

AWS D14.6/D14.6M:2012
An American National Standard

Specification for Welding of Rotating Elements of Equipment



AWS D14.6/D14.6M:2012
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

Clause Para. Variable			SMAW			SAW			FCAW			GMAW			GTAW			PAW			ESW			EGW			EBW		
			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			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					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 <u>in AWS Flux-Electrode Classification or Unlisted Flux-Electrode Classification</u>				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

Clause Para. Variable			SMAW			SAW			FCAW			GMAW			GTAW			PAW			ESW			EGW			EBW		
			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																				
	(20)	± Supplemental Filler Metal				X			X			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		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		X				
	(2)	Δ Temperature			X			X			X		X																
	(3)	> Maximum Preheat or Interpass Temperature from That Qualified		X			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		X				
	(2)	± Solution PWHT for M-8 Base Metal	X			X			X			X		X		X		X		X			X		X				
Gas																													
6.7.7	(1)	± Trailing, Chemical Composition, or both													X		X												
	(2)	Δ <u>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</u>							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

Clause Para. Variable			SMAW			SAW			FCAW			GMAW			GTAW			PAW			ESW			EGW			EBW		
			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			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			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	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			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.ihc.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.

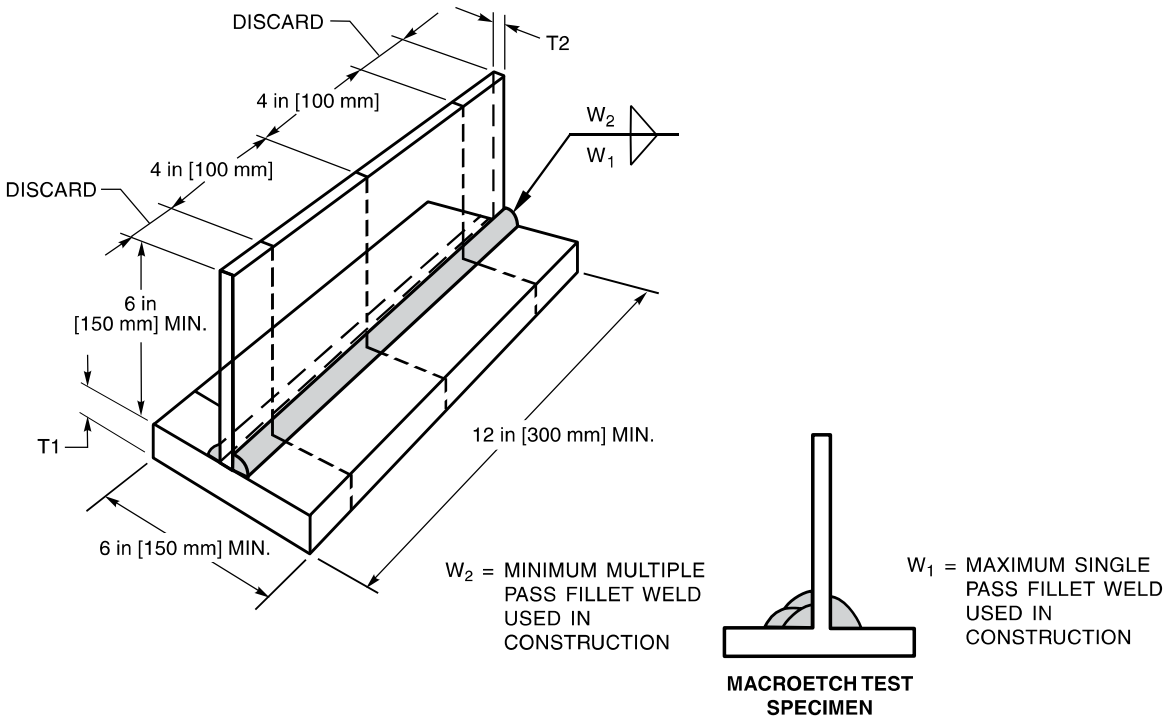
The test plate shall be welded as follows:

(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.

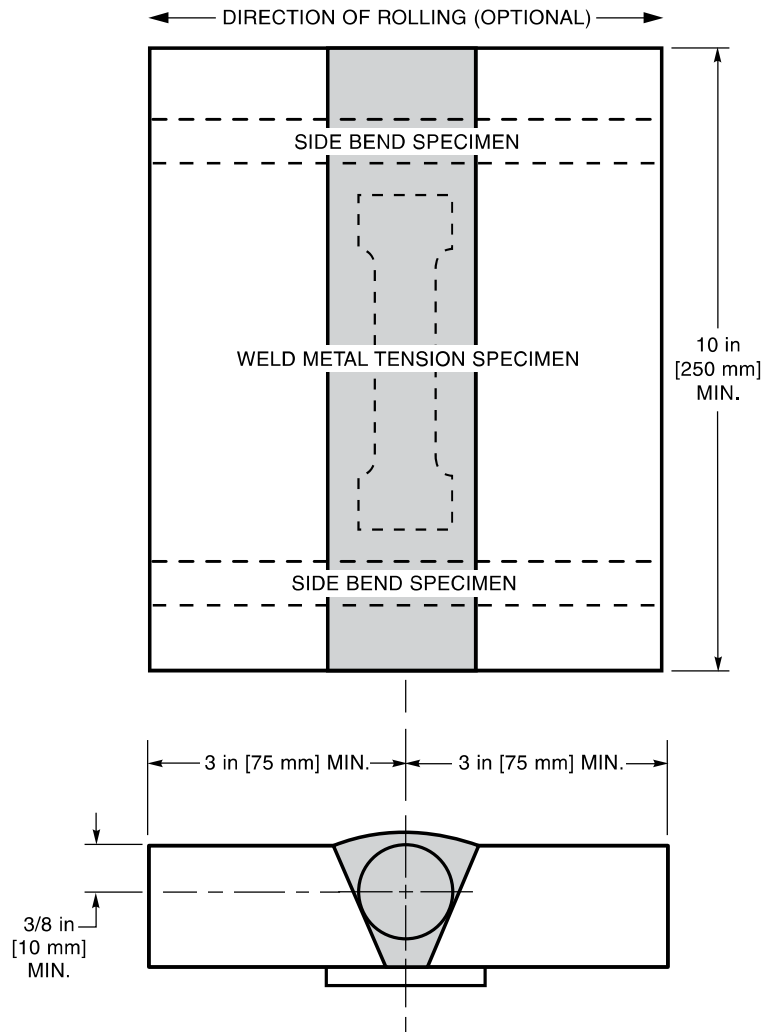


Figure 2—Location of Test Specimen on Welded Test Plate 1 in [25 mm] Thick—Consumables Verification for Fillet Weld WPS Qualification (see 6.5.5.2)

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*.

6.6.4 Electron Beam Welding. For electron beam welding, the WPS qualification test joint shall be prepared with the joint geometry duplicating the one to be used in production. If the production weld is to include a lapover (completing the weld by rewelding over the starting area of the weld, as for a girth weld) such lapover shall be included in the WPS qualification test joint. The mechanical testing outlined in AWS B2.1/B2.1M, *Specification for Welding Procedure and Performance Qualification*, shall apply for qualification testing.

Part C

Welding Process Variables

6.7 General. The welding process variables described in the following paragraphs are either essential to the PQR, supplementary to the PQR, or nonessential to the PQR, but are required to be stated in the WPS. The essential and nonessential variables for each welding process are tabulated in Table 1 (see 6.5.2).

6.7.1 Joints. When listed in Table 1 as an essential variable for the welding process used, the following changes require requalification:

- (1) A change in the dimension of the welding groove (regardless of groove type) exceeding the following:
 - (a) Root opening, with backing, +1/4 in –1/16 in [+6 mm –2 mm];
 - (b) Root face, +20% when backgouging is not used;
 - (c) Groove angle, +20°, –5°;
 - (d) Groove radius, +1/8 in [3 mm], –0.
- (2) The addition or deletion of backing.
- (3) The deletion of backing in complete joint penetration welds welded from one side.
- (4) The addition of backing and its nominal composition.
- (5) An increase in the fit-up gap beyond that initially qualified.

6.7.2 Base Metals. When listed in Table 1 as an essential variable for the welding process used, the following changes require requalification:

(1) Where the measurement of penetration can be made by visual or mechanical means, requalification is required where the base-metal thickness differs by 20% from that of the test-plate thickness when the test plate thickness is ≤ 1 in [25 mm], and 10% when the test-plate thickness is > 1 in [25 mm]. Where the measurement of penetration cannot be made, requalification is required where the base-metal thickness differs by 10% from that of the test plate when the test plate thickness is ≤ 1 in [25 mm], and 5% when the test plate thickness is > 1 in [25 mm].

(2) Welding procedure qualification for base metals that have specified impact test requirements shall be made using a base metal of the same type or grade or another base metal listed in the same group (see AWS B2.1/B2.1M, *Specification for Welding Procedure and Performance Qualification*) as the base metal to be used in production welding. When joints are to be made between base metals from two different groups, a procedure qualification must be made for the applicable combination of base metals, even though procedure qualification tests have been made for each of the two base metals welded to them. If the procedure qualification test for each base metal has used the same electrode or weld metal to qualify the two base metals separately, it will not be necessary to make weld impact tests to qualify the two together.

When a procedure has been previously qualified to satisfy all requirements other than notch toughness, it is then necessary only to prepare an additional test plate for that requirement. The test plates need to be long enough to provide the necessary notch toughness specimens. If a previously qualified weld procedure has satisfactory notch toughness values in the weld metal, then it is necessary only to test notch toughness specimens from the heat-affected zone (HAZ).

(3) The minimum base metal thickness qualified is the thickness (t) of the test coupon or 5/8 in [16 mm], whichever is less. This limitation does not apply when a WPS is qualified with a PWHT above the upper transformation temperature or when an austenitic material is solution annealed after welding.

(4) A change in base-metal thickness beyond the range qualified in AWS B2.1/B2.1M, *Specification for Welding Procedure and Performance Qualification*.

(5) For single or multiple-pass welding in which the depth of any pass is greater than 1/2 in [13 mm], an increase in thickness beyond 1.1 times that of the qualification test plate or pipe.

(6) For the short-circuiting transfer mode of the GMAW process where the qualification test coupon thickness is less than 1/2 in [13 mm], an increase in thickness beyond 1.1 times that of the qualification test coupon (for thicknesses of 1/2 in [13 mm] and greater, see AWS B2.1/B2.1M, *Specification for Welding Procedure and Performance Qualification*).

(7) A change from a base metal listed under one M-number to a base metal listed under another M-number. When joints are made between two base metals that have different M-numbers, requalification is required even though the two base metals have been independently qualified using the same procedure. However, for base metals of M-numbers 1, 3, 4, and 5 (of 3% maximum nominal chromium content), a procedure qualification test with one M-number metal shall qualify also for that M-number metal welded to each of the lower M-number metals, but not vice versa.

(8) A change from M-9A to M-9B, but not vice versa.

6.7.3 Electrodes, Filler Metals and Fluxes. When listed in Table 1 as an essential variable for the welding process used, the following changes require requalification:

(1) A change in the cross-sectional area of the filler metal added (excluding buttering) or in the wire feed speed greater than $\pm 10\%$ beyond that qualified.

(2) A decrease in the thickness or change in nominal specified chemical analysis of weld-metal buttering beyond that qualified.

(3) A change in the diameter of the filler metal.

(4) A change from one F-number listed in AWS B2.1/B2.1M, *Specification for Welding Procedure and Performance Qualification* to any other F-number or to any other filler metal not listed in AWS B2.1/B2.1M, *Specification for Welding Procedure and Performance Qualification*, except qualification under any F-number up to and including F-4. Qualification with an F-2X aluminum filler metal shall qualify to weld with any other F-2X filler metal.

(5) A change in the chemical composition of the weld deposit from one A-number to any other A-number in Table 3 or to a deposit analysis not listed in Table 3, except that qualification with A-1 shall qualify for A-2, and vice versa. Filler metals not listed in the Filler Metal Grouping Annex of AWS B2.1/B2.1M, *Specification for Welding Procedure and Performance Qualification*, can be used following the guidelines of 6.5.5.5.

(6) An increase in electrode and filler metal diameter is allowed without a new procedure qualification as shown below:

(a) for SMAW and SAW: $>1/32$ in [1 mm] increase

(b) for FCAW, GMAW, ESW, and EGW: range of increase = 0.010 in to 0.016 in [0.25 mm to 0.4 mm] or one increment, depending on size being used.

(7) Addition, deletion, or changes in nominal amount or composition of supplementary deoxidation material (in addition to filler metal) beyond that qualified. (Such supplementary material may be required for weld metal deoxidation for some metals being welded.)

(8) A change from one flux (acid, basic, and neutral) listed in a specification to any other flux (acid, basic, and neutral). In addition, a change in either the electrode or the flux when not classified in a specification. The presence or absence of 0.5% molybdenum in the electrode and flux combination shall not require requalification.

(9) Where the alloy content of the weld metal is largely dependent upon the composition of the flux used, any change in any part of the welding procedure that would result in the important alloying elements in the weld metal being outside of the specification range of chemistry given in the welding procedure specification. If there is evidence that the production welds are not being made in conformance to the welding procedure specification (WPS), the Buyer's Inspector may require that a check be made on the chemical composition of the weld metal. Such a check shall preferably be made on a production weld.

(10) A change in the size of flux particles.

(11) A change in the AWS filler metal classification or a change in a weld metal or filler metal composition not covered by AWS specifications.

(12) The addition or deletion of consumable inserts. When added, a change in the consumable insert's composition beyond that specified in the qualified WPS. Qualification in a single-welded groove joint, with or without consumable inserts, qualifies for fillet welds and single-welded groove joints with backing or double-welded groove joints.

(13) The addition or deletion of filler metal.

(14) A change in the type of flux or composition of the flux.

(15) A change from wire to strip electrodes, and vice versa.

(16) A change from consumable guide to nonconsumable guide, and vice versa.

(17) Any change in the method by which filler metal is added, such as preplaced shim, top strip, wire, wire feed, or prior weld metal buttering of one or both joint faces.

(18) For filler metal additions, any change from the nominal specified analysis of the filler metal qualified.

(19) A change from gas-shielded flux cored wire to self-shielded flux cored wire, and vice versa.

(20) The addition or deletion of supplemental filler metal.

(21) The addition or deletion of supplementary powdered filler metal.

(22) An increase in the amount of supplementary powdered filler metal.

(23) Where the alloy content of the weld metal is largely dependent upon the composition of the supplemental powdered filler metal, any change in any part of the welding procedure that would result in the important alloying elements in the weld metal being outside of the specification range of chemistry given in the welding procedure specification.

6.7.4 Welding Positions. The production welding positions qualified by a WPS shall conform to the requirements of Table 2. Welding positions qualified by performance tests are shown in AWS B2.1/B2.1M, *Specification for Welding Procedure and Performance Qualification*.

(1) The production welding position qualified by the WPS and PQR shall conform to the requirements of Table 2.

