

Specification for Welding of Rotating Elements of Equipment



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An American National Standard

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American National Standards Institute
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Specification for Welding of Rotating Elements of Equipment

4th Edition

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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 standard establishes material and workmanship standards for manufacturers, fabricators, repair organizations, purchasers, and owner/operators of rotating equipment which are fabricated or repaired by welding. Included are sections defining process qualifications, operator qualifications, quality control, inspection requirements, and repair requirements.



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Dedication

In Memoriam

Gordon Earle Cossaboom 1925–2007

This edition of AWS D14.6 is dedicated in memory of Gordon Earle Cossaboom. Gordon was the chair of the D14.6 standard when it was first published in 1981, and the second edition in 1996. Gordon was a member of the AWS D14G Subcommittee for about 33 years.

Gordon Earle Cossaboom, an AWS Life Member, graduated from the Boston Latin School in 1943. He served in the U.S. Army in Europe during WWII, then returned to Boston where he graduated from Northeastern University with a BS in civil engineering. After receiving his BS degree, he studied at The Ohio State University where he earned a MS degree in welding engineering.

In 1954, Cossaboom started his career at General Electric Company where he worked for several years. Later, he worked with Westinghouse Electric Company, Syosset, New York, and with the Eutectic Corporation. With these welding equipment manufacturers, he focused on new product development and participated in the development of CO₂ welding. In 1967, he joined American Standards' Industrial Products Division in Dearborn, Michigan, as manager of engineering.

From 1978 to 1986, Cossaboom worked as a welding engineer for the Manufacturing and Quality Division of Gilbert Commonwealth, Jackson, Michigan. From 1986 to his retirement in 1988, he served on the faculty at Ferris State University as an associate professor in the Welding Technology Department. He was an AWS member for 54 years and an active member of the Central Michigan Section.

Gordon was awarded the Samuel Wylie Miller Memorial Medal (Posthumous Recognition) in 2007. Gordon died at age 82 on January 10, 2007.

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Foreword

This foreword is not part of [AWS D14.6/D14.6M:2012](#), *Specification for Welding of Rotating Elements of Equipment*, but is included for informational purposes only.

This is the fourth edition of the D14.6 specification. AWS first published the Specification for Welding of Rotating Elements of Equipment in 1981 to provide a welding specification that would apply to dynamic applications for new, modified, or the repair of welded rotating elements. Rotating elements can range from a few inches in diameter to over 200 in [5 m] in diameter. This specification is directed toward (but not limited to) crushers, fans, impellers, centrifugal impellers, kilns, pulpers, gears, sheaves, drive trains, crankshafts, flywheels, power transmission shafts, air moving devices, blowers, and rotating elements of hydro electric generating equipment. By definition, the types of equipment covered by the specification are numerous and varied. The specifications that were used prior to this specification were ASME *Boiler and Pressure Vessel Code* in part or in whole and [AWS D1.1](#), *Structural Welding Code—Steel*. [AWS D14.6/D14.6M:2012](#) utilizes information from these codes. The sections on design have been omitted. It is felt that a separate study of how practices do or should differ in design of welding rotating equipment from those published for stationary structures is needed. Such a study was beyond the scope of this subcommittee.

This edition has some revisions that require the use of [AWS B2.1/B2.1M:2009](#), *Specification for Welding Procedure and Performance Qualification*, to supplement the information that has been removed from this edition. The following information has been removed and can be found in [B2.1/B2.1M:2009](#):

- (1) F number grouping for filler metals
- (2) Permitted welding processes
- (3) Procedure qualification specimen for groove welds
- (4) Allowable base metals and filler metals for performance qualification
- (5) Grouping of base metals by M number and specification number
- (6) The following figures:
 - (a) Limits of Welding Positions for Groove Welds
 - (b) Welding Test Positions—Plate Groove Welds
 - (c) Welding Test Positions—Pipe Groove Welds
 - (d) Limits of Welding Positions for Fillet Welds
 - (e) Welding Test Positions for Plate Fillet Welds
 - (f) Welding Test Positions for Pipe Fillet Welds
 - (g) Tension Test Specimens—Test Plate
 - (h) Tension Test Specimens—Test Pipe 2 in [50 mm] and 3 in [75 mm] Diameters
 - (i) Tension Test Specimens—Test Pipe 6 in [150 mm] and 8 in [200 mm] Diameters
 - (j) Tension Test Specimens—Cylindrical Test Bar for All-Weld-Metal and Crossweld Tensile Specimens
 - (k) Tension Test Specimens—Typical Locations for Multiple Specimens
 - (l) Transverse Side Bend Specimens

- (m) Transverse Face and Root Bend Specimens
- (n) Longitudinal Face and Root Bend Specimens
- (o) Jigs for Guided Bend Test—Standard Test Fixture
- (p) Jigs for Guided Bend Test—Alternate Wrap-Around Guided Bend Test Fixture
- (q) Jigs for Guided Bend Test—Alternate Roller-Equipped Guided Bend Test Fixture for Bottom Ejection of Test Specimens
- (r) Test Specimen Layout for Procedure Qualification
- (s) Location of Cladding Test Specimens
- (t) Weld Cladding Side Bend Test Specimens
- (u) Weld Cladding and Hardfacing Chemical Analysis Specimens
- (v) Test Specimen Layout for Performance Qualification of Welders and Welding Operators
- (w) Method of Applying Load on Fillet-Weld Break-Test Specimen
- (7) Welder performance requirements for welding positions

No restrictions are placed on the use of any welding process or procedure provided the weld produced by the process meets the qualification requirements of the specification. No attempt is made to limit or restrict technology progression on the Welding of Rotating Elements, nor should any such limitation be inferred. Similarly no limitation is intended on the use of any base metal, weld joint preparation, or welding consumable capable of being qualified.

