safety Standards and Locomotive Inspection*.

3. Terms and Definitions

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

Class 1 Weld. A structural weld requiring the most stringent level of inspection. The determination of a Class 1 weld is the responsibility of the designer and shall be noted on the manufacturing drawings. D15.1/D15.1M provides the acceptance criteria only (see Table 17.2).

[4] ASME standards are published by ASME International, 3 Park Avenue, New York, NY 10016-5990.
[5] ASNT standards are published by the American Society for Nondestructive Testing, PO Box 28518, 1711 Arlingate Lane, Columbus, OH 43228-0518.
[6] ASTM standards are published by ASTM International, 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959.
[7] CSA standards are published by the Canadian Standards Association, 178 Rexdale Boulevard, Toronto, Ontario, Canada, M9W 1R3.
[8] CFR standards are published by the Office of the Federal Register, 8601 Adelphi Road College Park, MD 20740-6001.

Class 2 Weld. The default level of inspection requirements of all welds not identified as Class 1.

company. The organization performing welding, including all facilities under common ownership that utilizes the same program of welding standards and documentation (see 5.3.3, 9.4.1, and 9.4.2).

designated inspector. The individual who is given responsibility by the manufacturer or company to inspect fabrication/production welding operations and completed welds. Inspection may or may not be the individual's sole responsibility.

essential variables. Those welding parameters considered critical to the welding operation. A change outside of the specified range requires requalification of the welding procedure specification.

Fabricator's Engineer. A designated individual with design authority employed by the fabricator, manufacturer, or outside repair facility who is responsible for the ongoing activities within the scope of the specification.

fillers. A nonconsumed metallic strip or bar used in a lap or T-joint to reduce a gap (see Figures 5.1 and 5.3).

fusion-type discontinuity. Slag inclusions, incomplete fusion, or similar discontinuities resulting in incomplete fusion between weld metal and base metal or between weld beads.

image quality indicator (IQI). A device whose image in a radiograph is used to determine radiographic quality level. It is not intended for use in judging the size nor for establishing acceptance limits of discontinuities.

manufacturer. The original builder, fabricator, or installer of equipment, as well as any company or organization performing repairs or alterations to such equipment.

multiple electrodes. The combination of two or more single or parallel electrode systems used to produce a weld bead. Each of the component systems may have its own independent power source and its own electrode feeder.

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

Owner's Engineer. A designated individual or company with engineering authority that represents or is employed by the Owner, operating railroad, or purchaser, as applicable.

parallel electrode. Two electrodes connected electrically in parallel and exclusively to the same power source. Both electrodes are usually fed by means of a single electrode feeder. Welding current, when specified, is the total for the two electrodes.

pipe. Tubular-shaped product of circular cross section.

verification inspector. The duly designated person who acts on behalf of the Owner or purchaser on all inspection and quality matters within the scope of the contract documents.

4. General Information

4.1 Base Metals. AWS B2.1/B2.1M, *Specification for Welding Procedure and Performance Qualification*, provides an extensive list of materials grouped into categories to minimize the number of qualification tests required. This in no way implies that materials in one group are interchangeable or equivalent for any given application. See Annex A for additional materials specific to this specification.

4.2 Since railroad equipment may be coated with lead base paint, all suspect coatings shall be removed in a safe manner prior to welding.

4.3 Clauses 1 through 17 give the general requirements for welded construction for metal components 1/8 in [3 mm] or greater in thickness. Unless otherwise stated, these requirements apply to all freight cars, locomotives, and passenger train vehicles. Clauses 18 through 23 cover specific requirements for the welding of base metals less than 1/8 in [3 mm] in thickness. Material 0.1196 in [3 mm] nominal may be considered 1/8 in [3 mm].

4.4 Companies shall be responsible for the quality of the welding done by their organization and their subcontractors and shall perform whatever tests are necessary beyond the requirements of this specification to assure that the welds achieve requirements of the design.

4.5 Requirements contained herein constitute acceptable industrial practices. They are not intended as a substitute for engineering judgment with respect to the suitability of application of listed joints to a welded structure.