(2) A change from any position to the vertical position uphill progression. In uphill progression, a change from stringer bead to a weave bead it requires requalification. This limitation does not apply when a WPS is qualified with PWHT above the upper transformation temperature or when an austenitic material is solution annealed after welding.

6.7.5 Preheat. When listed in Table 1 as an essential variable for the welding process used, the following changes require requalification:

(1) A decrease of 100°F [55°C] or more and shall follow the guidelines of 7.7 in the minimum specified preheat temperature from that qualified.

(2) A decrease in the temperature maintenance more than 50°F [10°C].

(3) An increase of more than 100°F [55°C] in the maximum interpass temperature recorded on the PQR. This limitation does not apply when a WPS is qualified with a PWHT above the upper transformation temperature or when an austenitic material is solution annealed after welding.

Table 2
Procedure Qualification—Production Welding Positions Qualified by Plate and Pipe Tests

Qualification Test			Type of Weld and Position of Welding Qualified ^a					
			Production Plate			Production Pipe		
			Groove			Groove		
			Fillet			Fillet		
Plate or Pipe	Weld Type	Positions ^b	CJP ^c	PJP ^c	Fillet	CJP ^c	PJP ^c	Fillet
Plate	Groove—Complete Joint Penetration (CJP)	1G	F	F	F	F	F	F
		2G	F, H	F, H	F, H	F, H	F, H	F, H
		3G	V	V	V	V	V	V
		4G	OH	OH	OH	OH	OH	OH
	Fillet	1F			F			F
		2F			F, H			F, H
		3F			V			V
		4F			OH			OH
	Groove—Complete Joint Penetration (CJP)	1G Rotated	F	F	F	F	F	F
		2G	F, H	F, H	F, H	F, H	F, H	F, H
		5G	F, V, OH	F, V, OH	F, V, OH	F, V, OH	F, V, OH	F, V, OH
		2G & 5G	All	All	All	All	All	All
		6G	All	All	All	All	All	All
		6GR	All	All	All	All	All	All
Pipe	Fillet	1F Rotated			F			F
		2F			F, H			F, H
		2F Rotated			F, H			F, H
		4F			F, H, OH			F, H, OH
		5F			All			All

^a Positions for welding: F = flat, H = horizontal, V = vertical, OH = overhead.

^b See Figures 2, 3, 5(A), and 5(B).

^c CJP = Complete Joint Penetration; PJP = Partial Joint Penetration.

Source: Adapted from AWS D1.1/D1.1M:2004, Table 4.1.

6.7.6 Postweld Heat Treatment. When listed in Table 1 as an essential variable for the welding process used, the following changes require requalification:

(1) A change in the specified postweld heat treatment temperature range requires WPS qualification for each of the following conditions:

- (a) Where no postweld heat treatment is used.
- (b) Where postweld heat treatment is used (which is defined as below the critical range).
- (c) Where a heat treatment of the weldment is applied above the upper critical range without additional postweld heat treatment.
- (d) Where a heat treatment of the weldment is applied above the upper transformation temperature range with additional postweld heat treatment.

(2) For M-8 base metal, the addition or deletion of a solution or stabilizing heat treatment.

6.7.7 Gas. When listed in Table 1 as an essential variable for the welding process used, the following changes require requalification:

- (1) The deletion of trailing shielding gas or a change in the composition, or both.

(2) A change from a single gas to any other single gas or a mixture of gases, or a change in specified percentage composition of a gas mixture, or deletion of shielding gas. The AWS classification of A5.32 shall be used to specify the shielding gas composition.

(3) A decrease of more than 10% or an increase greater than 25% in the rate of flow of the shielding gas or mixture. The rate of shielding gas flow specified in the WPS qualification may not be satisfactory in all applications unless the welding area on the weldment is properly and adequately protected from atmospheric disturbances.

(4) A change in composition and flow rates of orifice gas or shielding gas.

(5) The addition or deletion of gas backing, or a change of the gas backing flow rate or composition.

(6) Any change of environment such as from a vacuum to an inert gas, or vice versa.

6.7.8 Electrical Characteristics. When listed in Table 1 as an essential variable for the welding process used, the following changes require requalification:

(1) A change in the type of current or polarity or an increase in heat input.

(2) A change from spray transfer, globular transfer, or pulsed spray welding to short circuiting transfer, or vice versa.

(3) The addition or deletion of pulsed dc current.

(4) A change of $\pm 15\%$ from the current or voltage ranges qualified.

(5) A change in the beam current of more than $\pm 5\%$, or voltage of more than $\pm 2\%$, or beam focus current of more than $\pm 5\%$, or gun-to-work distance of more than $\pm 5\%$, or a change in oscillation length or width of more than $\pm 20\%$ from those values previously qualified.

(6) Any change in the beam pulsing frequency duration from that qualified.

(7) A change in the type of current or polarity.

6.7.9 Technique. When listed in Table 1 as an essential variable for the welding process used, the following changes require requalification:

(1) A change from the stringer bead technique to the weave bead technique, or vice versa.

(2) A change in the method of backgouging.

(3) A change in the width, frequency, or dwell time of oscillation.

(4) A change from multiple pass per side to single pass per side.

(5) A change from single electrode to multiple electrodes, or vice versa.

(6) A change from closed chamber to out-of-chamber conventional torch welding in M-5X metals, but not vice versa.

(7) A change from the melt-in technique to the keyhole technique of welding, or vice versa, or the inclusion of both techniques, though each has been individually qualified.

(8) The addition or deletion of nonmetallic retainers or nonfusing metal retainers.

(9) A change in the gun angle (axis of the beam).

(10) A change in the electrode spacing.

(11) A change from upward to downward, or from downward to upward, in the progression specified for any pass of a vertical weld, except that the cover or wash pass may be up or down. The root pass may also be run either up or down when the root pass is removed to sound weld metal in the preparation for welding the second side.

(12) A change in the type or model of the welding equipment.

(13) An increase in the absolute pressure of the vacuum welding environment beyond that qualified.

(14) Any change in filament type, size, or shape.

(15) The addition of a smoothing pass.

(16) A change of welding from one side to welding from both sides, or vice versa.

6.8 Special Processes

6.8.1 Corrosion Resistant Weld Metal Overlay. Welding procedure specifications (WPSs) qualified for corrosion resistant overlay welding in conformance to 6.6.3 shall be required to identify the essential variables listed in this clause. Any change in the qualified essential variables shall require requalification.

6.8.1.1 Essential Variables—All Welding Processes. For all welding processes, the WPS shall be set up as a new WPS and shall be completely requalified for any of the following changes:

- (1) A change from one welding process to any other welding process or combination of welding processes.
- (2) A change from the base metal listed under one M-number in AWS B2.1/B2.1M, *Specification for Welding Procedure and Performance Qualification*, to a metal listed under another M-number or to any other base metal group.
- (3) A change in the composition of the deposited weld metal from one A-number in Table 3 to any other A-number or to an analysis not listed in the table. Each American Iron Steel Institute (AISI) material of an A-8 or A-9 analysis (e.g., type 308, 309, 316) of Table 3, and each nonferrous alloy in AWS B2.1/B2.1M, *Specification for Welding Procedure and Performance Qualification*, shall require separate WPS qualification.
- (4) The addition of welding positions other than those already qualified.
- (5) An increase or decrease of 100°F [55°C] or more in the minimum specified preheat temperature, or a change in the specified minimum or maximum interpass temperature.
- (6) A change in the specified postweld heat treatment temperature, or an increase of 25% or more in the total time at postweld heat-treating temperature.
- (7) A change from multiple-layer to single-layer cladding, or vice versa.
- (8) A change in type of current (AC or DC) or polarity.

6.8.1.2 Essential Variables—Shielded Metal Arc Welding. For SMAW, the WPS shall be set up as a new WPS and shall be completely requalified when any of the following changes are made in addition to the essential variables given in 6.8.1.1:

- (1) A change in the nominal electrode diameter used for the first layer of deposit.
- (2) An increase of more than 10% in the current used in application for the first layer.

Table 3
A-Number Classification of Weld Metal Analysis for Procedure Qualification

A-No.	Types of Weld Deposit	Analysis ^a					
		C %	Cr %	Mo %	Ni %	Mn %	Si %
1	Mild Steel	0.20				1.60	1.00
2	Carbon-molybdenum	0.15	0.50	0.40–0.65		1.60	1.00
3	Cr (0.4% to 2%)-Mo	0.15	0.40–2.00	0.40–0.65		1.60	1.00
4	Cr (2% to 6%)-Mo	0.15	2.00–6.00	0.40–1.50		1.60	2.00
5	Cr (6% to 10.5%)-Mo	0.15	6.00–10.50	0.40–1.50		1.20	2.00
6	Chromium-martensitic	0.15	11.00–15.00	0.70		2.00	1.00
7	Chromium-ferritic	0.15	11.00–30.00	1.00		1.00	3.00
8	Chromium-nickel	0.15	14.50–30.00	4.00	7.50–15.00	2.50	1.00
9	Chromium-nickel	0.30	25.00–30.00	4.00	15.00–37.00	2.50	1.00
10	Nickel to 4%	0.15	1.50	0.55	0.80–4.00	1.70	1.00
11	Manganese-molybdenum	0.17		0.25–0.75	0.85	1.25–2.25	1.00
12	Nickel-chromium-molybdenum	0.15		0.25–0.80	1.25–2.80	0.75–2.25	1.00

^a Values in wt %. Single values shown are maximums.

6.8.1.3 Essential Variables—Submerged Arc Welding, Gas Metal Arc Welding, Flux Core Arc Welding, or Gas Tungsten Arc Welding. For SAW, GMAW, FCAW, or GTAW, the WPS shall be set up as a new WPS and shall be completely requalified when any of the following changes are made in addition to the essential variables given in 6.8.1.1:

- (1) For SAW, a change in the trade designation or type of flux used. Requalification is not required for a change in flux particle size.
- (2) A change from single-electrode to multiple-electrode techniques, or vice versa. A multiple-electrode process is defined as one in which two or more welding electrodes are acting on the same molten weld pool.
- (3) The addition or deletion of supplementary filler metal to the welding arc.
- (4) The addition or deletion of oscillation of the electrode or electrodes.
- (5) A change in the cross-sectional area of the electrodes or supplementary filler metal.
- (6) An increase of more than 10% in the welding current beyond the range specified.
- (7) A change in the voltage beyond the range specified.
- (8) A variation of more than 10% in travel speed.
- (9) In GMAW, FCAW, and GTAW, a change from a single gas to any other single gas or to a mixture of gases, or vice versa; a change in the specified percentage composition of a gas mixture; a decrease of 10% or more in the rate of flow of shielding gas or gas mixture.

6.8.1.4 Nonessential Variables. Changes other than those given in 6.8.1.1 through 6.8.1.3 may be made in a procedure without the necessity for requalification, provided the procedure specification is amended to show the changes.

Part D

Performance Qualification

6.9 Performance Qualification Tests. Each Manufacturer, Fabricator, Repair Organization, or Contractor shall qualify each welder or welding operator for each welding process to be used by that individual in production. Refer to Part A—General Requirements, 6.1 Scope, for welder and welding operator qualifications.

6.10 Essential Variables for Qualifying Welders and Welding Operators

6.10.1 General. When a welding procedure consists of more than one process, the welder or welding operator may be qualified by making tests with each individual welding process or with a combination of welding processes in a single test plate or pipe.

The limits of thickness for which a welder or welding operator will be qualified are dependent upon the thickness of the weld made by the welder with each process. This thickness shall be considered the test plate or pipe thickness as given in Table 4.

6.10.2 Failure to Meet Radiographic Standards. If a portion of a production weld, for which this specification does not require radiography, is selected for testing the welding operator's performance and does not meet the radiographic standards, the welding operator has failed the test. In this event, the entire production weld made by this welding operator shall be radiographed and repaired by a qualified welder or welding operator.

6.11 Qualification Test Joints

6.11.1 Test Assemblies. The test assemblies may be plate, pipe, or other product forms (see Table 4).

6.11.2 Pipe Joint Size. Welders and welding operators qualifying using pipe shall use a pipe of the diameter and thickness that meets the requirements of the production work they will be welding, as identified by the requirements of Table 4.

6.11.3 Plate Joint Size. Welders and welding operators who are qualifying shall use a plate thickness that meets the production requirements for the work they will be welding in accordance with the requirements of Table 4.

Table 4
Test Specimens for Performance Qualification of Welders and Welding Operators

Plate Transverse Bend Tests^a								
Type of Weld	Thickness (t) of Test Plate, As-Welded Condition, in [mm]	Thickness Range of Materials Qualified by Test Plate, in [mm]		Type and Number of Tests Required (Guided Bend Tests)			T-Joint Macro	T-Joint Break
		Min.	Max.	Side Bend	Face Bend	Root Bend		
Groove	≥ 1/16 [2] to ≤ 3/8 [10]	1/16 [2]	2t		1	1		
Groove	> 3/8 [10] to < 3/4 [20]	3/16 [5]	2t		1	1		
Groove	> 3/8 [10] to < 3/4 [20]	3/16 [5]	2t	Note b				
Groove	≥ 3/4 [20]	3/16 [5]	Unlimited ^c	2				
T-Joint Fillet Weld Tests^a								
Fillet	All thicknesses, sizes, and diameters						1	1
Plate Longitudinal Bend Tests^a								
Type of Weld	Thickness (t) of Test Plate, As-Welded Condition, in [mm]	Thickness Range of Materials Qualified by Test Plate, in [mm]		Type and Number of Tests Required (Guided Bend Tests)				
		Min.	Max.		Face Bend	Root Bend		
Groove	≥ 1/16 [2] to ≤ 3/8 [10]	1/16 [2]	2t		1	1		
Groove	> 3/8 [10]	3/16 [5]	2t		1	1		
Pipe Groove Weld Bend Tests								
Nominal Pipe Size of Sample Weld, in [mm]	Outside Diameter Qualified, in [mm] (No Maximum)	Pipe or Tube Wall Thickness Range Qualified, in [mm]		Type and Number of Tests Required (Guided Bend Tests)				
		Min.	Max.	Side Bend	Face Bend	Root Bend		
< 3/4 [20]	Minimum of lot less than size welded	1/16 [2]	2t		2	2		
≥ 3/4 [20] to ≤ 2 [50]	≥ 7/8 [22]	1/16 [2]	2t	Note b	2	2		
> 2 [50] for t ≥ 1/16 [2] to < 3/4 [20]	≥ 2-1/8 [54]	1/16 [2]	2t	Note b	2	2		
> 2 [50] for t ≥ 3/4 [20]	≥ 2-3/8 [60]	3/16 [5]	Unlimited ^c	4				

^a Either transverse or longitudinal bend tests may be used, but both are not required.

^b Side bend tests may be substituted for the required face and root bend tests for material thicknesses ≥ 3/8 in [10 mm] to < 3/4 in [20 mm].

^c Unlimited thickness is based on thickness unit of the qualified weld procedure.

7. Fabrication Requirements

7.1 General

7.1.1 All applicable paragraphs of this clause shall be observed in the production and inspection of welded assemblies and structures produced by any of the processes acceptable under this specification.