Underlined areas in text, tables, or figures indicate changes from the previous edition. A vertical line in the margin next to a figure, equation, or other item also indicates a revision from the previous edition.

Comments and suggestions for the improvement of this standard are welcome. They should be sent to the Secretary, AWS D14 Committee on Machinery and Equipment, American Welding Society, 550 N.W. LeJeune Road, Miami, FL 33126.

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Specification for Welding of Rotating Elements of Equipment

1. Scope

This specification establishes minimum acceptable requirements for weld joint detail and fabrication by welding of rotating elements in new equipment. This specification also applies to the modification or repair by welding of rotating elements in existing equipment. Equipment types covered by this specification include, but are not limited to: crushers, fans, impellers, centrifugal impellers, kilns, pulpers, gears, sheaves, drive trains, crankshafts, flywheels, power transmission shafts, air moving devices, blowers, and rotating elements of hydro electric generating equipment. The intent of this specification is not to include steam or combustion turbine rotors, blading, or camshafts. This specification also applies to such products and procedures that are agreed to by the Manufacturer, Fabricator, or Repair Organization and the Owner.

Requirements contained herein are not intended to nullify or void the requirements of any law or governmental agency regulation or other codes applied to components. Additional requirements may be invoked by contract documents. The specification establishes the minimum acceptable practice at the time of its publication. It is not intended to restrict new developments or in any way to inhibit advances in the art and science of welding.

This specification is intended to promote the following:

- (1) High quality construction and repair of welded rotating elements of equipment;
- (2) Adequate initial and sustained performance of welded rotating elements of equipment;
- (3) Personnel safety;
- (4) Clear, concise fabrication practices that will be readily understood by the Manufacturer, Fabricator, or Repair Organization, Fabricator, Owner, and user; and
- (5) Conservation of human and material resources in the fabrication of welded rotating elements of equipment.

This specification makes use of both U.S. Customary Units and the International System of Units (SI). These measurements may not be exact equivalents; therefore each system must be used independently of the other without combining in any way. The specification with the designation D14.6 uses U.S. Customary Units. The specification D14.6M uses SI Units. The latter are shown in appropriate columns in tables or within brackets ([]) when used in the text.

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 other sources, including, but not limited to ANSI Z49.1, *Safety in Welding, Cutting, and Allied Processes*, and applicable federal and state regulations.

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.

AISI Steel Specifications¹

AISI no longer publishes steel specifications.

¹ AISI standards can be obtained at www.steel.org.

ASTM Standards²

- (1) [ASTM E 94](#), *Guide for Radiographic Testing*
- (2) [ASTM E 164](#), *Recommended Practices for Ultrasonic Contact Examination of Weldments*
- (3) [ASTM E 165](#), *Standard Recommended Practice for the Liquid Penetrant Inspection Method*
- (4) [ASTM E 317](#), *Practice for Evaluating Performance Characteristics of Pulse-Echo Ultrasonic Testing Systems without the Use of Electronic Measurement Instruments*
- (5) [ASTM E 709](#), *Practice for Magnetic Particle Examination*
- (6) [ASTM E 747](#), *Practice for Design, Manufacture, and Material Grouping Classification of Wire Image Indicators (IQI) Used for Radiology*
- (7) [ASTM E 1025](#), *Standard Practice for Design, Manufacture, and Material Grouping Classification of Hole-Type Image Quality Indicators (IQI) Used for Radiology*
- (8) [ASTM E 1316](#), *Terminology for Nondestructive Examinations*

ASME Standards³

- (1) ASME Boiler and Pressure Vessel Code:
 - (a) Section V, *Nondestructive Examination*
 - (b) Section VIII, *Unfired Pressure Vessels*
 - (c) Section IX, *Qualification Standard for Welding and Brazing Procedures, Welders, Brazers, Welding and Brazing Operators*
- (2) ASME B16.9, *Factory-Made Wrought Steel Butt Welding Fittings*
- (3) ASME B16.11, *Forged Fittings, Socket-Welding and Threaded*
- (4) ASME B16.28, *Wrought Steel Butt Welding Short Radius Elbows and Returns*
- (5) [ASME B31.1](#), *Power Piping*
- (6) ASME B46.1, *Surface Texture, Surface Roughness, Waviness and Lay*

AWS Standards⁴

- (1) [AWS A1.1](#), *Metric Practice Guide for the Welding Industry*
- (2) [AWS A2.4](#), *Standard Symbols for Welding, Brazing, and Nondestructive Examination*
- (3) [AWS A3.0](#), *Standard Welding Terms and Definitions, Including Terms for Adhesive Bonding, Brazing, Soldering, Thermal Cutting, and Thermal Spraying*
- (4) [AWS A5.32/A5.32M](#), *Specification for Welding Shielding Gases*
- (5) AWS A5.X, For pertinent A5 electrode standards, see Table 1.
- (6) [AWS B2.1/B2.1M](#), *Specification for Welding Procedure and Performance Qualification*
- (7) [AWS B4.0](#) and [B4.0M](#), *Standard Methods for Mechanical Testing of Welds*
- (8) [AWS D1.1](#), *Structural Welding Code—Steel*
- (9) [AWS D14.8M](#), *Standard Methods for the Avoidance of Cold Cracks*

² ASTM standards are published by the American Society for Testing and Materials, ASTM International, 100 Barr Harbor Drive, P.O. Box C700, West Conshohocken, PA 19428, www.astm.org.