4.6 Additionally, they are not intended to nullify or void any rules or requirements contained in the U.S. Department of Transportation Locomotive Inspection Act (45 USC-22), or the Federal Railroad Administration's *Railroad Locomotive Safety Standards and Locomotive Inspection* (49 CFR Part 229). Requirements contained herein are not intended to nullify or void the requirements of any law or governmental agency regulation nor any specification of the Association of American Railroads.

4.7 All references to the need for approval shall be interpreted to mean approval by either the Fabricator's Engineer or the Owner's Engineer, as defined in Clause 3, Terms and Definitions. It is understood that in some cases and under some specific contracts, approval will need to be obtained by both the Fabricator's Engineer and the Owner's Engineer. In such cases, the references assigned to only one entity shall apply to both entities.

4.8 Specific areas of application to locomotives and passenger train vehicles include, but are not limited to the following:

(1) Structural components including primary and secondary load-bearing members of the locomotive under-frame, center plate bearings, truck bolsters, draft gear pockets, equipment bases and supports, collision posts, main generators (alternator), traction motor frames, and car body structures.

(2) Air reservoirs not covered by the provisions of the ASME *Boiler and Pressure Vessel Code*.

(3) Fuel tank manufacture and repair.

(4) Air compressor and air system piping.

(5) Electrical components including eddy current clutches, reverser contacts, and motor commutator terminations.

4.9 Engines and engine components may require specialized processes and procedures unique to the original equipment manufacturer. Repair or rework of the engine and its components shall be in accordance with the original equipment manufacturer's specification, or equivalent.

4.10 The repair and reconditioning of specific car components are described in the AAR *Field Manual of Interchange Rules* and its referenced documents, which may include exceptions or additions, or both, to the provisions of this document (see 8.7).

4.11 Design of joints subject to fatigue loading is outside the scope of this specification. For freight cars and their components requiring fatigue analysis, refer to Chapter VII, "Fatigue Design of Freight Cars," of AAR *Manual of Standards and Recommended Practices, Section C-II, Design, Fabrication and Construction of Freight Cars, M-1001*.

5. Requirements for All Welding

5.1 General—Welding Procedure Specification Data. The following matrix indicates the welding data to be included in a WPS for each welding process. A WPS may be presented in any format, written or tabular provided the data required in this matrix are included. The WPS may list variables recorded on the PQR within the full range permitted for a qualification variable and practical limits determined by the Company for other than qualification variables.

5.2 Processes. The welding processes covered by Clauses 1 through 17 are shielded metal arc welding (SMAW), submerged arc welding (SAW), gas metal arc welding (GMAW), flux cored arc welding (FCAW), gas tungsten arc welding (GTAW), and flash welding (FW). This does not preclude the use of other welding processes in the construction, alteration, or repair of railcars, locomotives and their components. However, the requirements for the design, qualification, inspection, and testing related to the use of such processes are the responsibility of the Fabricator's Engineer. The company wishing to use such processes shall generate documented evidence to justify their use and to define the essential variables.

	FCAW-G	FCAW-S	FW	GMAW	GTAW	SAW	SMAW
5.1.1 Joint Design							
(1) Joint type and dimensions.	X	X	X	X	X	X	X
(2) Treatment of backside, method of gouging/preparation.	X	X		X	X	X	X
(3) Backing material, if used.	X	X		X	X	X	X
(4) Total cross section area.			X				
(5) Method or equipment used to minimize flash.			X				
(6) End preparation method.			X				
5.1.2 Base Metal							
(1) M-Number and Group Number.	X	X	X	X	X	X	X
(2) Thickness range qualified.	X	X		X	X	X	X
(3) Diameter (tubular only).	X	X		X	X	X	X
(4) Diameter (solid and tubular).			X				
(5) The coating description or type, if present.	X	X	X	X	X	X	X
5.1.3 Filler Metal							
(1) Specification, classification, F- and A-Number, or if not classified the nominal composition.	X	X		X	X	X	X
(2) Weld metal thickness by process and filler metal classification.	X	X		X	X	X	X
(3) Filler metal size or diameter.	X	X		X	X	X	X
(4) Flux-electrode classification.						X	
(5) Penetration enhancing flux.					X		
(6) Supplemental filler metal.	X	X		X	X	X	
(7) Consumable insert and type.					X		
(8) Energized filler metal “hot.”					**X**		
5.1.4 Position							
(1) Welding position(s).	X	X		X	X	X	X
(2) Progression for vertical welding.	X	X		X	X	X	X
5.1.5 Preheat and Interpass							
(1) Preheat minimum.	X	X	X	X	X	X	X
(2) Interpass temperature maximum (if applicable).	X	X		X	X	X	X
(3) Preheat maintenance.	X	X		X	X	X	X
5.1.6 Heat Treatment							
(1) PWHT temperature and time.	X	X	X	X	X	X	X