7.1.2 All items of equipment for welding, oxygen cutting, and arc gouging shall be so designed and manufactured and be in such condition as to enable qualified welders and welding operators to follow the procedures and attain the results prescribed elsewhere in this specification.

7.1.3 Welding shall not be done when the ambient temperature is lower than 0°F [−20°C], when surfaces are wet or exposed to rain, snow, or high wind, or when welders are exposed to inclement weather conditions. Unless specified otherwise herein, the minimum base-metal temperature for welding shall be 50°F [10°C]. Local protection and heating may be used to correct these conditions.

7.1.4 Welds shall be as specified by design requirements and detailed drawings. The location of welds shall not be changed without design engineering approval and drawing revisions.

7.1.5 Production welding shall be accomplished using a welding procedure specification (WPS) qualified in conformance to Clause 6, Part B of this document.

7.1.6 Welders or welding operators performing production welding shall be qualified in conformance to Clause 6, Part D of this document.

7.1.7 Welds requiring a combination of processes may be performed by one or more welders or welding operators. Welders or welding operators may perform only that portion of the weld for which they have been qualified.

7.2 Preparation of Base Metal

7.2.1 Surfaces and edges to be welded shall be smooth, uniform, and free from fins, tears, cracks, and other discontinuities that would adversely affect the quality or strength of the weld. Surfaces to be welded shall also be free from moisture, loose or thick scale, slag, rust, grease, or other foreign material that will interfere with producing sound welds.

7.2.2 Surfaces within 1/2 in [13 mm] of any weld location shall be free from any paint or other material that would prevent proper welding.

7.2.3 Machining, air carbon arc or oxygen cutting or gouging, plasma arc cutting, chipping, or grinding may be used for the preparation of base metal, backgouging, or the removal of defective welds or metal. Oxygen gouging shall not be used on quenched and tempered steel. When oxygen, air carbon arc, or plasma arc cutting is employed, all scale, slag, gouges, or other irregularities on the surface shall be removed by mechanical means. Thermally cut or gouged surfaces of M-8 base metal shall be ground to bright metal. All re-entrant corners shall be free from sharp notches.

7.2.4 The type of material used for backing straps, rings, and spacer blocks shall be as specified in the design drawings or approved welding procedure.

7.3 Assembly

7.3.1 The parts to be joined by fillet welds shall be brought into contact as close as practicable. The root opening shall not exceed 3/16 in [5 mm] except when the geometry of the joint will not allow the root opening to be closed sufficiently to meet this tolerance. In such cases a maximum root opening of 5/16 in [8 mm] may be used provided suitable backing is used. Backing may be of flux, glass tape, iron powder, or similar suitable material. Backing may also be produced by the deposition of weld beads on the edge of the mating member using a qualified welding procedure specification compatible with the weld procedure used to make the final fillet weld. If the root opening is greater than 1/16 in [2 mm], the leg of the fillet weld shall be increased by the amount of the root opening or the Contractor shall demonstrate that the effective throat depth has been attained. The separation between faying surfaces of lap joints shall not exceed 1/16 in [2 mm]. The separation between the underside of butt joints and the face of the backing bar shall not exceed 1/16 in [2 mm].⁹

⁹ See AWS D1.1/D1.1M:2004, *Structural Welding Code—Steel*, 5.22, page 187.

7.3.2 Dimensions of the cross section of groove welded joints shall not vary from those shown on the detail drawings by more than the following workmanship tolerances:

- (1) Root face of joint, $+0, -1/16$ in [2 mm]
- (2) Root opening of joints without steel backing, $\pm 1/16$ in [2 mm]
- (3) Root opening of joints with steel backing, $+1/8$ [3 mm], $-1/16$ in [2 mm]
- (4) Groove angle of joint, $+10^\circ, -5^\circ$

7.3.3 Root openings wider than those permitted by the above tolerances, but not greater than twice the thickness of the thinner part or $1/2$ in [13 mm], whichever is less, may be built up to acceptable dimensions using a qualified welding procedure specification prior to the joining of the parts.

7.3.4 Complete joint penetration welding procedures, in which the joint is welded from both sides, shall require either backgouging of the underside of the root pass before welding the second side, or demonstration by actual welding tests that backgouging may be omitted without detriment to the joint. Backgouging shall require removal of the backside of the joint to sound metal.

7.3.5 Each weld pass shall be thoroughly cleaned using slag hammers, grinding wheels, rotary burrs, or wire brushes, as required. Pneumatic chippers may be used, provided they do not peen or distort the weld.

7.3.6 Preheating and interpass temperature control shall be such as to ensure that the full thickness of the weld joint and the adjacent weld metal are at the temperature specified by the welding procedure.

7.3.7 Tack Welds

7.3.7.1 Tack welds and temporary welds shall be made with filler materials meeting the same requirements as the final welds. Multiple-pass tack welds shall have cascaded ends.

7.3.7.2 Tack welds and temporary welds shall be deposited by qualified welders. Tack welds to be incorporated in the final weld shall be deposited using a qualified welding procedure. Tack welds not incorporated in a final weld and temporary welds shall be removed when required by the contract specification. When they are removed, the surface shall be made flush with the original surface.

7.4 Weld Surface Conditions

7.4.1 The faces of fillet welds may be slightly convex, flat, or slightly concave as shown in Figures 3(A), 3(B), and 3(C), but shall have no discontinuities such as shown in Figure 3(D). Except at outside corner joints, the convexity shall not exceed the value of $0.1S + 0.03$ in [0.8 mm] where S is the actual size of the fillet weld in inches or millimeters [see Figures 3(B) and 3(C)].

7.4.2 Groove welds shall preferably be made with slight or minimum reinforcement, except as may be otherwise specified. In the case of the butt and corner joints, the reinforcement shall not exceed $1/8$ in [3 mm] in height and shall have gradual transition to the plane of the base-metal surface [see Figure 3(E)]. Groove welds shall be free of discontinuities as shown for butt joints in Figure 3(F).

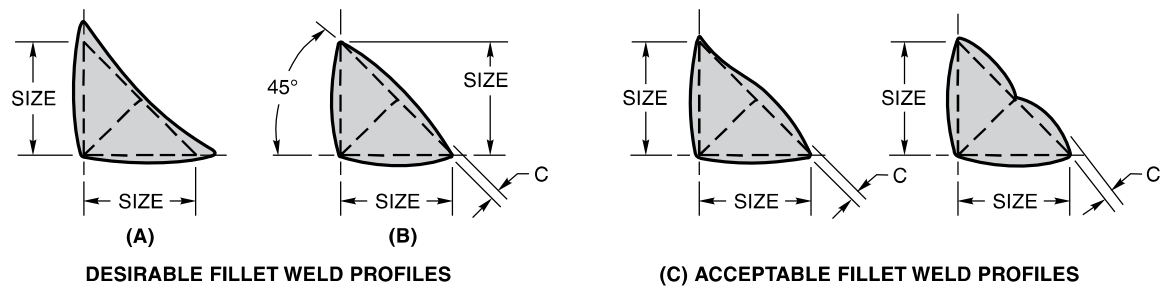
7.4.3 Surfaces of butt joints required to be flush shall be finished so as not to reduce the thickness of the thinner base metal or weld metal by more than $1/32$ in [1 mm], or leave reinforcement that exceeds $1/8$ in [3 mm]. However, all reinforcement must be removed where the weld forms part of the faying or contact surfaces. Any reinforcement must blend smoothly into the plate surfaces.

7.4.4 Undercut, regardless of depth, shall not occur within 3 in [75 mm] of the end of any joint and shall be no more than $1/32$ in [1 mm] in depth elsewhere in the joint. Continuous length of undercut shall be no more than 6 in [150 mm].

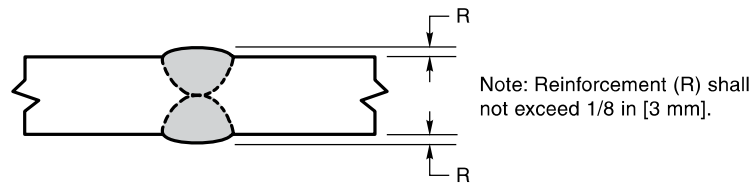
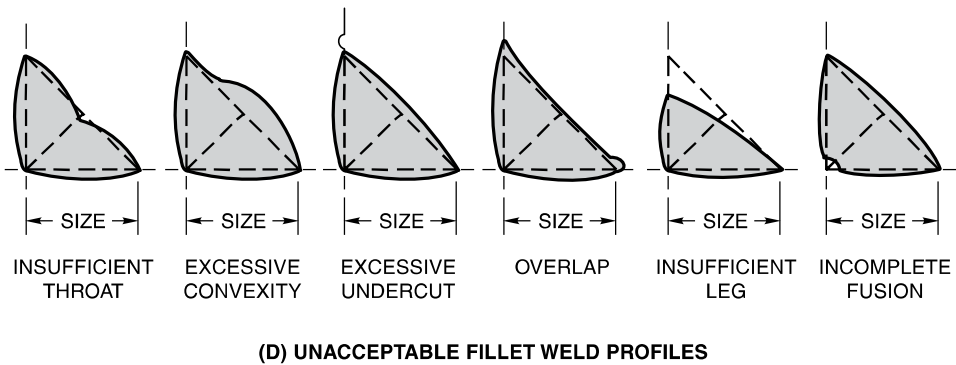
7.4.5 Welds shall be free from cracks, incomplete fusion, and other discontinuities shown in Figure 3.

7.4.6 Where surface finishing of a weld is required, its value should not exceed $500 \mu\text{in}$ [12.5 μm] (reference ASME B46.1, *Surface Texture*).

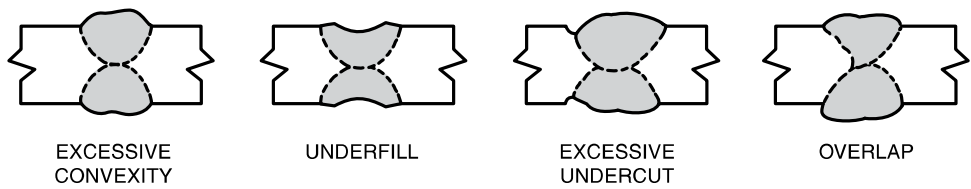
7.4.7 The frequency of visible porosity in fillet welds shall not exceed one pore of $3/32$ in [2.5 mm] maximum diameter in each 4 in [100 mm] of length. Groove welds shall have no visible porosity.



Note: Convexity (C) shall not exceed 0.1 times the actual leg size (or the length of the longer of the two legs if they are unequal) plus 1/32 in [1 mm].



Note: Reinforcement (R) shall not exceed 1/8 in [3 mm].



Note: A fillet weld shall be permitted to be 1/16 in [2 mm] less than the specified nominal fillet size for welds 3/8 in [10 mm] or larger. For fillet weld sizes less than 3/8 in [10 mm], the undersize portion should not exceed 10% of the length of the weld.

Weld Size in [mm]	Tolerances in [mm]
< 3/8 [10]	-1/32 [1] +1/16 [2]
≥ 3/8 [10]	-1/16 [2] +1/16 [2]

Figure 3—Acceptable and Unacceptable Weld Profiles

7.4.8 All welds, welding procedures, and performance qualifications shall conform to the requirements in the applicable paragraphs of Clause 8.

7.5 Corrections. All corrections shall be done in conformance to Clause 9, Modification and Repair.

7.6 Peening. Shot and mechanical peening provide for improved fatigue life in the weld joint as a result of the surface material being placed in compression.^{10, 11, 12} Mechanical peening can be applied to intermediate weld passes to reduce residual stresses, cracking, and distortion. All peening shall be done using an approved written procedure.

7.6.1 Controlled Shot Peening. Controlled shot peening may be used on external surfaces to improve fatigue life. Controlled shot peening procedures shall include Almen intensity, shot size, pressure, and percent coverage. (See SAE AMS-S-13165, *Shot Peening of Metal Parts*.)

7.6.2 Hammer Peening. Hammer peening may be used on external surfaces to improve fatigue life. Peening should be controlled to prevent introducing stress concentrations to, or cracking of, the weld or base metal. Controlled air hammer peening procedures shall specify hammer size, peening tool radius, air pressure, and extent and density of coverage (see 7.6.4).

7.6.3 Peening Applications

- (1) No peening shall be done on the root pass.
- (2) Hammer or needle peening may be used on intermediate weld layers for control of shrinkage stresses in thick welds to prevent cracking.
- (3) Peening of the surface layer of the weld and the base metal at the edges of the weld is permitted for fatigue life improvement. Under controlled conditions, both shot and mechanical peening places the exposed material in compression which reduces residual tensile stresses at the weld surface, the toe of the weld, and the base metal adjacent to the weld.
- (4) All slag shall be removed prior to peening. The use of manual slag hammers, chisels, and lightweight tools such as needle descaling guns for the removal of slag and spatter is permitted, but is not considered peening.

7.6.4 Specification for Pneumatic Hammer Peening for Fatigue Life Improvement. Peening of weld toes may be performed with the use of a small pneumatic hammer (Ingersoll #2 or equivalent) and peening tool as shown in Figure 4(A). All welds shall pass the required NDT examination prior to peening, followed by a second required NDT examination after peening.

The peening tool shall be made from a chisel or other tool designed for the pneumatic hammer. The tool tip shall conform to the dimensions shown in Figure 4(A). All sharp edges and burrs shall be removed and the tool shape maintained in this geometric shape and condition.

Best peening results will be obtained by operating the pneumatic hammer at approximately 25 psi [1.7 bar] air pressure. The axis of the hammer shall be perpendicular to the longitudinal axis of the weld toe and inclined 60° to 70° above the weld toe plane as shown in Figure 4(B). Peening is done by slowly moving the peening tool of an operating hammer along the weld toe. Peening shall continue until the weld toe becomes smooth (absence of weld ripples), approximately three to four passes at 30 inches per minute [760 mm/min.]. The depth of indentation due to peening should be approximately 1/32 in to 1/16 in [1 mm to 2 mm].