³ ASME standards are published by the American Society of Mechanical Engineers, Three Park Avenue, New York, NY 10016.

⁴ AWS standards are published by the American Welding Society, 550 N.W. LeJeune Road, Miami, FL 33126.

Table 1
Welding Procedure Process Variables

			SMAW			SAW			FCAW			GMAW			GTAW			PAW			ESW			EGW			EBW		
Clause	Para.	Variable	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C
Joint Design																													
6.7.1	(1)	Groove Design	X			X			X			X			X			X			X			X			X		
	(2)	± Backing																X			X					X			
	(3)	– Backing (complete joint penetration welds)	X			X			X			X			X														
	(4)	+ Backing													X			X											
	(5)	> Fit-up Gap																								X			
Base Metal																													
6.7.2	(1)	Δ Penetration																								X			
	(2)	Δ Group Number		X			X			X			X			X			X			X			X				
	(3)	Thickness of ≤ 5/8 in [16 mm] Minimum Qualified		X			X			X			X			X						X							
	(4)	Δ t Beyond Thickness Qualified	X			X			X			X			X			X			X			X			X		
	(5)	> Pass Thickness Limit	X			X			X			X			X			X											
	(6)	> Base Metal Thickness (GMAW-S)									X																		
	(7)	Δ M-Number	X			X			X			X			X			X			X			X			X		
	(8)	Δ M-Number from 9-A to 9-B	X			X			X			X			X			X			X			X			X		
Electrodes, Filler Metals, and Other Consumables																													
6.7.3	(1)	Δ Cross Section or Wire Speed																								X			
	(2)	< t or Δ Chemical Composition																								X			
	(3)	Δ <u>Diameter</u> of Filler Metal												X			X												
	(4)	Δ F-Number	X			X			X			X			X			X			X			X					
	(5)	Δ Chemistry (i.e., A-No.)	X			X			X			X			X			X			X			X			X		
	(6)	> Diameter	X			X			X			X						X			X								
	(7)	± or Δ of Supplementary Deoxidizers																								X			
	(8)	Δ in AWS Flux-Electrode Classification or Unlisted Flux-Electrode Classification				X												X											
	(9)	Δ Chemistry by > to < of Alloy Flux				X																							
	(10)	Δ Size of Flux Particles					X																						
	(11)	Δ Filler Metal Classification		X	X		X	X		X	X		X	X		X	X		X	X		X	X		X	X		X	
	(12)	± Consumable Insert											X			X													
	(13)	± Filler Metal											X			X										X			
	(14)	Δ Flux Type or Chemistry																X											
	(15)	Δ Wire to Strip or Vice Versa																X			X								

(Continued)

Table 1 (Continued)
Welding Procedure Process Variables

			SMAW			SAW			FCAW			GMAW			GTAW			PAW			ESW			EGW			EBW		
Clause	Para.	Variable	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C
	(16)	Δ Guide Type																		X									
	(17)	Δ Method of Addition																		X			X			X			
	(18)	Δ Chemical Composition																								X			
	(19)	Δ FCAW-S to FCAW-G or vice versa							X																		X		
	(20)	± Supplemental Filler Metal				X			X			X			X			X			X			X			X		
	(21)	± Supplemental Powder Filler Metal				X																							
	(22)	> Supplemental Powder Filler Metal				X																							
	(23)	Δ Chemistry by > or < Supplemental Powder				X																							
Positions																													
6.7.4	(1)	+ Position (see also 6.7.4)	X			X			X			X			X			X											
	(2)	Δ Position to Vertical		X						X			X			X			X							X			
Preheat																													
6.7.5(1)	(1)	A decrease ≥ 100°F [55°C] from minimum preheat	X			X			X			X			X			X			X			X			X		
	(2)	Δ Temperature			X			X			X			X															
	(3)	> Maximum Preheat or Interpass Temperature from That Qualified		X			X			X			X			X			X										
Postweld Heat Treatment																													
6.7.6(1)	(1)	Δ PWHT	X			X			X			X			X			X			X			X			X		
	(2)	± Solution PWHT for M-8 Base Metal	X			X			X			X			X			X			X			X			X		
Gas																													
6.7.7	(1)	± Trailing, Chemical Composition, or both														X			X										
	(2)	Δ from a Single Gas to Any Other Single Gas or a Mixture of Gases, or a Single Change in Specified Percentage of a Gas Composition Outside the Tolerances given in AWS A5.32, or Deletion of Shielding Gas								X			X			X							X						
	(3)	Δ Flow Rate							X			X			X								X						
	(4)	Δ Chemical Composition, Flow Rate, or both															X												
	(5)	± Backing Gas; Δ Flow Rate, Consumption, or both											X			X			X										
	(6)	Δ Environmental																								X			

(Continued)