	FCAW-G	FCAW-S	FW	GMAW	GTAW	SAW	SMAW
(2) Amplitude and number of PWHT cycles following welding cycle.			X				
5.1.7 Shielding Gas							
(1) Torch shielding gas and flow rate range.	X			X	X		
(2) Root shielding gas and flow rate range.					X		
(3) Shielding gas composition pressure, and purging time.			X				
5.1.8 Electrical							
(1) Current (or wire feed speed), current type, and polarity.	X	X		X	X	X	X
(2) Voltage range (except for manual welding).	X	X		X	X	X	
(3) Specification, classification, and diameter of tungsten electrode.					X		
(4) Transfer mode.	X	X		X			
(5) Pulsed current mode shall be indicated.	X	X		X	X		X
(6) Flash time.			X				
(7) Upset current time.			X				
5.1.9 Variables							
(1) Welding process and whether manual, semiautomatic, mechanized, or automatic.	X	X		X	X	X	X
(2) For mechanized or automatic, single or multiple electrode and spacing.	X	X		X	X	X	
(3) Single or multipass.	X	X		X	X	X	X
(4) Contact tube to work distance.	X	X		X		X	
(5) Cleaning.	X	X		X	X	X	X
(6) Peening.	X	X		X	X	X	X
(7) Stringer or weave bead.	X	X		X	X	X	X
(8) Travel-speed range for mechanized or automatic welding and manual applications requiring heat input calculations.	X	X		X	X	X	
(9) Type and model of equipment.			X				
(10) Upset length and force.			X				
(11) Distance between clamping dies.			X				
(12) Preparation of clamping area.			X				
(13) Clamping force.			X				
(14) Forward and/or reverse speeds.			X				
(15) Use of thermal processes.			X				
(16) Supporting PQR number(s), SWPS number, or Prequalified, as applicable.	X	X	X	X	X	X	X

5.2.1 Friction Stir Welding (FSW). When using FSW for fabrication purposes in the railcar industry, AWS D17.3/D17.3M, *Specification for Friction Stir Welding of Aluminum for Aerospace Applications* may be used as a guide for the development of procedure, welding operator, fabrication, and inspection requirements. The resolution of discrepancies between the requirements of this document and AWS D17.3/D17.3M shall be agreed upon by the customer and Fabricator's Engineer. These differences may include, but are not limited to, weld classes, essential variables in procedure qualification, eye examinations and period of effectiveness in welding operator qualification, calibration of welding equipment, qualifications of NDT personnel, NDT inspection requirements for each class of weld, and the acceptance criteria for each class of weld.

5.2.2 Capacitor Discharge Welding. When using capacitor discharge welding to apply thermocouples and/or insulation pins associated with post weld heat treatment, a written welding procedure is required and the welding operator shall be trained on proper use of the specified welding equipment. Welding operator training shall be documented. Neither qualification of the welding procedure, nor the performance qualification of the operator is required. Capacitor discharge welds used in this application shall be subject to the acceptance criteria for a temporary weld as specified in 17.1.