7.7 Postweld Heat Treatment (PWHT)

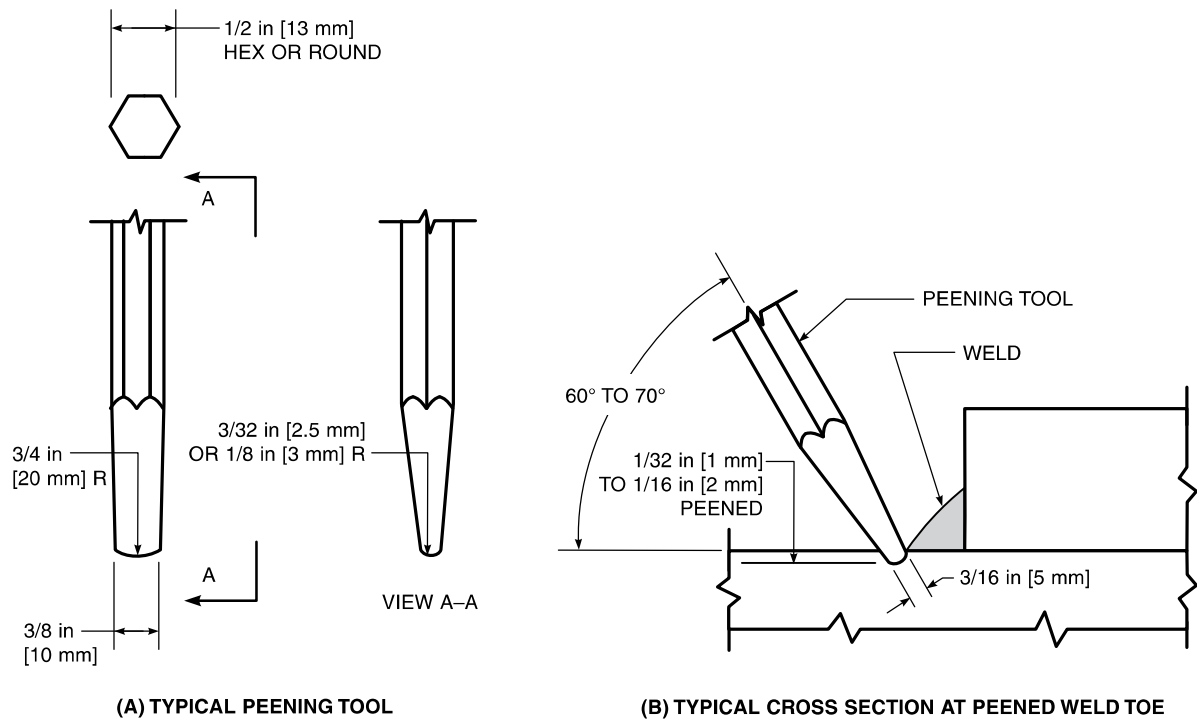
7.7.1 For the heat treatment of all materials listed in this clause, the furnace air temperature shall not exceed 600°F [315°C] at the time of loading of the parts.

7.7.2 Above 600°F [315°C], the rate of increase in temperature of the furnace shall 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 shall not be a greater variation in temperature than 250°F [120°C] throughout the part being heat treated.

¹⁰ Bremen, U., Smith, I. F. C., and Hirt, M. A., *Crack Growth Behavior in a Welded Joint Improved by Residual Stress Method*. International Conference: Fatigue of Welded Construction, Ed., Maddox, S. J. The Welding Institute: 1987.

¹¹ Booth, G. S., *Improving the Fatigue Performance of Welded Joints*. The Welding Institute: 1983.

¹² Metal Improvement Company, Inc. *Shot Peening Application*, Eighth Edition.



Source: Adapted from AWS D14.1-97, Figure 11.

Figure 4—Pneumatic Hammer Peening

7.7.3 Above 600°F [315°C], cooling shall 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 shall not be a greater variation in temperature than 200°F [110°C] throughout the part being heat treated.

7.7.4 The temperature of the part during heat treating shall be measured with thermocouples attached to the part and using a calibrated temperature recording device.

7.7.5 M-1 Materials. For M-1 material,¹³ the following minimum preheat and interpass temperatures are mandatory:

≤ 1-1/2 in [38 mm]	50°F [10°C]
> 1-1/2 in [38 mm] to ≤ 2-1/2 in [63 mm]	150°F [65°C]
> 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 shall be accomplished at a temperature from 1100°F [595°C] to 1200°F [650°C] and shall 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].

¹³ 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.

7.7.6 M-3, M-4, and M-5 Materials

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

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

7.7.6.2 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 mandatory. The following PWHT temperatures within the ranges shown are required for these materials.

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

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

7.7.7 M-6 and M-7 Materials

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

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

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

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

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

7.7.9 M-9 Material

7.7.9.1 Minimum preheat and interpass temperatures shall be as follows:

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

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

7.7.10 M-10 Materials

7.7.10.1 M-10A materials shall be preheated and interpass temperatures maintained in conformance to the following:

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

7.7.10.2 M-10A material over 1 in [25 mm] thick shall be PWHT at 1050°F [565°C] ±50°F [30°C] for one hour per 1 in [25 mm] of thickness.

7.7.10.3 M-10B materials shall be preheated and PWHT same as M-4 materials.

7.7.10.4 M-10C materials shall be preheated and PWHT same as M-10A materials.

7.7.10.5 M-10E materials shall be preheated at 300°F [150°C] and shall 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] ±50°F [30°C] shall be sufficiently rapid to prevent embrittlement.

7.7.10.6 M-10F materials shall be preheated and PWHT same as M-3 materials.

7.7.10.7 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.

7.7.10.8 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 mandatory for thicknesses in excess of 1/2 in [13 mm]. This material shall be rapidly cooled from the PWHT temperature.

7.7.11 M-11 Materials

7.7.11.1 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. AWS D14.8M, *Standard Methods for the Avoidance of Cold Cracks*, may be used to determine preheat and interpass temperatures.

7.7.11.2 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.

7.7.11.3 For M-11A Groups 3, 4, 5, and 6 materials, preheat in conformance to 7.7.10.1. PWHT shall be mandatory and shall be accomplished at a temperature 50°F [30°C] below the tempering temperature. The time at temperature shall be a minimum of 1/2 hour per 1 in [25 mm] of thickness but not less than 1/2 hour.

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

8. Inspection and Quality Control

8.1 General Requirements

8.1.1 The Inspector designated by the Purchaser shall determine that fabrication by welding is performed in conformance to requirements of this specification.

8.1.2 Detail drawings showing the size, length, type, and location of all welds shall be made available to the Inspector for use at the Manufacturer, Fabricator, Repair Organization's, or Contractor's facility.

8.1.3 The Inspector shall be qualified in conformance to AWS QC1, *Standard for AWS Certification of Welding Inspectors*, or an equivalent program (CSA-W178.2, *Certification of Welding Inspectors*). The Inspector shall be familiar with the requirements of this specification.

8.1.4 The Manufacturer, Fabricator, or Repair Organization shall have and maintain a quality control system that will establish that all requirements of this specification will be met. A recommended quality system is outlined in Annex C.

8.2 Examination and Inspection

8.2.1 The Inspector may review the procedure qualification test records that are required by other clauses of this specification. The Inspector may witness the welding and testing of procedure qualification tests required by this specification and occurring within the time frame of the contract.

8.2.2 The Inspector shall permit welding to be performed only by welders and welding operators who are qualified in conformance to the requirements of this specification. The Inspector may witness the welding and testing of performance qualification tests during the time frame of the contract. The records of previously qualified welders and welding operators may be reviewed for accuracy, completeness, and conformance to the current contract in force.

8.2.3 When the quality of a welder's or welding operator's work appears to be below the requirements of this specification, the Inspector may require testing of a welder's or welding operator's capability by means of simple tests, such as the fillet weld break test, or by complete requalification in conformance to this specification.

8.2.4 The Inspector shall ascertain that the size, length, and location of welds conform to the requirements of the specifications and to the detail drawings, that no specified welds are omitted, and that no unspecified welds have been added.

8.2.5 The Inspector shall ascertain that only welding procedures that meet the provisions of this specification are employed.

8.2.6 The Inspector shall ascertain that electrodes are used only in the position and with the type of welding current and polarity for which they are classified.

8.2.7 The Inspector may observe the technique and performance of each welder and welding operator during production to make certain that the applicable requirements of this specification are met.

8.2.8 The Inspector shall examine the work to determine that it meets the requirements of this specification. Size and contour of welds shall be measured with suitable gauges. Visual inspection for cracks in welds and base metal, and other discontinuities, should be aided by a strong light sufficient to properly illuminate the area.

8.2.9 The Inspector may identify with a distinguishing mark all parts or joints that have been inspected and accepted, and shall maintain a written record of such parts and joints not accepted and the corrective actions taken.

8.2.10 Final visual or specified NDT inspection of welds may begin immediately after the final, completed welds have cooled to near ambient temperature except for materials known to be sensitive to delayed hydrogen-induced cracking (e.g., ASTM A 514 and A 517). For such materials, a minimum delay of 24 hours (preferably 48 hours) is required before NDT inspections may proceed.

8.3 Obligations of the Manufacturer, Fabricator, or Repair Organization

8.3.1 When the Manufacturer, Fabricator, or Repair Organization and Buyer's Inspector agree upon a nonconformance to this specification, the Manufacturer, Fabricator, or Repair Organization shall correct such nonconformities.

8.3.2 There shall be a system agreed upon with the Buyer's Inspector for correction of nonconformities.

8.3.3 In the event that repair of rejected welds shall so damage the base metal that it is not in accordance with the intent of the design drawings and specifications, the Manufacturer, Fabricator, or Repair Organization shall resolve the deficiency in a manner approved by the designer.

8.3.4 The Manufacturer, Fabricator, or Repair Organization shall be responsible for the necessary corrections of all welds in conformance to the requirements of this specification.

8.3.5 Corrections and repairs shall be accomplished by methods permitted in Clause 9.

8.4 Nondestructive Testing (NDT)

8.4.1 When nondestructive testing is required by contract, it shall be so stated in the information furnished to the Manufacturer, Fabricator, or Repair Organization. This information shall designate the welds to be examined, the extent of examination of each weld, and the method of testing.

8.4.2 Recommended nondestructive testing methods and acceptance criteria for use with this specification are in Annex D. Alternate methods of inspection may be agreed upon between Buyer and Manufacturer, Fabricator, or Repair Organization.

8.4.3 Personnel performing NDT other than visual shall be qualified and certified in conformance to the latest edition of the American Society for Nondestructive Testing, Recommended Practice No. SNT-TC-1A, or a written practice that is acceptable by the manufacturer and buyer or owner. Individuals who perform NDT shall be qualified for the following:

(1) NDT Level II

(2) NDT Level I working under the direction of a Level II or Level III

NOTE: Certification of Level I and Level II personnel shall be performed by a Level III who was certified and qualified per the requirements of SNT-TC-1A guidelines.

8.4.4 When nondestructive testing is specified, it shall be the Manufacturer's, Fabricator's, or Repair Organization's responsibility to ensure that all welds meet the quality requirements of applicable clauses of this specification.

8.4.5 If nondestructive testing other than visual inspection is not specified in the original contract agreement, but is subsequently requested by the Buyer, Manufacturer, Fabricator, or Repair Organization shall perform any requested testing or shall permit any testing to be performed. The Buyer shall be responsible for all associated costs, including

handling, surface preparation, nondestructive testing, and repair of discontinuities, other than those listed in 7.4 of this specification, at rates mutually agreeable between Buyer and Manufacturer, Fabricator, or Repair Organization.

8.5 Preparation and Disposition of Reports

8.5.1 A report form shall be kept by the Manufacturer, Fabricator, or Repair Organization that clearly identifies the work and the area of inspection. This report shall contain sufficient information to identify the weld, the person doing the inspecting, and the acceptability status of the welds inspected.

8.5.2 The Manufacturer's, Fabricator's, or Repair Organization's obligation to retain test reports shall cease upon delivery of those reports to the designated recipient, or at the end of one full year after completion of work.

9. Modification and Repair

9.1 Scope

9.1.1 This clause pertains to the modification and repair of weld and base metal defects on the Manufacturer's, Fabricator's, or Repair Organization's premises or otherwise under the Manufacturer's, Fabricator's, or Repair Organization's control.

9.1.2 Repair or modification work performed by those other than the Manufacturer, Fabricator, or Repair Organization should have approval from the Manufacturer, Fabricator, or Repair Organization and be performed to the Manufacturer's, Fabricator's, or Repair Organization's specifications.

9.2 Qualification

9.2.1 All repairs by welding on the Manufacturer's, Fabricator's, or Repair Organization's premises, before acceptance of the product by the purchaser, shall be made utilizing a qualified procedure as per Clause 6 of this specification.

9.2.2 All field repairs shall be done by a process and qualified procedure mutually acceptable to the Buyer and the Manufacturer, Fabricator, or Repair Organization.

9.3 Removal of Metal. Where required by 9.4, the removal of weld metal or portions of the base metal that require repair may be done by machining, grinding, chipping, oxygen gouging, or air carbon arc gouging. This shall be done in such a manner that the remaining weld metal or base metal does not contain stress risers. Oxygen gouging shall not be used on quenched and tempered steels. Unacceptable portions of the weld shall be removed without substantial removal of the base metal.

9.4 Repair of Type of Defect

9.4.1 Overlap or Excessive Convexity. Excess weld metal shall be removed as per 9.3 of this specification.

9.4.2 Excessive Concavity of Weld or Crater, Undersize Welds, Undercutting. Surfaces shall be prepared as per 9.3 (if required) and additional weld metal deposited.

9.4.3 Excessive Weld Porosity, Excessive Slag Inclusions, Incomplete Fusion. Unacceptable portions shall be removed, as per 9.3, and rewelded using a qualified welding procedure specification.

9.4.4 Cracks in Weld or Base Metal. The extent of the crack shall be determined by use of magnetic-particle inspection, liquid penetrant inspection, or other suitable methods. The crack and sound metal 2 in [50 mm] beyond each end of the crack shall be removed (see 9.3) and rewelded using a qualified welding procedure specification.

9.4.5 Distortion. Members distorted by welding, or otherwise, shall be straightened by mechanical means or by carefully supervised application of a limited amount of localized heat. The temperature of heated areas, as measured by a temperature-indicating device, shall be no higher than 50°F [30°C] below the original tempering temperature for quenched and tempered steel, or 1200°F [650°C] for other carbon steels. Unstabilized austenitic stainless steel with more than 0.03% carbon shall not be heat straightened with temperatures in excess of 800°F [430°C]. For all other materials to be straightened by heating, the temperature shall be no higher than the temperature recommended by the material's producer.

9.4.6 Inaccessible Defects. If work has been performed that has rendered a defect inaccessible, or has created new conditions that make correction of the defect dangerous or ineffectual, then the original conditions shall be restored by removing weld members before the corrections are made. If this is not done, the deficiency shall be compensated for by additional work performed according to an approved, revised design.

9.5 Peening. Peening may be used during a repair procedure on intermediate weld layers for control of shrinkage stress in thick welds to prevent cracking. No peening shall be done on the root or surface layer of the weld or in the base metal at the edges of the weld, except when it is done in conformance to 7.6. Care shall be taken to prevent overlapping or cracking of the weld or base metal.

9.6 Postweld Heat Treatment. Repairs to parts or assemblies where postweld heat treatment is required by this specification shall be stress relieved or otherwise heat treated after the repairs have been completed, examined, and accepted.

9.7 Temper Bead. Competent technical advice should be obtained from the manufacturer of the item or from another qualified source on quenched and tempered steels and normalized castings, under certain conditions (postweld heat treatment) in accordance with the original fabrication practice may be inadvisable or impractical. In such instances, a repair weld may be performed using alternative methods, such as temper bead or controlled deposition weld. A qualified welding procedure is required.

9.8 Cleaning

9.8.1 All repair welds shall be cleaned in conformance to the applicable cleaning specification.

9.8.2 Repair welding shall not be painted or coated until after the work has been inspected and accepted.

9.9 Testing and Inspection

9.9.1 Any repair or replaced weld shall be retested by the method originally used when the defect was found, and the same technique and quality acceptance criteria shall be applied.