Table 1 (Continued)
Welding Procedure Process Variables

			SMAW			SAW			FCAW			GMAW			GTAW			PAW			ESW			EGW			EBW		
Clause	Para.	Variable	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C
Electrical Characteristics																													
6.7.8	(1)	Δ Current Type (I), Polarity, or > Heat input		X			X			X			X			X			X			X							
	(2)	Δ Mode of Metal Transfer								X	X																		
	(3)	± Pulsed Current													X				X										
	(4)	± 15% Current or Voltage			X			X			X			X			X		X	X					X			X	
	(5)	Δ Beam Parameters (EBW)																								X			
	(6)	Δ Pulsing Frequency (EBW)																								X			
	(7)	Δ Current Type or Polarity			X			X			X	X		X				X			X			X			X		
Technique																													
6.7.9	(1)	Δ Bead Technique			X			X			X			X			X			X									
	(2)	Δ Method of Back Gouging			X			X			X			X			X			X									
	(3)	Δ Oscillation						X			X			X			X	X			X			X					
	(4)	Δ Multiple pass to single pass per side		X	X		X	X		X	X		X	X		X	X		X	X									
	(5)	Δ Single to Multiple electrode, or vice versa					X	X		X	X		X	X		X	X	X			X								
	(6)	— Chamber											X			X													
	(7)	Δ Melt-in to Keyhole or vice versa															X												
	(8)	± Retainers			X			X			X			X			X	X			X								
	(9)	Δ Gun Angle																								X			
	(10)	Δ Electrode Spacing						X			X			X			X			X			X			X			
	(11)	↑ to ↓ or Vice Versa	X						X			X		X			X												
	(12)	Δ Type or Model of Equipment																								X			
	(13)	> Absolute Pressure (Vacuum)																								X			
	(14)	Δ Filament Configuration																								X			
	(15)	+ <u>Smoothing</u> pass																								X			
	(16)	Δ 1 to 2 Sides or Vice Versa																								X			

Notes:

- See also 7.7 for specific preheat and postweld heat treatment requirements for different materials.
- The symbol A when marked with an "X" signifies that the given variable is essential and must be documented in both the PQR and WPS. If this variable is changed from that qualified (i.e., documented on the PQR), the welding procedure specification must be requalified.
- The symbol B when marked with an "X" signifies that the given variable is essential only when fracture toughness is a requirement. When fracture toughness is a requirement, these variables are the same as those in Symbol A.
- The symbol C when marked with an "X" signifies that the given variable is nonessential and may be changed on the WPS without requalification, but the WPS must be revised.

Table 1 Legend:

Δ = Change
+ = Addition
- = Deletion
< = Decrease
> = Increase
t = Thickness
↑ = Uphill
↓ = Downhill

SAW = Submerged Arc Welding
SMAW = Shielded Metal Arc Welding
FCAW = Flux Cored Arc Welding
GMAW = Gas Metal Arc Welding
GTAW = Gas Tungsten Arc Welding

PAW = Plasma Arc Welding
ESW = Electroslag Welding
EGW = Electrogas Welding
EBW = Electron Beam Welding

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

(11) [AWS QC1](#), *Standard for AWS Certification of Welding Inspectors*

ASNT Standard⁵

SNT TC-1A, *Recommended Practice, Personnel, Qualification, and Certification in Nondestructive Testing*

CSA Standard⁶

W178.2, *Certification of Welding Inspectors*

Military Standard⁷

MIL-STD-2035A, *Nondestructive Testing Acceptance Criteria*

SAE Standard⁸

SAE AMS-S-13165, *Shot Peening of Metal Parts*

3. Definitions and General Provisions

3.1 Definitions. All of the terms listed in this clause are used in various parts of this document and require definition for correct interpretation of the text. Most of these terms are not contained in AWS A3.0, *Standard Welding Terms and Definitions, Including Terms for Adhesive Bonding, Brazing, Soldering, Thermal Cutting, and Thermal Spraying*.

A-numbers. A classification system of weld metal analysis used for procedure qualification.

buttering. The deposition of weld metal on one or both faces of the joint prior to preparation of the joint for final welding.

Buyer or Owner. The person, company, or agency that purchases the rotating equipment.

Engineer. The responsible technical authority.

F-numbers. A grouping of electrodes and welding rods based on their usability characteristics, which fundamentally determine the ability of welders to make satisfactory welds with a given filler metal. This grouping system is used to reduce the number of welding procedure and performance qualifications where this can logically be done. Referred to the same as in [AWS B2.1/B2.1M](#), *Specification for Welding Procedure and Performance Qualification*.

Fabricator. The person, shop, Contractor, or agency performing the actual welding. The person may be employed by the Manufacturer's company or the Fabricator may be an independent shop doing work on a subcontract basis. Referred to as the Employer in [AWS B2.1/B2.1M](#), *Specification for Welding Procedure and Performance Qualification*.

heat treatment. A combination of heating and cooling operations applied to a metal or alloy in the solid state to obtain desired conditions or properties.

Inspector. The person designated by the Manufacturer, Owner, or Repair Organization who shall ascertain that all fabrication by welding is performed in conformance to the requirements of this specification.

M-numbers. A classification system that groups base metals for welding procedure and performance qualification on the basis of mechanical properties, chemical composition, and metallurgical compatibility to minimize the number of welding qualifications where this can logically be done. Under this system, base metals have been divided into general categories (e.g., Material numbers M-1, M-1A, M-2, M-2A, M-3, etc.) and further subdivided into groups. Referred to the same as in [AWS B2.1/B2.1M](#), *Specification for Welding Procedure and Performance Qualification*.

⁵ ASNT standards are published by the American Society for Nondestructive Testing (ASNT), 1711 Arlingate Lane, P.O. Box 28518, Columbus, OH 43228-0518.

⁶ CSA standards are published by the Canadian Standards Association, 178 Rexdale Boulevard, Toronto, Ontario, M9W 1R3, Canada.

⁷ Military standards are published by Global Engineering Documents, 15 Inverness Way East, Englewood, CO 80112-5776, www.global.ihs.com.