5.3 Welding Procedure Qualification

5.3.1 Welding of steels listed in Clauses 7 and 8, Tables 8.1 and 8.2, using SMAW, SAW, GMAW (except short circuiting transfer), and FCAW procedures conforming to the provisions of Clauses 5 through 8 shall be deemed as prequalified and are therefore approved for use without performing procedure qualification tests. Standard Welding Procedure Specifications (SWPSs) published by the AWS Committee on Welding Qualification in accordance with AWS B2.1/B2.1M, *Specification for Welding Procedure and Performance Qualification*, shall also be accepted. The use of Prequalified Welding Procedure Specifications (PWPSs) and Standard Welding Procedure Specifications (SWPSs) is not intended as a substitute for engineering judgment with respect to the suitability of application of these procedures to a welded assembly or weld repair.

5.3.2 Other materials or welding procedure specifications using one of the processes covered by this specification may be used, provided they are qualified by applicable tests as prescribed in Clause 10. The acceptability of qualification to other standards is the Fabricator's Engineer's responsibility, to be exercised based upon the specific structure, or service conditions, or both.

5.3.3 Qualification of a procedure by one company shall not qualify that procedure for any other company (see 9.4.1), unless the company that developed the qualified procedure contracts with a second company to perform the production welding to that procedure.

5.3.4 The welding of the test coupon to produce a Procedure Qualification Record (PQR) shall not be subcontracted.

5.3.5 Proprietary procedures for the manufacture of new engine blocks qualified in accordance with the manufacturer's requirements are the responsibility of the manufacturer.

5.3.6 This specification does not define prequalified joints and welding procedure specifications for base metals less than 1/8 in [3 mm] thick. Welding procedure specifications for these materials are qualified in accordance with Clause 18.

5.3.7 Welding Procedure Specifications qualified in accordance with any of the following specifications, within the limitations of the essential variables and methods of testing specimens of this specification, shall be considered acceptable:

(1) ASME *Boiler and Pressure Vessel Code*, Section IX

(2) AAR M-1002, *Specification for Tank Cars*, Appendix W

(3) AWS D1.1/D1.1M, *Structural Welding Code—Steel*

(4) AWS D1.2/D1.2M, *Structural Welding Code—Aluminum*

(5) AWS D1.3/D1.3M, *Structural Welding Code—Sheet Steel*

(6) AWS D1.5M/D1.5, *Bridge Welding Code*

(7) AWS D1.6/D1.6M, *Structural Welding Code—Stainless Steel*

(8) ASTM A488, *Practice for Steel Castings, Welding, Qualifications of Procedures and Personnel*

(9) AWS B2.1/B2.1M, *Specification for Welding Procedure and Performance Qualification* (qualification by visual inspection alone is prohibited)

(10) CSA W47.1, *Certification of Companies for Fusion Welding of Steel Structures*

(11) CSA W47.2, *Certification of Companies for Fusion Welding of Aluminum*

5.4 Qualification of Welders and Welding Operators

5.4.1 All welders (including tack welders) and welding operators performing work in accordance with this specification shall be qualified in accordance with 9.3, except for those cases defined in 5.4.2, 5.4.3, or 5.4.4.

5.4.2 Welders or welding operators who are qualified for the materials, processes, and procedures being used in accordance with one of the following specifications shall be considered qualified to weld within limitations of the essential variables and method of testing specimens of this specification:

(1) ASME, *Boiler and Pressure Vessel Code*, Section IX

(2) AAR M-1002, *Specification for Tank Cars*, Appendix W

(3) AWS D1.1/D1.1M, *Structural Welding Code—Steel*

(4) AWS D1.2/D1.2M, *Structural Welding Code—Aluminum*

(5) AWS D1.3/D1.3M, *Structural Welding Code—Sheet Steel*

(6) AWS D1.5M/D1.5, *Bridge Welding Code*

(7) AWS D1.6/D1.6M, *Structural Welding Code—Stainless Steel*

(8) ASTM A488, *Practice for Steel Castings, Welding, Qualifications of Procedures and Personnel*

(9) AWS B2.1/B2.1M, *Specification for Welding Procedure and Performance Qualification* (qualification by visual inspection alone is prohibited)

(10) CSA W47.1, *Certification of Companies for Fusion Welding of Steel Structures*

(11) CSA W47.2, *Certification of Companies for Fusion Welding of Aluminum*

5.4.3 If the operator of a totally automated welding machine has no control over welding variables and no control over the location of the filler metal or heat source, then the operator does not require qualification in accordance with Clause 11.