9.9.2 The Buyer's Inspector or the Manufacturer, Fabricator, or Repair Organization shall make a permanent record of the repair as to the type of repair, location, repair procedure, and the final acceptance of the repair. Such information shall be recorded and filed with the repair documentation.

Annex A (Informative)

Guidelines for the Preparation of Technical Inquiries

This annex 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.

A1. 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.

A2. Procedure

All inquiries shall be directed to:

Managing Director
Technical Services Division
American Welding Society
550 N.W. LeJeune Road
Miami, FL 33126

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.

A2.1 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.

A2.2 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.

A2.3 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.

A2.4 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.

A3. 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.

A4. Publication of Interpretations

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

A5. 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.

A6. 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.

Annex B (Informative)

Sample Forms

This annex 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.

B1. General

The qualification tests for each welder or welding operator shall be documented by the Qualifier for both acceptable and unacceptable tests. There is no required format for Welding Procedure Specifications (WPSs), Procedure Qualification Records (PQRs), and Performance Qualification Test Records (PQTRs). Any form may be used. Examples of forms for documenting qualification tests appear as Figures F.1 through F.5 of AWS B2.1/B2.1M:2009 or the most current AWS B2.1/B2.1M, *Specification for Welding Procedure and Performance Qualification*.

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Annex C (Informative)

Quality Control System

This annex 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.

C1. General

The quality control system used by the Manufacturer should meet the requirements of this specification and AWS B5.17:2008, *Specification for the Qualification of Welding Fabricators*, may be used as a guide in establishing this quality program. Accreditation of quality systems of welding fabricators may be obtained through the AWS Certified Welding Fabricator (CWF) or equivalent programs. A written description of the system should be available to the Purchaser's Inspector for review. Depending on the circumstances, the description may contain information of a proprietary nature relating to the Manufacturer's process. Therefore, information about the system should be treated as confidential.

C2. Recommended Contents for Quality Control Systems

The following elements are a guide to the features that should be covered in the written documentation of the quality system. These elements are applicable to both shop and field work.

C2.1 Authority and Responsibility. The authority and responsibility of those in charge of the quality system should be clearly established. Personnel performing quality control functions should have sufficient and well-defined authority to identify problems in quality control, the quality system, and the authority to act on correcting them. An organizational chart showing the relationships between management, engineering, purchasing, manufacturing, field construction, inspection, and quality control should be in place to identify responsibilities and interactions of the organizational groups.

C2.2 Control of Specifications and Drawings. The quality system should contain procedures to ensure the latest applicable drawings, specifications, and instructions (including authorized changes) are used for manufacturing, inspection, and testing.

C2.3 Control of Materials

C2.3.1 The quality system should include control procedures for purchasing and receiving that will assure the proper identification of received materials. Documentation (including material certifications or material test reports) should be obtained, retained, and meet the requirements of the specification or contract. The quality system should also contain provisions to assure the intended, correct use of the materials in the manufacturing or construction process.

C2.3.2 The Buyer's Inspector should make certain that only materials conforming to the specification are used, and that the materials have proper identification and are properly stored.

C2.4 Examination and Inspection Controls. The quality system should contain provisions for the proper description and documentation of the manufacturing and inspection processes (including results) to permit the Purchaser's Inspector to properly determine if conformance to the contractual specifications has been met.

C2.4.1 Nondestructive Examination. The quality system should include provisions for identifying the test methods that the Manufacturer uses to conform to the requirements of this specification.

C2.4.2 Heat Treatment. The quality system should provide for documentation that ensures conformity to heat treatment requirements (if any) of this specification are met.

C2.4.3 Corrections of Nonconformities. The quality system should describe the method used to correct nonconformities and documentation thereof.

C2.5 Calibration of Measurement and Test Equipment. The quality system should contain provisions for the calibration of examination, measurement, and test equipment.

C2.6 Records Retention. The quality system should contain provisions for the retention and maintenance of records so that record retrieval is possible for a specified time interval. The records should be maintained on forms specified in the quality system and should be available for review by the purchaser or the purchaser's representative.

Annex D (Informative)

Inspection Methods

This annex is not part of AWS D14.6/14.6M:2012, *Specification for Welding of Rotating Elements of Equipment*, but is included for informational purposes only.

D1. Method: Liquid Penetrant Inspection of Welds

D1.1 General. The procedures and standards set forth herein are to govern liquid penetrant inspection of welds (see ASTM E 165, *Standard Recommended Practice for the Liquid Penetrant Inspection Method*) when such inspection is required by the purchase specification.

D1.2 Personnel Qualification

D1.2.1 Personnel performing liquid penetrant examinations shall be qualified in conformance with the current edition of the American Society for Nondestructive Testing Recommended Practice No. SNT-TC-1A.

D1.3 Written Procedure Requirements

D1.3.1 Liquid Penetrant Examinations shall be performed in accordance with a written procedure which shall as a minimum contain the following:

- (1) Type of penetrant, developer, emulsifiers, or compatible groups of materials;
- (2) method of applying applicable materials such as penetrants, emulsifiers if required and developers;
- (3) methods of removing excess materials including maximum water pressures if the wet washable technique is required;
- (4) dwell times of penetrants, emulsifiers if utilized, developers, based on the material manufacturer's recommendations and/or ASTM E 165/ASME Section V guidelines for types of imperfections sought;
- (5) type of drying aides;
- (6) temperature limits for performing examination;
- (7) time limits for evaluations;
- (8) personnel qualification requirements; and
- (9) the acceptance criteria of D1.7 of this annex shall be noted within the written procedure .

D1.4 Extent of Inspection

D1.4.1 Information furnished to the Manufacturer, Fabricator, or Repair Organization shall clearly identify the extent of the liquid penetrant inspection to be performed.

D1.4.2 Drawings with symbols in accordance with AWS A2.4, *Standard Symbols for Welding, Brazing, and Nondestructive Examination*, or equivalent information, shall be used.

D1.5 Equipment

D1.5.1 Penetrant Equipment. Aerosol cans, air, or CO₂-powered spray guns, paint brushes, spraying, or dipping may be used to apply the liquids.

D1.5.2 Drying Equipment. Paper towels, lint-free cloths, compressed air, circulating air, oven drying with circulating air as long as the part temperature does not exceed 125°F [52°C] and the drying time is minimal to prevent evaporation of the penetrant material.

D1.5.4 Lighting for Fluorescent Penetrants. A darkened area for black light use is necessary with no more than 2 ft-candles white light leakage. The black and white light intensities shall be measured with annually calibrated light meters. A minimum of 1000 μW/cm² on the surface of the part being examined shall be required. Additionally, a five-minute warm up period is required for the black light. Personnel performing the examination must allow a five minute period in a darkened area to allow their eyes to adjust/adapt to dark viewing.

D1.6 Procedure

D1.6.1 Material. Liquid penetrant materials used on nickel-base alloys or austenitic stainless steels shall be sulphur- and halogen-free, meeting the requirements of ASTM D 129 and ASTM D 808 for sulphur content and total halogens. The residual amount of total sulphur and halogens shall not exceed 1/2% by weight. The penetrant materials for each evaluation shall be compatible, as defined by the penetrant material Manufacturer, Fabricator, or Repair Organization.

D1.6.2 Temperature. The temperature of the penetrant materials and components to be inspected shall be between 50°F [2°C] and 125°F [52°C]. If examination is required beyond the temperature ranges mentioned, subject penetrant procedure shall be demonstrated/qualified per ASTM E 165 or ASME Section V guidelines and noted within the required written procedure.

D1.6.3 Surface Finish of Completed Welds. As-welded surfaces shall be considered suitable for inspection, without any grinding, provided the following conditions are met:

- (1) There shall be no unacceptable overlap or undercut along the length of or within the weld.
- (2) The deposited metal must be fused smoothly and uniformly into the plate surfaces.
- (3) The finished weld and adjacent base material (1 in [25 mm] each side of the weld) shall be clean, reasonably smooth, and free from irregularities, grooves, depressions and weld spatter.

D1.6.4 Precleaning. All parts must be clean and dry before the liquid penetrant is applied. “Clean” means that the materials must be free of any rust, scale, welding flux, slag, spatter, grease, paint, oily films, and dirt that might interfere with liquid penetrant inspection. All of these contaminants are of a type that may prevent the liquid penetrant from entering the discontinuities. If precleaning is necessary, the following procedures are recommended.

- (1) Rust, scale, slag, weld spatter, or other hard, tenacious materials shall be removed by wire brushing, pickling, grinding, or machining.
- (2) All types of grinding wheels are permitted on carbon steel. All other materials shall be ground with rubber resin-bonded aluminum oxide or silicon carbide wheels.
- (3) All oil and grease shall be removed with residue-free solvents using paper towels or lint-free cloth.
- (4) Residue-free solvents (initial flash point over 200 °F [93°C]) may be used as hand-wipe solvents or as dip-tank degreasing solvents. These solvents are suitable for removing grease and oils, but are generally not adequate if solid materials are imbedded in the void areas.

D1.6.5 Application of Penetrant. The surface shall be thoroughly dry before application of the liquid penetrant. The penetrant may be applied by spraying, brushing, or immersion. The area to be inspected shall be completely covered. The dwell time shall be as recommended by the penetrant manufacturer. Precautions should be taken to prevent inspection materials from entering inaccessible areas.

D1.6.6 Removal of Excess Penetrant

D1.6.6.1 Removal (Water Washable). The water pressure, water temperature, and application distance, shall be as recommended by the penetrant manufacturer or a maximum of 40 psi [0.28 MPa] with a coarse water spray and the water temperature shall be maintained with the range of 50°F [10°C] and 100°F [38°C].

D1.6.6.2 Removal (Solvent). As much penetrant as possible shall be removed by first wiping the surface thoroughly with a clean dry cloth or absorbent paper. The remaining excess penetrant shall be removed by wiping the surface with a clean cloth or absorbent paper dampened with remover. Flushing of the surface with any liquid, following application of the penetrant and prior to developing, is prohibited.

D1.6.6.3 Removal (Post Emulsifier). With post-emulsifying penetrants, an additional step is required. This step is the application of a liquid emulsifier prior to the rinsing operation. The emulsifier may be applied by brushing, spraying, or dipping. Emulsifying times of 10 seconds to 5 minutes can be used, depending upon prevailing conditions, such as surface roughness or the type of discontinuity sought. The emulsifying time is critical, and shall be as recommended by the penetrant manufacturer. Once the emulsifying time has been set for a particular test, it should not vary more than $\pm 10\%$. After emulsification, the mixture is removed by a water spray, in accordance with the penetrant manufacturer's recommendation.

D1.6.7 Application of Developer

D1.6.7.1 Dry. After the surface has been thoroughly dried, the developer shall be applied by dipping, spraying, or brushing. Application of the developer by spraying is preferable. The surface shall be completely covered with developer. It is suggested that the aerosol can or sprayer be held no less than 10 in [250 mm] from the work and be applied in short, dusting strokes. The application of excess developer should be avoided, since it is possible for a thick coating of developer to mask indications.

D1.6.7.2 Liquid. The liquid developer is a suspension of powder in water or a volatile solvent. It is applied by dipping, spraying, or brushing. In any case, a film of powder is left on the surface when the developer dries. Where a water suspension developer is used, drying time may be decreased by the use of warm air.

D1.6.8 Examination. Visual examination of the surface being inspected shall be made within a minimum of ten minutes and a maximum of sixty minutes (dwell time) after the developer has dried.

D1.6.9 Final Cleaning. When the inspection is concluded, the penetrant materials shall be removed as soon as possible by means of brushing or wiping with paper towels or lint-free cloths, in accordance with D1.6.4.

D1.7 Acceptance Standards. All surfaces required to be examined shall be free of linear indications (cracks, laps, fissures, etc.) and of four, or more, rounded imperfections in a line separated by 1/16 in [2 mm] or less (edge-to-edge). In addition, the following requirements of 7.4, Weld Surface Conditions shall be applied:

- (1) Linear indications are those indications in which the length is more than three times the width.
- (2) Rounded imperfections are indications that are circular or elliptical, with the length less than three times the width.
- (3) Indications less than 1/64 in [0.4 mm] are considered nonrelevant.

D1.8 Defect Removal and Repair. Unacceptable imperfections shall be removed and re-examination made to assure complete removal. Whenever a defect is removed and subsequent repair by welding is not required, the excavated area shall be blended into the surrounding surface so as to avoid sharp notches, crevices, or corners. Where welding is required after removal of a defect, the area shall be cleaned, and welding performed in conformance to a qualified welding procedure. Completed repairs shall be re-examined by the method originally used for detection of the defect (see Clause 8).

D1.9 Examination Records. For each examination the following information shall be recorded:

- (1) Procedure identification;
- (2) component name and identification such as either part number, serial number, heat number, weld identification number, contract number, etc.;
- (3) liquid penetrant type (visible or fluorescent);

- (4) type (number or letter designation) of each penetrant, penetrant remover, emulsifier, and developer used;
- (5) dwell times;
- (6) inspection results;
- (7) map or record of indications; and
- (8) inspector's name, certification level, and date.

D2. Method: Magnetic-Particle Inspection of Welds (MT)

D2.1 General. The procedures and standards set forth herein are to govern magnetic-particle inspection of welds (see ASTM E 709, *Practice for Magnetic Particle Examination*) when such inspection is required by the purchase specification.

D2.2 Personnel performing magnetic particle examinations shall be qualified in conformance with the current edition of the American Society of Nondestructive Testing Recommended Practice No. SNT-TC-1A.

D2.3 Written Procedure Requirements

D2.3.1 Magnetic particle examinations shall be performed in accordance with a written procedure which shall as a minimum contain the following:

- (1) Magnetizing technique which shall be defined as either prod, yoke, circular, longitudinal, or multi-directional;
- (2) magnetizing current type and amount;
- (3) surface condition requirements;
- (4) type of ferromagnetic particles to be utilized, color, wet, dry, fluorescent, etc.;
- (5) directions of magnetic fields;
- (6) method of particle application and removal;
- (7) calibration of equipment and materials;
- (8) temperature limits for either wet or dry examinations;
- (9) demagnetization limits/requirements;
- (10) lighting requirements;
- (11) acceptance criteria, D2.10 shall be utilized; and
- (12) personnel qualification requirements.

D2.4 Extent of Inspection

D2.4.1 Information furnished to the Manufacturer, Fabricator, or Repair Organization shall clearly identify the extent of the magnetic-particle inspection to be performed.

D2.4.2 Drawings with symbols in accordance with AWS A2.4, *Standard Symbols for Welding, Brazing, and Nondestructive Examination*, or equivalent information, shall be used.

D2.5 Equipment

D2.5.1 Source of Magnetic Field. The following magnetizing equipment are capable of inducing a magnetic flux of suitable intensity in the desired direction.