⁸ SAE standards are published by SAE World Headquarters, 400 Commonwealth Drive, Warrendale, PA 15096-0001, <http://www.sae.org/servlets/index>.

Manufacturer. The person, company, or agency responsible for the design and performance of a rotating component. Referred to as the Employer in [AWS B2.1/B2.1M, Specification for Welding Procedure and Performance Qualification](#).

postweld heat treatment. Any heat treatment subsequent to welding.

temperature maintenance. Practice of maintaining a specified temperature for some specified time interval after welding is finished or until postweld heat treatment is initiated, if postweld heat treatment is required.

Repair Organization. The organization that provides repair or modification to a rotating component. Referred to as the Employer in [AWS B2.1/B2.1M, Specification for Welding Procedure and Performance Qualification](#).

User. The person, company, or agency that utilizes the rotating equipment.

3.2 Responsibilities

3.2.1 Manufacturer, Fabricator, or Repair Organization's Responsibility. The Manufacturer, Fabricator, or Repair Organization shall do the following:

- (1) Ensure that all aspects of welding meet the requirements of this specification (see 8.1.4).
- (2) Ensure that welding and nondestructive examination symbols are in conformance with the latest edition of [AWS A2.4, Standard Symbols for Welding, Brazing, and Nondestructive Examination](#).
- (3) Detail joint preparation and ensure joint compatibility with processes applied and materials employed.
- (4) Select processes for all welding.
- (5) Establish written welding procedure specifications (WPSs) for all welding.
- (6) Ensure the standards of workmanship applied to all welds and welding procedures conform to the applicable paragraphs of Clause 8.
- (7) Qualify, maintain, and use welding procedure specification (WPS) and performance records that meet the requirements of this specification for welding process(es) selected.
- (8) Maintain records of tests and procedures relating to welding and forward copies to the Owner, when required in the contract (see 8.1.4).

(Subclause 8.3 may be referred to for additional obligations.)

3.2.2 Owner's Responsibility. The Owner shall do the following:

- (1) Specify in the contract and prior to manufacture any additional fabrication or testing requirements (see Clause 7 and 8.4).
- (2) Specify in the contract the conditions under which the Owner and/or User may conduct in-plant or onsite inspection to meet this specification.
- (3) Ensure, when Inspectors are provided by the Owner, that they meet the personnel requirements of Clause 8.

3.2.3 Additional Responsibilities. For modification and/or repair, additional responsibilities are listed in Clause 9.

4. Materials

4.1 Base Metals

4.1.1 Materials selected for use in welded fabrication of rotating elements shall conform to the specifications established by a recognized material specifying organization (i.e., ASTM, ASME, API, etc.). Materials other than those so covered may be used upon agreement between Owner and Manufacturer, Fabricator, or Repair Organization.

4.1.2 The approved materials for welding procedures and welder performance qualification, are listed in [AWS B2.1/B2.1M, Specification for Welding Procedure and Performance Qualification](#), or at <http://files.aws.org/technical/B2.1-B2.1M-BMG-2009.pdf>, or from the current link at the AWS web site at www.aws.org. The materials are listed by material number and group number, based on mechanical properties, chemical composition, and metallurgical

compatibility to minimize the number of welding qualifications where this can logically be done. Base metals have been divided into general categories (e.g., M-numbers M-1, M-1A, M-2, M-2A, M-3, etc.) and further subdivided into groups. The grouping does not imply that base metals may be indiscriminately substituted for a base metal that was used in the qualification test without consideration of the compatibility from the standpoint of metallurgical properties, postweld heat treatment, design, mechanical properties, and service requirements.

4.2 Welding Electrodes, Filler Metals, and Consumables

4.2.1 Welding electrodes, filler metals, and fluxes shall conform to the pertinent AWS specifications (AWS A5 standards) shown in the filler metal grouping annex in [AWS B2.1/B2.1M, Specification for Welding Procedure and Performance Qualification](#). Welding electrodes, filler metals, and fluxes not covered by an AWS standard shall require a separate welding procedure qualification.

5. Welding Processes

All of the welding processes listed below may be used in the fabrication or repair of rotating elements. Welding processes and process variables are discussed in detail later in Clause 6. Processes not listed below may be utilized provided the Manufacturer, Fabricator, or Repair Organization can show evidence that the process used consistently produces welds which meet the requirements of Clause 6, and the Owner agrees to use the process.

- (1) Shielded Metal Arc Welding (SMAW)
- (2) Submerged Arc Welding (SAW)
- (3) Flux-Cored Arc Welding (FCAW)
- (4) Gas Metal Arc Welding (GMAW)
- (5) Gas Tungsten Arc Welding (GTAW)
- (6) Plasma Arc Welding (PAW)
- (7) Electroslag Welding (ESW)
- (8) Electrogas Welding (EGW)
- (9) Electron Beam Welding (EBW)

6. Welding Procedure and Performance Qualification

Part A *General Requirements*

6.1 Scope. Welding procedures and welders shall be qualified using [AWS B2.1/B2.1M, Specification for Welding Procedure and Performance Qualification](#), within the limits of Parts B, C, and D of Clause 6 of this specification. Procedures, welders, and welding operators qualified to other codes and specifications (such as ASME IX, [AWS D1.1](#) or other codes or specifications approved by the owner/buyer) shall be acceptable to this specification if the previous qualifications meet the requirements of this specification.