5.4.4 Personnel operating robotic arc welding equipment shall be qualified. AWS D16.4M/D16.4, *Specification of Robotic Arc Welding Personnel*, is the preferred method of demonstrating such qualification.

5.4.5 A thread-deforming weld to retain a nut on a bolt shall be made by a qualified welder or tack welder as defined in 5.4.1.

5.5 Design of Welded Joints

5.5.1 Drawings and Welding Procedure Specifications

5.5.1.1 When drawings are specified, complete information regarding location, type, and extent of welds shall be clearly documented. Detailed drawings or welding procedure specifications shall indicate clearly, by welding symbols or sketches, details of welded joints and preparation of base material. Width and thickness of fused metallic backing shall be detailed. Where welding symbols do not adequately define requirements, sketches or notes shall be provided.

5.5.1.2 Drawings should note those joints or groups of joints where it is especially important that welding sequence and technique be controlled carefully to minimize shrinkage stresses and distortion.

5.5.1.3 All welding shall be performed in accordance with a written welding procedure specification that meets the requirements of Clauses 7 and 8, for prequalified steel joints or has been qualified in accordance with Clause 10 (see also 5.3.1). A welding procedure specification may cover a range of qualified joint dimensions and welding conditions.

5.5.1.4 When there are special inspection requirements, these shall be noted on the drawings, in the welding procedure specification, or in the contract specification.

(1) All welds that are Class 1 shall be identified as such on the drawing.

5.5.2 Effective Weld Areas, Lengths, and Sizes

5.5.2.1 Groove Welds. The effective area shall be the effective weld length multiplied by the groove weld size.

(1) The effective weld length for any groove weld shall be the length of the specified weld.

(2) The effective size of a complete joint penetration groove weld shall be the thickness of the thinner part joined. No increase is permitted for weld reinforcement.

(3) The effective size of a partial joint penetration groove weld shall be defined by 7.1 for prequalified procedures or in accordance with 10.6.2.

(4) The minimum weld size for all partial joint penetration groove welds shall conform to Table 5.1.

(5) Partial penetration groove welds made from one side shall be designed to prevent tension across the weld root.

5.5.2.2 Fillet Welds. The effective area is the effective weld length measured through the centerline of the theoretical throat multiplied by the theoretical throat. Stress in a fillet weld shall be considered as applied to this effective area, for any direction of applied load. The theoretical throat is the minimum distance minus any convexity between the joint root and the face of fillet weld.

(1) The minimum length of any fillet weld segment shall be four times the nominal weld size but not less than 1-1/2 in [38 mm] unless limited by part size. In joints connected only by fillet welds, the minimum size of fillet weld to be used shall be as shown in Table 7.3.

(2) The effective length of a fillet weld is the length of the full size fillet (specified size). No reduction in effective length shall be made for either the start or termination of the weld if the weld is full size throughout its length.

(3) The effective length of a curved fillet weld shall be measured along the centerline of the effective throat. If the weld area of a fillet weld in a hole or slot computed from this length is greater than the area found in 5.5.2.3, the hole or slot area shall be used as the effective area of the fillet weld.

(4) Fillet welds in holes or slots in lap joints shall be in accordance with 5.5.4.2 and shall not be considered as plug or slot welds.

(5) Fillet welds used in skewed T-joints shall be in accordance with 5.5.4.3.

NOTE: Annex C2 contains a formula governing the calculation of required leg sizes for fillet welds in skewed T-joints. A convenient tabulation of measured leg size (W) and acceptable root openings (R) related to the effective weld throat (E) has been provided for dihedral angles between 60° and 135°.

5.5.2.3 Combination Groove and Fillet Welds. The effective throat of a combination partial joint penetration groove weld and fillet weld is the shortest distance from the weld root to the face of the weld, less any convexity (minus 1/8 in [3 mm] for any prequalified groove details requiring such deduction) (see Annex C1).