D2.5.1.1 Prod Method. Portable prod-type electrical contacts shall be spaced 3 in to 8 in [75 mm to 200 mm] apart. The current shall be 90 A to 100 A per inch of prod spacing for material thickness 3/4 in [20 mm] or less. For material greater than 3/4 in [20 mm], 100 A to 125 A per inch of prod spacing shall be utilized. The strength of the magnetic field shall be verified by the method specified in ASTM E 709.

D2.5.1.2 Coil Method. Multiple coils shall be looped around the part and be capable of producing a magnetic field strength of 3000 A to 10 000 A turns using direct current.

D2.5.1.3 Yoke Method. Either alternating current or permanent yokes shall be used. Strength of the magnetic field shall be verified by the method specified in ASTM E 709.

D2.5.2 Lighting. The test area shall have a minimum of 100 ft-candles [1260 lumens] of illumination for proper evaluation of the visual indications revealed on the test surface.

D2.5.3 Lighting for Fluorescent Examination. A darkened area for black light use is necessary with no more than 2 ft-candles white light leakage. The black and white light intensities shall be measured with annually calibrated light meters. During fluorescent wet MT examinations, a maximum of 2 ft-candles white light leakage is allowed. The minimum fluorescent intensity shall be $1000 \mu\text{W}/\text{cm}^2$ as measured 15 in (0.381 m) minimum from the black light filter face. Additionally, a five minute warm up period is required for the black light. Personnel performing the examination must allow a five-minute period in a darkened area to allow their eyes to adjust/adapt to dark viewing.

D2.6 Examination Medium. The magnetic particles used for detection of discontinuities shall be as follows:

D2.6.1 Dry Particles. Dry particles used shall be of high permeability and low retentivity and of such size and shape as will produce suitable indications. It is desirable that the color be such as to provide adequate contrast with the background of the surface being examined.

D2.6.2 Wet Particles. Wet particles used shall be red or black, or, alternatively, may be fluorescent when viewed under ultraviolet illumination. The particles shall be suspended in suitable liquid medium in the concentration recommended by the manufacturer of the particles. More details on the use of wet particles are given in ASTM E 709.

D2.7 Surface Preparation

D2.7.1 Surface Finish of Complete Welds and Adjacent Base Materials. As-welded surfaces shall be considered suitable for inspection, without any grinding, provided the following conditions are met:

- (1) There shall be no un-acceptable overlap or undercut along the length of the weld.
- (2) Deposited weld metal must be fused smoothly and uniformly into base metal surfaces.
- (3) The finished weld and adjacent base material (1 in on either side of the weld zone) shall be clean, reasonably smooth, and free of irregularities, grooves, depressions, and weld spatter.
- (4) The surfaces to be examined shall be dry and free of oil, scale, paint, slag, welding flux, spatter, grease, oily films, and dirt that may interfere with the examination.

D2.7.2 Precleaning. The parts to be examined shall be dry and free of oil or other foreign matter which might interfere with the formation or interpretation of magnetic particle patterns or indications.

D2.8 Application of Magnetic Field

D2.8.1 Direction. The magnetic field shall be applied in two directions with the second as nearly perpendicular to the first as possible.

D2.8.2 Extent. Examination of welds by the magnetic particle method shall be made over an area including the weld and base metal and extending at least 1 in [13 mm] on each side of the weld.

D2.8.3 Precaution. Care shall be taken to prevent local overheating, arcing, or burning of the surface being inspected. The magnetizing current shall not be turned on until after prods have been properly positioned in contact with the surface, and the current shall be turned off before the prods are removed.

D2.8.4 Sequence of Operation. Inspection shall be performed by the continuous method, leaving the magnetizing current on during the period the inspection medium is being applied and the excess removed.

D2.9 Particle Application and Removal

D2.9.1 Dry Particles. Dry particles may be applied by means of mechanical shakers, bulb blowers, or mechanical blowers. Excess particles shall be removed by means of a dry air current of sufficient force to remove the excess particles. Extreme care should be taken so that any particles indicating discontinuities are not disturbed.

D2.9.2 Wet Particles. Wet particles may be applied by means of spraying or dipping (see ASTM E 709).

D2.10 Acceptance Standards. All surfaces required to be examined shall be free of cracks, laps, fissures, or other linear indications. Indications less than 1/64 in [0.4 mm] are considered nonrelevant. Inline porosity, which appears as a linear accumulation of magnetic powder, shall be removed. Also, the requirements of 7.4 are applicable.

D2.11 Defect Removal and Repair. Unacceptable imperfections shall be removed and re-examined to assure the complete removal. Whenever a defect is removed and subsequent repair by welding is not required, the excavated area shall be blended into the surrounding surface so as to avoid sharp notches, crevices, or corners. Where welding is required after removal of a defect, the area shall be cleaned, and the welding shall be performed in conformance to a qualified welding procedure. Completed repairs shall be re-examined by the method originally used for detection of the defect (see Clause 8).

D2.12 Examination Records

D2.12.1 For each examination the following information shall be recorded on the magnetic particle inspection report:

- (1) procedure identification
- (2) component name and identification such as part number, serial number, heat number, weld identification number(s), contract number, drawing, etc.
- (3) magnetizing technique utilized
- (4) identification of type of MT particles (wet, dry, fluorescent)
- (5) light intensity during the examination, either visible or fluorescent
- (6) inspection results
- (7) calibration date of equipment
- (8) maps or records of indications
- (9) inspector's name, certification level, and date

D3. Radiographic Testing of Groove Welds in Butt Joints

D3.1 General

D3.1.1 The procedure and standards set forth in Clause D3 of this annex are to govern radiographic testing of welds when such inspection is required by the contract documents. The requirements listed herein are specifically for testing groove welds in butt joints. The methodology shall conform to ASTM E 94, *Guide for Radiographic Testing*, except as provided herein.

D3.1.2 Variation in testing procedure, equipment, and acceptance standards, not included herein, may be used upon agreement between the purchaser and the Manufacturer, Fabricator, or Repair Organization. Such variations include, but are not limited to, the following:

- (1) Radiographic testing of fillet, T-, and corner welds;
- (2) Changes in source-to-film distances;
- (3) Unusual application of film;
- (4) Unusual penetrameter application (including film side penetrameters);
- (5) Radiographic testing of thicknesses greater than 6 in [150 mm]; and
- (6) Film types, densities, and variations in exposure, development, and viewing techniques.

D3.1.3 Information furnished to the Manufacturer, Fabricator, or Repair Organization prior to purchase shall clearly identify the extent of radiographic testing.

D3.1.4 When complete testing is specified, the entire length of the weld in each designated joint shall be inspected.

D3.1.5 When spot testing is specified, the number of spots in each designated category of welded joints to be radiographed in a stated length of weld, shall be included in information furnished prior to purchase. Each spot radiograph shall show at least 8 in [200 mm] of weld length. If a spot radiograph shows discontinuities that require repair as defined in D3.3.2, two adjacent spots shall be inspected. If discontinuities requiring repair are shown in either of these spots, the entire length of weld in that welded joint shall be tested radiographically.

D3.2 Radiographic Procedure

D3.2.1 Radiographs shall be made using a single source of either x-ray or gamma radiation. The radiographic sensitivity shall be judged based on penetrameter image or wire image quality indicators (IQI). Radiographic technique and equipment shall provide sufficient sensitivity to clearly delineate the required penetrameters and the essential holes as described in D3.2.6 and Tables D.1 and D.2. Identifying letters and numbers shall show clearly in the radiograph.

Table D.1
Penetrameter Requirements

Nominal Material Thickness Range (T), in [mm]	Penetrameter Identification	Essential Hole	Penetrameter Thickness, in [mm]
$T \leq 0.25$ [6]	10	2T	0.010 [0.254]
0.25 [6] $< T \leq 0.375$ [10]	12	2T	0.012 [0.305]
0.375 [10] $< T \leq 0.50$ [13]	15	2T	0.015 [0.381]
0.50 [13] $< T \leq 0.625$ [16]	15	2T	0.015 [0.381]
0.625 [16] $< T \leq 0.75$ [20]	17	2T	0.017 [0.432]
0.75 [20] $< T \leq 0.875$ [22]	20	2T	0.020 [0.508]
0.875 [22] $< T \leq 1.00$ [25]	20	2T	0.020 [0.508]
1.00 [25] $< T \leq 1.25$ [32]	25	2T	0.025 [0.635]
1.25 [32] $< T \leq 1.50$ [38]	30	2T	0.030 [0.762]
1.50 [38] $< T \leq 2.00$ [50]	35	2T	0.035 [0.889]
2.00 [50] $< T \leq 2.50$ [65]	40	2T	0.040 [1.016]
2.50 [65] $< T \leq 3.00$ [75]	45	2T	0.045 [1.143]
3.00 [75] $< T \leq 4.00$ [100]	50	2T	0.050 [1.270]
4.00 [100] $< T \leq 6.00$ [150]	60	2T	0.060 [1.524]

Table D.2
Wire Image Quality Indicator (IQI) Requirements

DIN 62 Fe (Wire Type) Penetrameters	
Nominal Material Thickness Range (T), in [mm]	Source Side Maximum Wire Size, in [mm]
$T \leq 0.25$ [6]	0.005 [0.13]
0.25 [6] $< T \leq 0.375$ [10]	0.006 [0.16]
0.375 [10] $< T \leq 0.50$ [13]	0.008 [0.20]
0.50 [13] $< T \leq 0.625$ [16]	0.010 [0.25]
0.625 [16] $< T \leq 0.75$ [20]	0.013 [0.33]
0.75 [20] $< T \leq 1.25$ [32]	0.016 [0.40]
1.25 [32] $< T \leq 1.50$ [38]	0.020 [0.51]
1.50 [38] $< T \leq 1.75$ [45]	0.025 [0.64]
1.75 [45] $< T \leq 2.00$ [50]	0.032 [0.81]
2.00 [50] $< T \leq 2.50$ [65]	0.040 [1.02]
2.50 [65] $< T \leq 3.00$ [75]	0.050 [1.27]
3.00 [75] $< T \leq 3.50$ [90]	0.063 [1.60]
3.50 [90] $< T \leq 4.00$ [100]	0.080 [2.03]
4.00 [100] $< T \leq 5.00$ [125]	0.098 [2.50]
5.00 [125] $< T \leq 6.00$ [150]	0.126 [3.20]
6.00 [150] $< T \leq 8.00$ [200]	0.160 [4.06]

D3.2.2 Radiography shall be performed in conformance to all applicable safety requirements.

D3.2.3 When the contract documents require the removal of weld reinforcement, the welds shall be prepared for radiography by grinding as per 7.4.3. Other weld surfaces need not be ground or otherwise smoothed for purposes of radiographic testing, unless surface irregularities or the junction between weld and base metal may cause objectionable discontinuities to be obscured in the radiograph.

D3.2.3.1 Extension bars and run-off plates may be removed prior to radiographic inspection.

D3.2.3.2 When weld reinforcement or backing is not removed, or wire IQI alternate placement is not used, shims which extend at least 1/8 in [3 mm] beyond three sides of the required penetrameter or wire IQI, shall be placed under the penetrameter or wire IQI so that the total thickness between the penetrameter and the film is approximately equal to the average thickness of the weld measured through its reinforcement and backing.

D3.2.4 Radiographic film shall be Type 1 or Type 2 as described in ASTM E 94. Lead foil screens shall be used as described in ASTM E 94. Fluorescent screens shall not be permitted.

D3.2.5 Radiographs shall be made with a single source of radiation centered, as near as practicable, with respect to the length and width of that portion of the weld being examined.

D3.2.5.1 Gamma ray sources, regardless of size, shall be capable of meeting the geometric unsharpness limitation of ASME *Boiler and Pressure Vessel Code*, Section V, Article 2.

D3.2.5.2 The source-to-subject distance shall not be less than the total length of film being exposed in a single plane.

D3.2.5.3 The source-to-subject distance shall not be less than seven times the thickness of weld, plus reinforcement and backing, if any, nor such that the inspecting radiation shall penetrate any portion of the weld represented in the radiograph at an angle greater than 26.5° from a line normal to the weld surface.

D3.2.6 Penetrameters or wire IQIs shall show clearly on each radiograph. The minimum number and their required locations shall be as follows:

(1) For welds joining nominally equal thicknesses, where a radiograph represents 10 in [250 mm] or greater weld length, two penetrameters or wire IQIs placed as shown in Figure D.1.

(2) Where a radiograph represents less than 10 in [250 mm] of weld, one penetrameter or wire IQI placed as shown in Figure D.2.

(3) For welds at a transition in thickness, where a radiograph represents 10 in [250 mm] or greater of weld length, two penetrameters or wire IQIs on the thinner plate and one penetrameter or wire IQI on the thicker plate, or two wire IQIs at the alternate wire IQI placement locations as shown in Figure D.3.

(4) When a radiograph represents less than 10 in [250 mm] of weld length, one penetrameter or wire IQI on each thickness or one wire IQI at the alternate wire IQI placement location as shown in Figure D.4. Penetrameters or wire IQI shall be placed on the source side with penetrameters parallel to the weld joint and holes at the outer edge of the area being radiographed.

D3.2.6.1 The thickness of the penetrameter or wire IQI set and the essential hole, or wire shall be as specified in Tables D.1 and D.2. A smaller essential hole or wire or a thinner penetrameter or a wire IQI using smaller wires, or both, may be selected by the Contractor, provided all other provisions for radiography are met. Thickness shall be measured as T_1 or T_2 , or both, at the locations shown in Figures D.1, D.2, D.3, and D.4, and may be increased to provide for the thickness of allowable weld reinforcement, provided shims are used as specified in D3.2.3.2. Backing material shall not be considered part of the weld or reinforcement in penetrameter or wire IQI selection.

D3.2.6.2 Penetrameters shall be manufactured from steel, preferably stainless steel, and shall conform to the specifications of ASTM E 1025, *Standard Practice for Design, Manufacture, and Material Grouping Classification of Hole-Type Image Quality Indicators (IQI) Used for Radiology*. Other penetrameters, such as those that are ASME-approved, may be used, provided they have identification numbers indicating penetrameter thickness, in thousandths of an inch, have the same essential dimensions, and comply with all other conditions of this paragraph. Each penetrameter shall be manufactured with three holes, one of which shall be of diameter equal to twice the penetrameter thickness (2T). The diameter of the two remaining holes shall be selected by the Manufacturer, Fabricator, or Repair Organization. They will ordinarily be equal to one times (1T) and four times (4T) the penetrameter thickness. Penetrameter designations 10 through 25 shall contain a 4T hole.