6.2 Exception to [AWS B2.1/B2.1M, Welding Procedure and Performance Qualification](#). The use of special test weldments prescribed in B2.1 may be used when accepted by the Owner.

6.3 Responsibility for Welding. Each Manufacturer, Fabricator, or Repair Organization is responsible for the welding done and shall conduct the tests required in this clause. It is not permissible for the Manufacturer, Fabricator, or Repair Organization to have the welding of the test weldments performed by another organization. It is permissible, however, to subcontract any or all of the work of preparation of test materials for welding, and subsequent work on preparation of test specimens from the completed weldment, performance of nondestructive examination, and mechanical tests, provided the Manufacturer, Fabricator, or Repair Organization accepts the responsibility for any such work.

6.3.1 A Manufacturer, Fabricator, or Repair Organization may approve a subcontractor's welding procedure and performance qualification records for work to be performed by the subcontractor, provided that the records meet this specification.

6.3.2 Each Manufacturer, Fabricator, or Repair Organization shall maintain welding procedure specifications and records of the results obtained in welding procedure qualification records (PQR) and welder and welding operator performance qualifications. These records shall be certified by the Manufacturer, Fabricator, or Repair Organization and shall be accessible to the Buyer's Inspector. Refer to Annex B for reference to forms.

6.4 Notch-Toughness Tests. When specified in the contract, CVN or other impact toughness testing shall be performed. When required, the owner shall specify the material(s) to be tested, whether the base metal, weld metal, or HAZ. In addition, the specimen locations, orientations, test temperatures and acceptance criteria shall be specified. Test procedures and apparatus shall conform to the requirements of AWS B4.0 or B4.0M, Standard Methods for Mechanical Testing of Welds, or other applicable standards.

Part B

Procedure Qualification

6.5 General Requirements

6.5.1 Responsibilities of the Manufacturer, Fabricator, Repair Organization, or Contractor. Each Manufacturer, Fabricator, Repair Organization, or Contractor shall list the variables applicable to the welding that each performs in construction of weldments built in conformance to this specification. These variables shall be listed in a document known as a welding procedure specification (WPS).

Each Manufacturer, Fabricator, or Repair Organization shall qualify the WPS by the welding of test assemblies, the testing of specimens as required in this specification, and the recording of the welding data and test results in a document known as a procedure qualification record (PQR). The welders or welding operators, working to produce weldments to be tested for qualification of procedures, shall be under the full supervision and control of the Manufacturer, Fabricator, Repair Organization, or Contractor during the production of these test weldments. A WPS may require the support of more than one PQR while, alternatively, one PQR may support more than one WPS. For additional information, see [AWS B2.1/B2.1M, Specification for Procedure and Performance Qualification](#).

6.5.2 Welding Procedure Specification (WPS). The WPS shall list in detail the various base-metal M-numbers to be joined by welding, their thicknesses, the filler metals to be used, the range of preheat and postweld heat treatment, and other variables described for each welding process as either essential or nonessential variables (see Table 1). Copies of the WPS shall be available for reference by the welders or welding operators and the Purchaser's Inspector. A recommended form for this WPS is given in Annex B.

Changes may be made in the nonessential variables to suit production requirements without requalification of the procedure, provided such changes are documented in either an amendment to the original WPS or a new WPS. A change in any essential variable shall require requalification to be recorded in another PQR.

The Manufacturer, Fabricator, Repair Organization, or Contractor shall certify that he or she has qualified for each welding procedure specification, has performed the procedure qualification test(s), and has documented it with the necessary PQR.

6.5.3 Procedure Qualification Record (PQR). The specific facts involved in qualifying a WPS shall be recorded in a form called the PQR, which shall document the essential variables of the specific welding process or processes, as listed in Table 1, and the test results. These documents shall be certified by the Manufacturer, Fabricator, Repair Organization, or Contractor, and shall be available for examination by the Inspector. Recommended forms are given in Annex B.

6.5.4 Combination of Welding Processes or Procedures

6.5.4.1 More than one WPS having different essential, supplementary essential, or nonessential variables may be used in a single production joint. Each WPS may include one or a combination of processes, filler metals, or other variables.

Where more than one WPS specifying different processes, filler metals, or other essential or supplementary essential variables is used in a joint, Table 4.3 from AWS B2.1/B2.1M:2009 shall be used to determine the range of base metal thickness and maximum weld metal thickness qualified for each process, filler metal, or set of variables, and those limits shall be observed. Alternatively, qualification of WPSs for root deposits only may be made in accordance with 6.5.4.

When following a WPS that has more than one welding process, filler metal, or set of variables, each process, filler metal, or set of variables may be used individually or in different combinations, provided the following:

(1) The essential, nonessential, and required supplementary essential variables associated with the process, filler metal, or set of variables are applied.

(2) The base metal and deposited weld metal thickness limits of Table 4.3 of AWS B2.1/B2.1M:2009 for each process, filler metal, or set of variables are applied.

6.5.4.2 For GTAW, SMAW, GMAW, PAW, and SAW, or combination of these processes, a PQR for a process recording a test coupon that was at least 1/2 in [13 mm] thick may be combined with one or more other PQRs recording another welding process and any greater base metal thickness. In this case, the process recorded on the first PQR may be used to deposit the root layers using the process(es) recorded on that PQR up to 2t.

6.5.5 Type of Tests Required

6.5.5.1 Mechanical Tests. The type, quantity of test specimens, and required fixtures used for testing are given in [AWS B2.1/B2.1M](#) (Test Methods), *Specification for Welding Procedure and Performance Qualification*. The mechanical testing of EBW welds may require special consideration because they typically have a high aspect ratio.