(1) Limits for fillet weld convexity and concavity are found in 6.4.1.

5.5.2.4 Plug and Slot Welds

(1) The effective area is the nominal area of the hole or slot in the plane of the faying surface.

(2) Plug or slot welds may be used as follows:

(a) To transmit shear in a lap joint

(b) To prevent buckling of lapped joint members

(c) To join component members

(d) To repair worn members

(3) The minimum center-to-center spacing of plug welds shall be four times the diameter of the hole.

(4) The ends of the slot shall be semicircular or shall have the corners rounded to a radius not less than the thickness of the part containing it, except those ends which extend to the edge of the joint member.

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

(6) For material less than 1/4 in [6 mm] thick, the depth of filling shall be equal to the thickness. The depth of filling of plug or slot welds in materials 1/4 in to 5/8 in [6 mm to 16 mm] thick shall be equal to the thickness of the base material to 1/16 in [1.5 mm] under. In material over 5/8 in [16 mm] in thickness it shall be at least one-half the thickness of the base metal, but not less than 5/8 in [16 mm]. In any case, minimum depth of filling need not exceed the thickness of the underlying material.

(7) The allowable loads on plug welds of base metal less than 1/4 in [6 mm] thick shall be limited as follows:

$P \leq 0.88TDF_b$ and $P \leq 0.24D^2F_w$

where

P = Allowable load, pound force [Newtons]
D = Hole diameter, in [mm]
T = Base metal thickness, in [mm]
F_b = Minimum tensile strength of base metal, psi [MPa] from the applicable material specification
F_w = Minimum tensile strength of weld metal as specified in the applicable AWS Classification, psi [MPa]

5.5.3 Filler Plates

5.5.3.1 Filler plates may be used only in accordance with Figures 5.1 and 5.3 and as described in 5.5.3.2 and 5.5.3.3.

5.5.3.2 A filler plate less than 1/4 in [6 mm] thick shall not be used to transfer stress but shall be kept flush with the welded edges of the stress-carrying joint member. The sizes of welds along such edges shall be increased over the required sizes by an amount equal to the thickness of the filler (see Figure 5.1).

5.5.3.3 Any filler plate 1/4 in [6 mm] or more in thickness shall extend beyond the edges of the joint member and comply with the requirements of Figure 5.3.

5.5.4 Details of Fillet Welds

5.5.4.1 For fillet welds in lap joints, if the fillet size equals the thickness of the edge being welded, there is the possibility of the weld size not being as large as it appears because of edge melting. It is a common practice in material 1/4 in [6 mm] or greater to keep the fillet size 1/16 in [1.5 mm] less than the thickness to avoid this problem. When this practice is not followed, precautions should be taken to assure the needed throat size [see Figure 5.4(B)].

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

5.5.4.3 Skewed T- Joints. T-joints having a dihedral angle (Ψ) between the joined parts greater than 100° or less than 80° are defined as skewed T-joints. Such joints are considered pre-qualified if in accordance with 7.3.1 and Figure 5.4(A). The Fabricator's Engineer shall specify the required effective weld throat (E), root opening (R), and measured leg size (W). These details shall be clearly shown on the drawing. Dihedral angles of less than 60° and equal to or greater than 30° are permitted; however, in such cases, the weld is considered to be a partial joint penetration groove weld and the Fabricator's Engineer shall specify a minimum joint penetration. Angles less than 30° shall not be considered as effective in transmitting design loads.

5.5.5 Intermittent Fillet Welds

5.5.5.1 Intermittent fillet welds should be avoided in primary load-carrying members.

5.5.5.2 Intermittent fillet welds may be used to transfer calculated stress across a joint or faying surfaces when the strength required is less than that developed by a continuous fillet weld of the smallest permitted size, and to join components of built-up members.

5.5.5.3 The effective length of any segment of intermittent fillet welding shall be not less than four times the weld size, with a minimum of 1-1/2 in [38 mm].