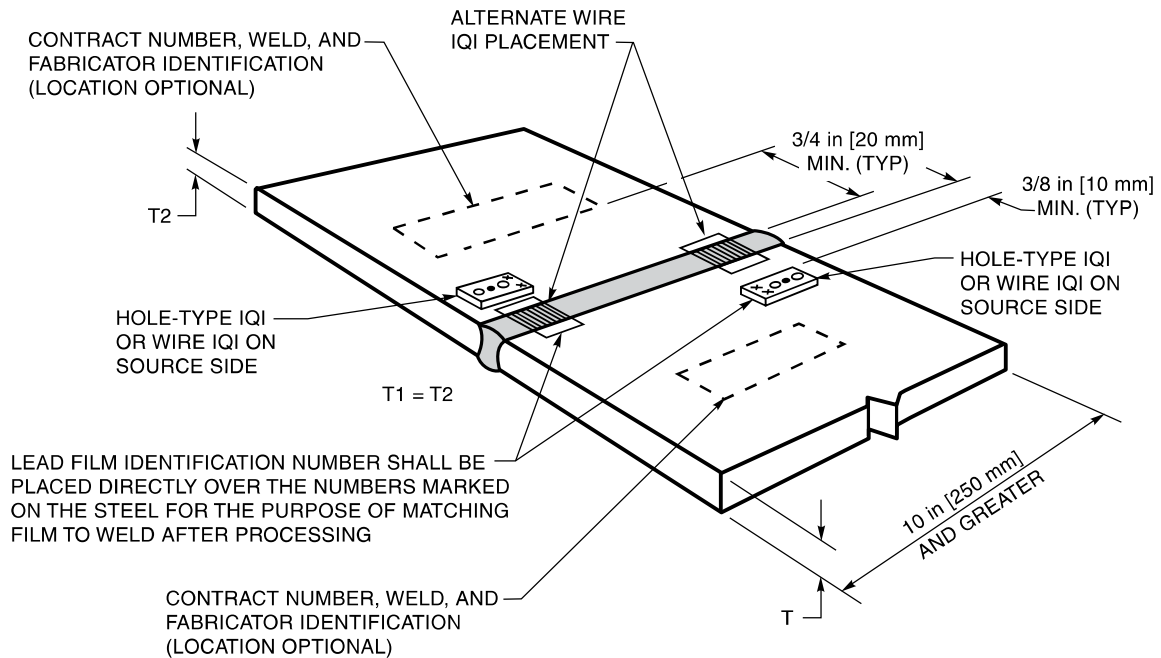


Figure D.1—Radiographic Identification and Penetrameter or Wire IQI Locations on Approximately Equal-Thickness Joints 10 in [250 mm] and Greater in Length

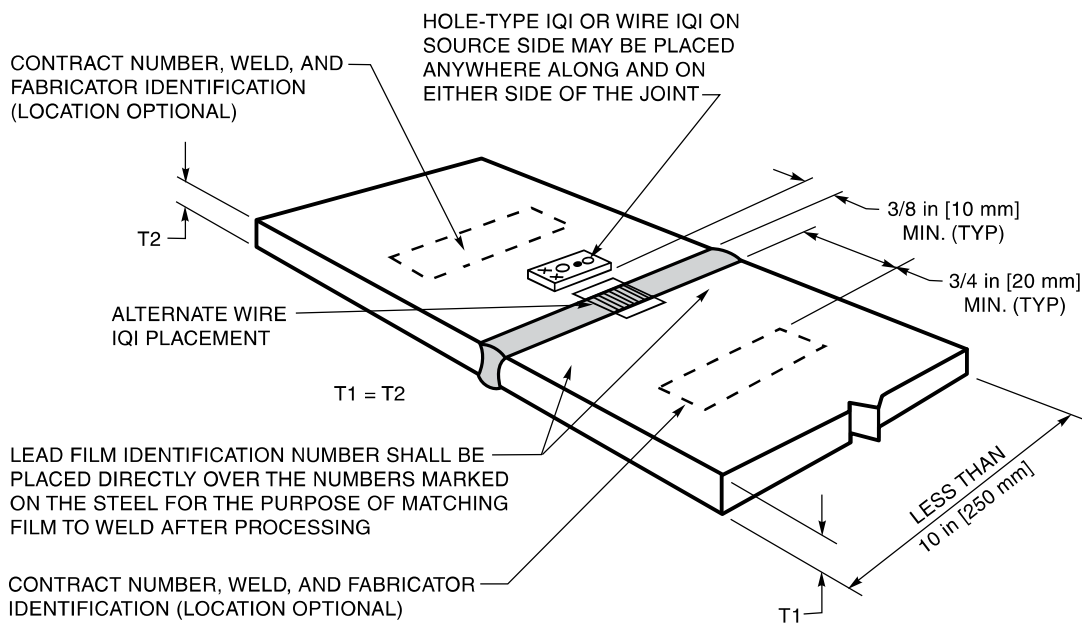


Figure D.2—Radiographic Identification and Penetrameter or Wire IQI Locations on Approximately Equal-Thickness Joints Less Than 10 in [250 mm] in Length

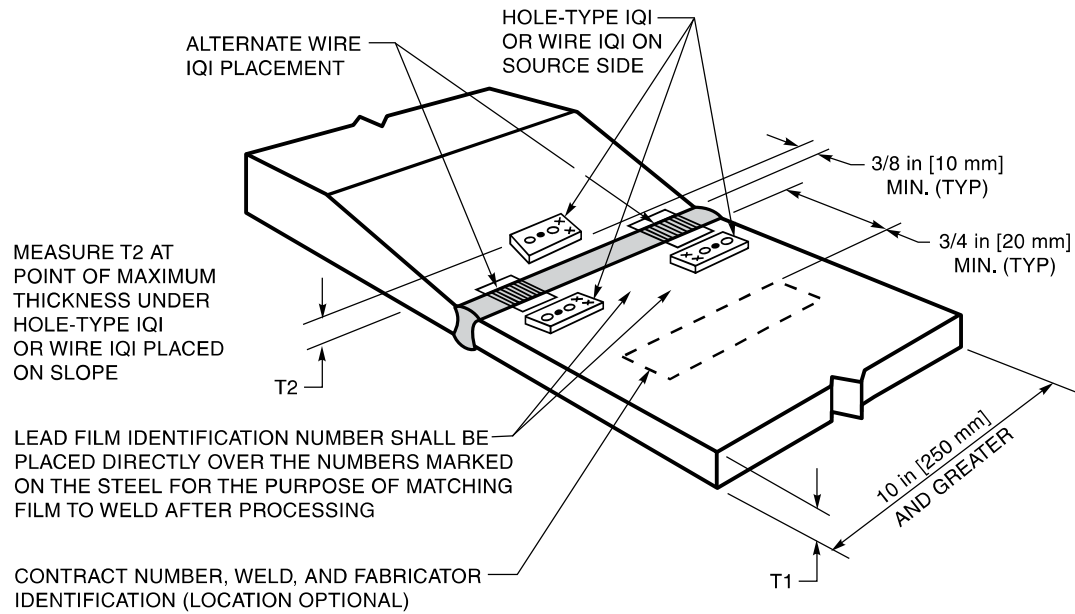


Figure D.3—Radiographic Identification and Penetrameter or Wire IQI Locations on Transition Joints 10 in [250 mm] and Greater in Length

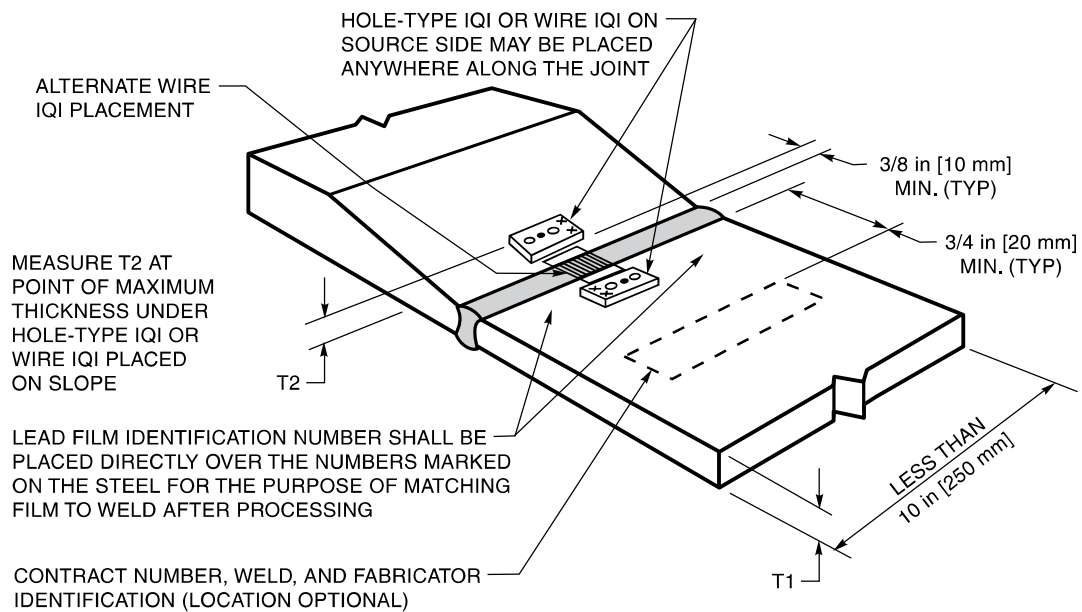


Figure D.4—Radiographic Identification and Penetrameter or Wire IQI Locations on Transition Joints Less Than 10 in [250 mm] in Length

D3.2.6.3 Wire IQIs shall be manufactured in conformance to ASTM E 747, *Practice for Design, Manufacture, and Material Grouping Classification of Wire Image Indicators (IQI) Used for Radiology*.

D3.2.7 Welded joints shall be radiographed and the film indexed by methods that will provide complete and continuous inspection of the joint within the limits specified to be examined. Joint limits shall show clearly in the radiographs. Short film, short screens, excessive undercut by scattered radiation, or any other process that obscures portions of the total weld length shall render the radiograph unacceptable.

D3.2.7.1 Films shall have sufficient length and shall be placed to leave at least 1/2 in [13 mm] of film, exposed to direct radiation from the source, beyond each free edge where the weld is terminated.

D3.2.7.2 Welds longer than 14 in [350 mm] may be radiographed by overlapping film cassettes and making a single exposure, or by using single film cassettes and making separate exposures. The provisions of D3.2.5 shall apply.

D3.2.7.3 To check for back-scattered radiation, a lead symbol "B," 1/2 in [13 mm] high, 1/16 in [2 mm] thick shall be attached to the back of each film cassette. If the "B" image appears on the radiograph, the radiograph shall be considered unacceptable.

D3.2.8 Film widths shall be sufficient to cover all portions of the weld joint, including the heat-affected zones, and shall provide sufficient additional space for the required penetrameters or wire IQI and film identification without infringing upon the area of interest in the radiograph.

D3.2.9 All radiographs shall be free from mechanical, chemical, or other blemishes to the extent that they cannot mask or be confused with the image of any discontinuity in the area of interest in the radiograph. Such blemishes include, but are not limited to the following:

- (1) Fogging;
- (2) Processing defects such as streaks, water marks, or chemical stains;
- (3) Scratches, finger marks, crimps, dirtiness, static marks, smudges, or tears;
- (4) Loss of detail due to poor screen-to-film contact; and
- (5) False indications due to defective screens or internal faults.

D3.2.10 The transmitted film density through of the body of the required penetrometer(s) and the area of interest shall be a minimum of 1.8 for single-film viewing for radiographs made with an X-ray source and a minimum of 2.0 for radiographs made with a gamma ray source. For composite viewing of double-film exposures, the minimum density shall be 2.6. Each radiograph of a composite set shall have a minimum density of 1.3. The maximum density shall be 4.0 for either single or composite viewing.

D3.2.10.1 The density measured shall be H&D density (radiographic density), which is a measure of film blackening, and is expressed as:

$$\text{H\&D} = \log I_0/I$$

where:

- I_0 = light intensity of the film, and
 I = light transmitted through the film

D3.2.10.2 When weld transitions in thickness are radiographed and the ratio of the thickness of the thicker section to the thickness of the thinner section is 3 or greater, radiographs should be exposed to produce single-film densities of 3.0 to 4.0 in the thinner section. When this is done, the minimum density requirements of D3.2.10 shall be waived unless otherwise provided in the contract documents. Even though the minimum density of D3.2.10 does not apply under these conditions, a minimum density for composite or triple viewing must maintain a 2.0 minimum to 4.0 maximum film density and shall reveal proper radiographic sensitivity as defined within D3.2.1.

D3.2.10.3 If the density of the radiographic film anywhere through the area of interest varies by more than minus 15% or plus 30% from the density through the body of the hole IQI or adjacent to the designated wire of a wire IQI, within minimum/maximum allowable density ranges specified in D3.2.10 then an additional IQI shall be used for each exceptional area and the radiograph retaken.

D3.2.10.3.1 When shims are utilized with hole type IQI, the 30% density restriction of D3.2.10.2 may be exceeded, provided the required IQI sensitivity is met.

D3.2.11 A radiograph identification mark and two location identification marks shall be placed at each radiograph location. A corresponding radiograph identification mark and two location identification marks, all of which shall show in the radiograph, shall be produced by placing lead numbers or letters, or both, over each of the identical identification and location marks to provide a means for matching the developed radiograph to the weld. Additional identification information may be preprinted no less than 3/4 in [20 mm] from the edge of the weld or shall be produced on the radiograph by placing lead figures on the material. Information required to show on the radiograph shall include the Owner's contract identification, initials of the radiographic inspection company, initials of the Fabricator, the Fabricator shop order number, the radiographic identification mark, and the date and the weld repair number, if applicable.

D3.3 Acceptance Standards

D3.3.1 Terminology

D3.3.1.1 Rounded Indications. Indications with a maximum length of three times the width or less on the radiograph are defined as rounded indications. These indications may be circular, elliptical, conical, or irregular in shape and may have tails. When evaluating the size of an indication, the tail shall be included. The indication may be from any imperfection in the weld, such as porosity, slag, or tungsten.

D3.3.1.2 Aligned Indications. A sequence of four or more rounded indications shall be considered to be aligned when they touch a line parallel to the length of the weld drawn through the center of the two outer rounded indications.

D3.3.1.3 Thickness, t. Thickness, t, is the thickness of the weld, excluding any allowable reinforcement. For a butt weld joining two members having different thicknesses at the weld, t is the thinner of these two thicknesses. If a full-penetration weld includes a fillet weld, the thickness of the throat of the fillet shall be included in t.

D3.3.2 Acceptance Criteria

D3.3.2.1 Image Density. Density within the image of the indication may vary and is not a criterion for acceptance or rejection.