6.5.5.2 Base Metals—Groove and Fillet Welds. WPS qualification tests for groove and fillet welds may be made on groove welds using reduced-section tension specimens and guided bend specimens. The groove weld tests shall qualify the WPS for use with groove welds within the range of essential variables listed. Groove weld tests shall also qualify the WPS for use with fillet welds in all thicknesses, sizes of fillet welds, and diameters of pipe or tube, within the applicable essential variables. Where a WPS qualification of fillet welds only is required, tests shall be made in conformance to 6.5.5.3. The tests shall qualify the fillet WPS for use with fillet welds in all thicknesses of metal, sizes of fillet welds, and diameters of pipe or tube for use with the applicable essential variables.

6.5.5.3 Procedure Specimens—Fillet Weld Test. The dimensions and preparation of the fillet weld test specimen for procedure qualification shall conform to Figure 1. The test specimen shall not contain cracks. It shall be cut transversely to provide two sections, each approximately 4 in [100 mm] long, and shall conform to the requirements of 6.5.5.4.

6.5.5.4 Specimen Preparation for Macroetch Examination and Acceptance Criteria. One face of each cross section shall be smoothed and etched with a suitable etchant (e.g., see [AWS B2.1/B2.1M](#), *Specification for Welding Procedure and Performance Qualification*, [Macroetch Procedure](#)) to give a clear definition of the weld metal and HAZ. Visual examination of the cross section shall show fusion to the root but not necessarily beyond. The weld metal and HAZ shall be free of cracks, and the welds shall conform to the applicable weld surface conditions and weld sizes noted in 7.4.

6.5.5.5 Consumables Verification Tests. When the WPS specifies a consumable that has not been established in conformance with the Filler Metal Grouping Annex of [AWS B2.1/B2.1M](#), *Specification for Welding Procedure and Performance Qualification*, then a complete joint penetration (CJP) groove weld test plate shall be welded to qualify the proposed combination of welding consumable and material.

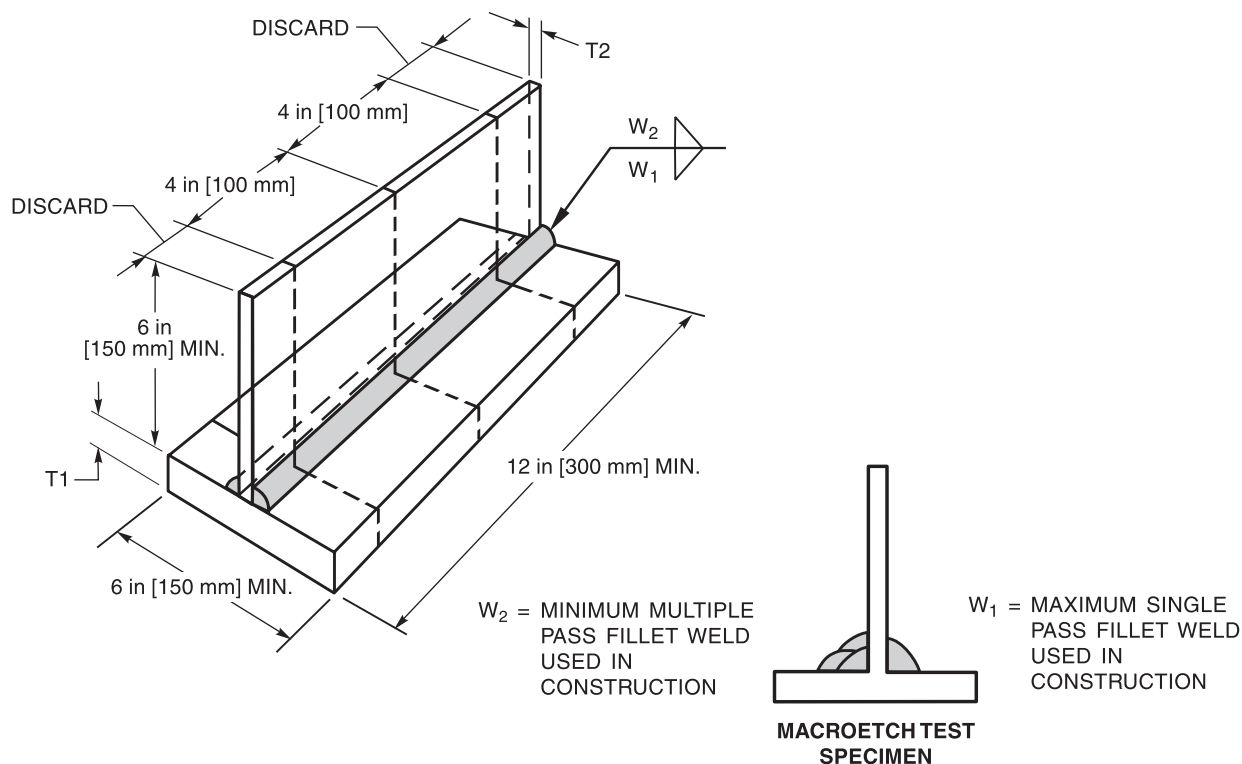
The test plate shall be welded as follows:

(1) The test plate shall have the groove configuration as shown in Figure 2, with backing of the same M-number listing of base metals as listed in B2.1.

(2) The plate shall be welded in the 1G position.

(3) The plate length shall be adequate to provide the test specimens as specified in Figure 2.

(4) The machine setting of amps, volts, travel speed, and gas flow shall approximately be the same as the settings used to make the production welds. Those settings establish the WPS that will be used to make production welds. Changes made to essential variables shall be as specified in Table 1.



INCHES			MILLIMETERS		
Weld Size	T1 min.	T2 min.	Weld Size	T1 min.	T2 min.
1/8	1/4	3/16	3	6	5
3/16	1/2	3/16	5	12	5
1/4	3/4	1/4	6	20	6
5/16	1	5/16	8	25	8
3/8	1	3/8	10	25	10
1/2	1	1/2	13	25	12
5/8	1	5/8	16	25	16
3/4	1	3/4	20	25	20
>3/4	1	1	>20	25	25

Note: Where the maximum plate thickness used in production is less than the value shown above, the maximum thickness of the production pieces may be substituted for T1 and T2.

Source: Adapted from AWS D1.1/D1.1M:2010, Figure 4.19.

Figure 1—Fillet Weld Soundness Test for Procedure Qualification

The test plate shall be tested as follows:

(1) Two side bend specimens as shown in Figure 2 and one all weld metal cylindrical specimen as shown in AWS B2.1/B2.1M, *Specification for Welding Procedure and Performance Qualification* (Figure B-3B, reduced section tension specimen—round), shall be removed from the test plate as shown in Figure 1.

(2) Two side bend specimens shall be tested and conform to the requirements of AWS B2.1/B2.1M, *Specification for Welding Procedure and Performance Qualification*.

(3) The tension test specimen shall be tested and conform to the requirements of AWS B2.1/B2.1M, *Specification for Welding Procedure and Performance Qualification*, or agreed to by the Engineer and Owner.

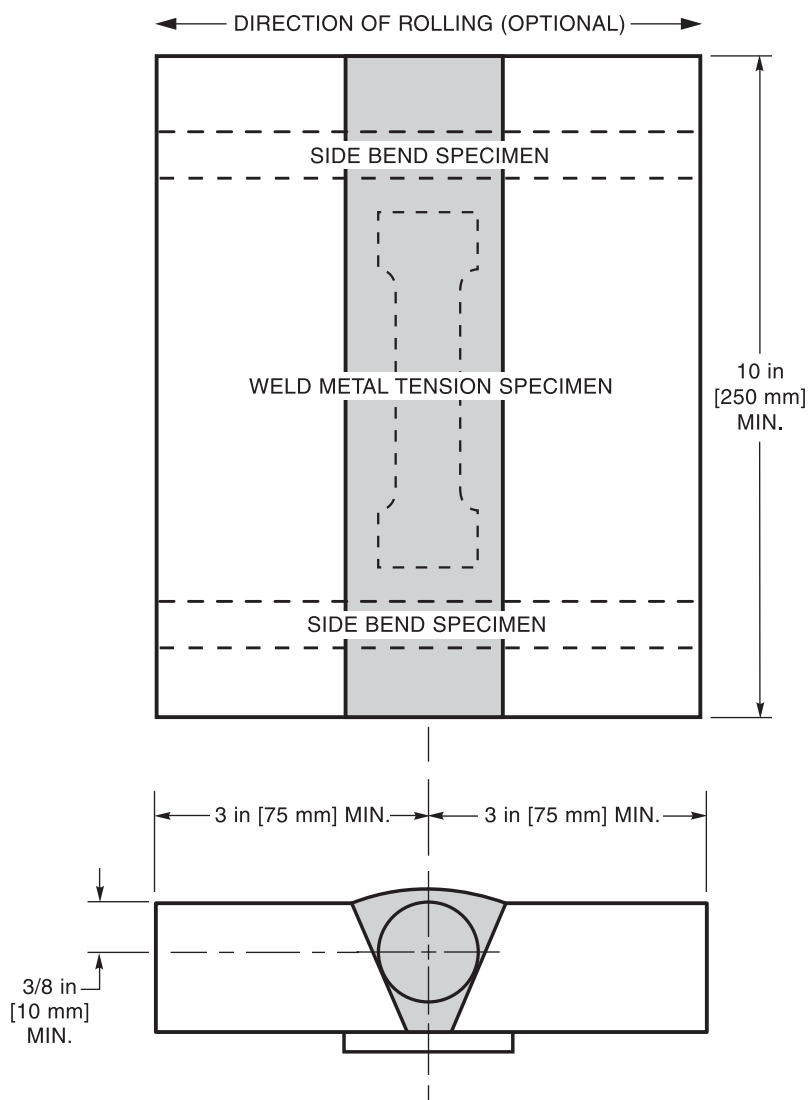


Figure 2—Location of Test Specimen on Welded Test Plate 1 in [25 mm] Thick—Consumables Verification for Fillet Weld WPS Qualification (see 6.5.5.2)

6.6 Preparation of Test Joint

6.6.1 Base Metal and Filler Metal. The base metals and filler metals shall be one or more of those listed in the WPS. The dimensions of the test assembly shall be sufficient to provide the required test specimens. The base metals may consist of plate, pipe, or other product forms. Qualification in plate also qualifies for pipe welding and vice versa.

6.6.2 Type and Dimension of Groove Welds. The test joint shall be welded using a type of welding groove proposed in the WPS within the limits noted in 6.7.1 for the essential joint design variables listed in Table 1.

6.6.3 Corrosion Resistant Overlay Cladding. Welding procedure qualification for corrosion resistance overlay cladding shall be as specified for cladding in [AWS B2.1/B2.1M](#), *Specification for Welding Procedure and Performance Qualification*.