D3.3.2.2 Relevant Indications (see Table D.3 for example). Only those rounded indications shall be considered which exceed the following dimensions:

Table D.3
Examples of Acceptance Indications^a

Thickness t, in [mm]	Maximum Size of Acceptable Rounded Indication, in [mm]		Maximum Size of Nonrelevant Indication, in [mm]
	Random	Isolated	
< 1/8 [3]	1/4t	1/3t	1/10t
≥ 1/8 [3] to < 3/16 [5]	0.031 [0.8]	0.042 [1.1]	0.015 [0.4]
≥ 3/16 [5] to < 1/4 [6]	0.047 [1.2]	0.063 [1.6]	0.015 [0.4]
≥ 1/4 [6] to < 5/16 [8]	0.063 [1.6]	0.083 [2.1]	0.015 [0.4]
≥ 5/16 [8] to < 3/8 [10]	0.078 [2.0]	0.104 [2.6]	0.031 [0.8]
≥ 3/8 [10] to < 7/16 [11]	0.091 [2.3]	0.125 [3.2]	0.031 [0.8]
≥ 7/16 [11] to < 1/2 [13]	0.109 [2.8]	0.146 [3.7]	0.031 [0.8]
≥ 1/2 [13] to < 9/16 [14]	0.125 [3.2]	0.168 [4.3]	0.031 [0.8]
≥ 9/16 [14] to < 5/8 [16]	0.142 [3.6]	0.188 [4.8]	0.031 [0.8]
≥ 5/8 [16] to < 11/16 [17]	0.156 [4.0]	0.210 [5.3]	0.031 [0.8]
≥ 11/16 [17] to < 3/4 [20]	0.156 [4.0]	0.230 [5.8]	0.031 [0.8]
≥ 3/4 [20] to ≤ 2 [50]	0.156 [4.0]	0.250 [6.4]	0.031 [0.8]
> 2 [50]	0.156 [4.0]	0.375 [9.5]	0.063 [1.6]

^a This table contains examples only.

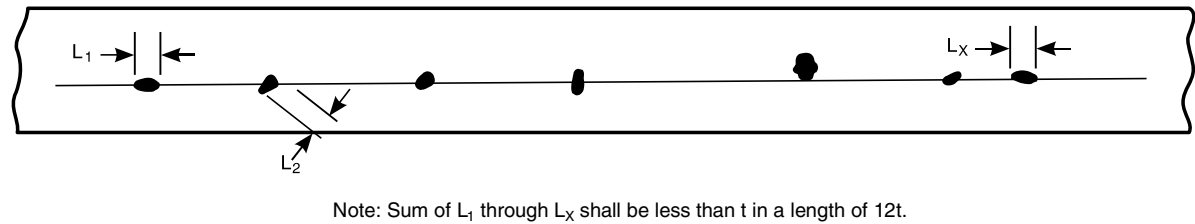
- (1) 1/10 of t for t less than 1/8 in [3 mm];
- (2) 1/64 in [0.4 mm] for t from 1/8 in [3 mm] to 1/4 in [6 mm], incl.;
- (3) 1/32 in [0.8 mm] for t greater than 1/4 in [6 mm] to 2 in [50 mm], incl.;
- (4) 1/16 in [2 mm] for t greater than 2 in [50 mm].

D3.3.2.3 Maximum Size of Rounded Indications. The maximum permissible size of any indication shall be 1/4 of t, or 5/32 in [4 mm], whichever is smaller; except that an isolated indication separated from an adjacent indication by 1 in [25 mm] or more may be 1/3 t or 1/4 in [6 mm].

D3.3.2.4 Aligned Rounded Indications. Aligned rounded indications are acceptable when the summation of the diameters of the indications is less than t in a length of 12t (see Figure D.5). The length of groups of aligned rounded indications and the spacing between the groups shall meet the requirements of Figure D.6.

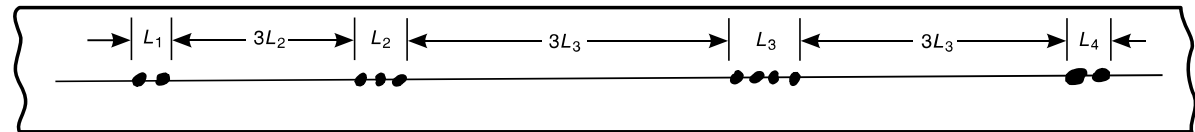
D3.3.2.5 Spacing. The distance between adjacent rounded indications is not a factor in determining acceptance or rejection, except as required for isolated indications or groups of aligned indications.

D3.3.2.6 Rounded Indication Charts. The rounded indications characterized as imperfections shall not exceed that shown in the charts. The charts in Figures D.7 through D.12 illustrate various types of assorted, randomly dispersed and clustered rounded indications for different weld thicknesses greater than 1/8 in [3 mm]. These charts represent the maximum acceptable concentration limits for rounded indications. The charts for each thickness range represent full-



Adapted from ASME *Boiler and Pressure Vessel Code*, 2004 Section VIII, Division 1, Appendix 4, Figure 4.1 with permission from ASME.

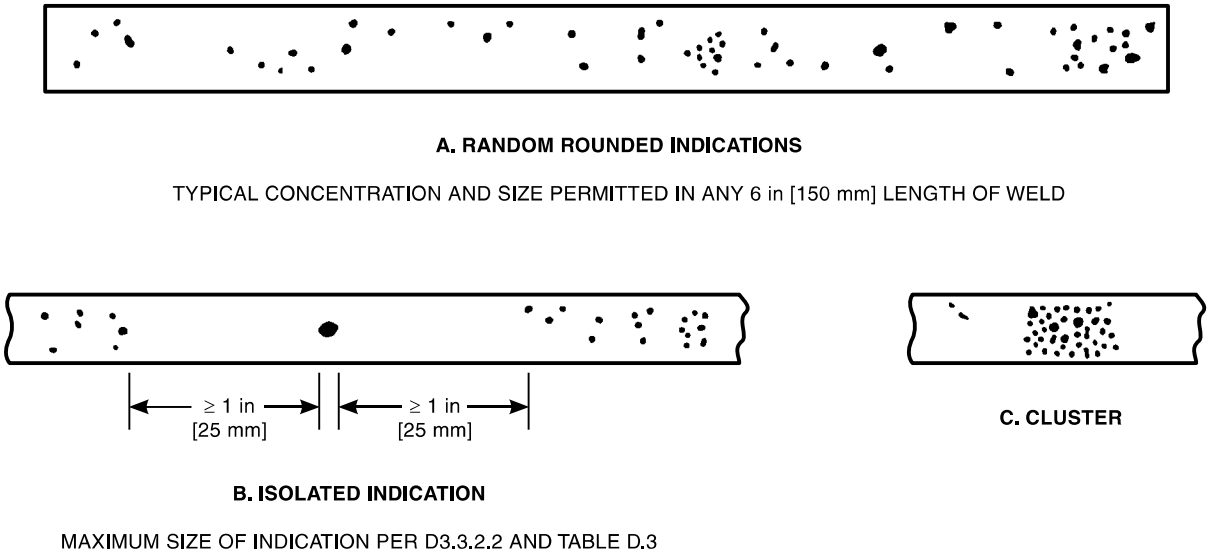
Figure D.5—Examples of Aligned Rounded Indications



Note: Sum of the group lengths shall be less than t in a length of 12t.	
Maximum Group Length	Minimum Spacing Between Groups
L = 1/4 in [6 mm] for t < 3/4 in [20 mm]	
L = 1/3t for 3/4 in [20 mm] ≤ t ≤ 2-1/4 in [57 mm]	
L = 3/4 in [20 mm] for t > 2-1/4 in [57 mm]	
3L where L is the length of the longest adjacent group being evaluated	

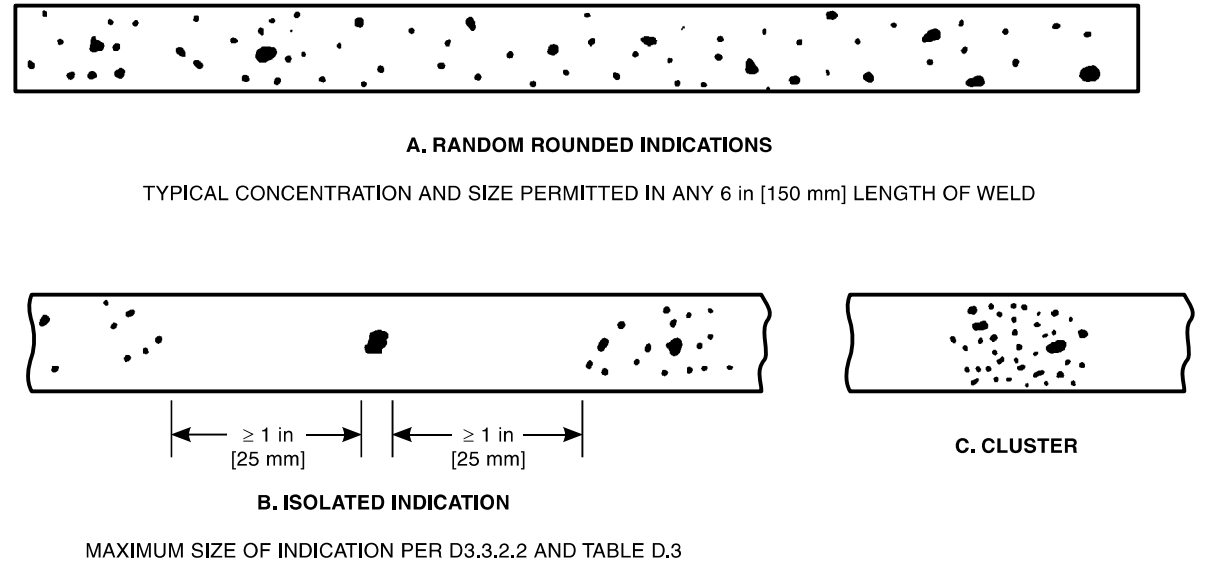
Adapted from ASME *Boiler and Pressure Vessel Code*, 2004 Section VIII, Division 1, Appendix 4, Figure 4.2 with permission from ASME.

Figure D.6—Examples of Groups of Aligned Rounded Indications



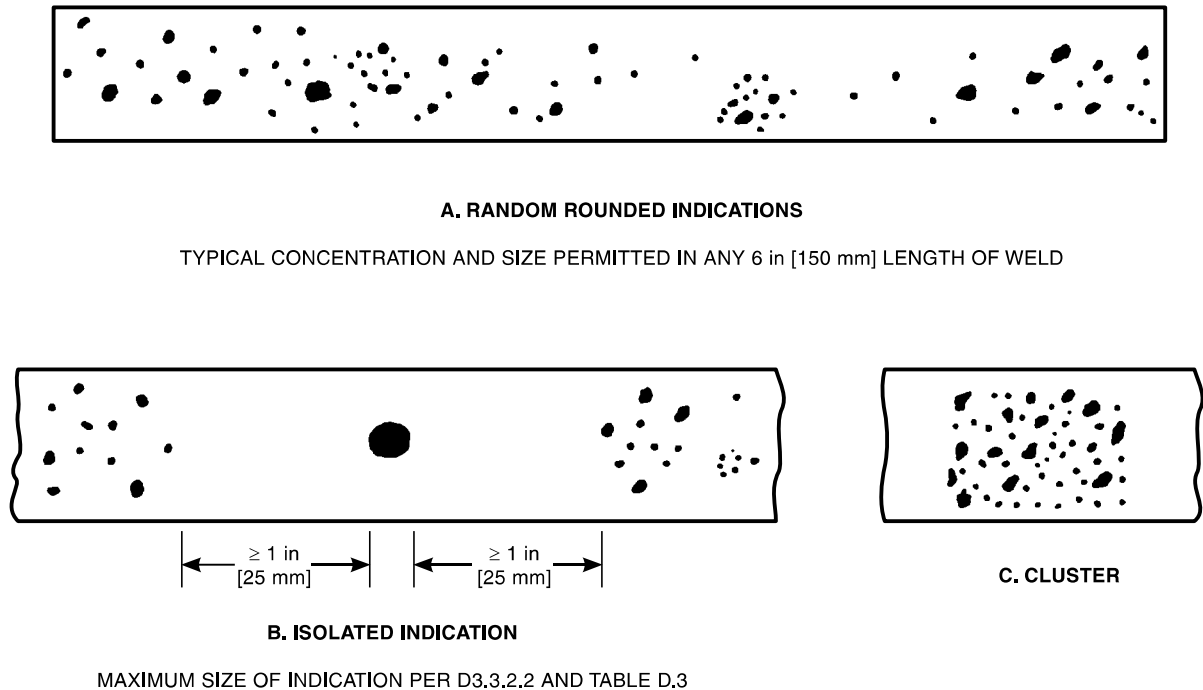
Adapted from ASME *Boiler and Pressure Vessel Code*, 2004 Section VIII, Division 1, Appendix 4, Figure 4.3 with permission from ASME.

Figure D.7—Charts for Thickness Equal to 1/8 in to 1/4 in [3 mm to 6 mm], Inclusive



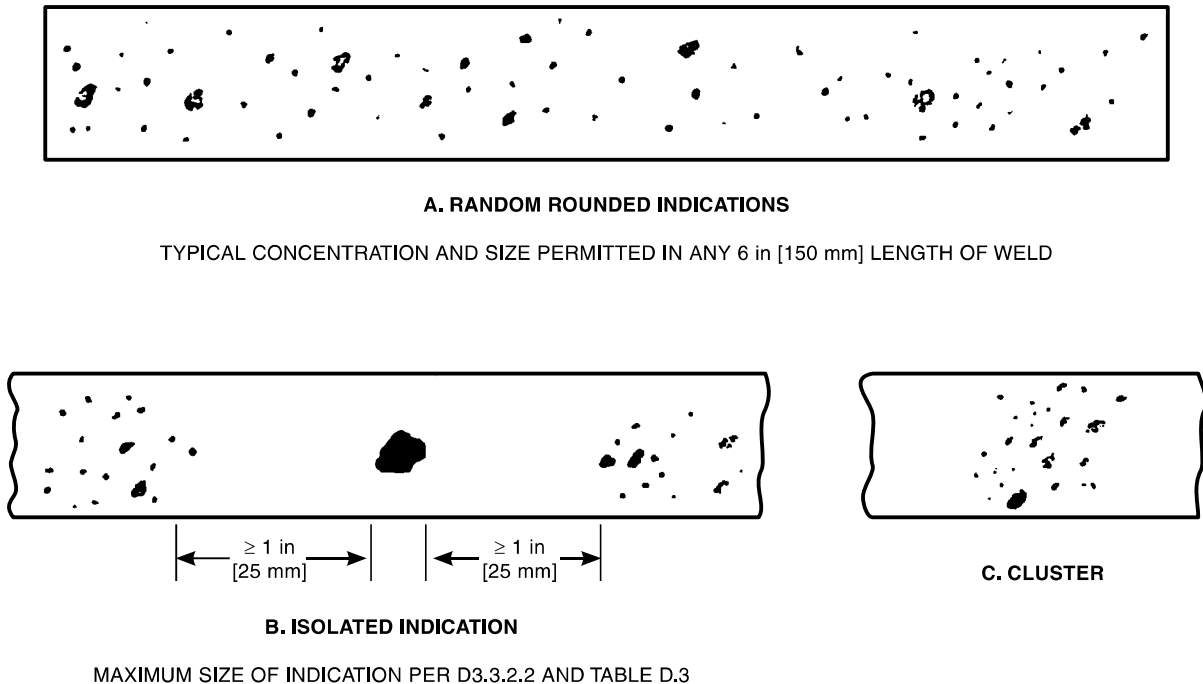
Adapted from ASME *Boiler and Pressure Vessel Code*, 2004 Section VIII, Division 1, Appendix 4, Figure 4.4 with permission from ASME.

Figure D.8—Charts for Thickness Over 1/4 in to 3/8 in [6 mm to 10 mm], Inclusive



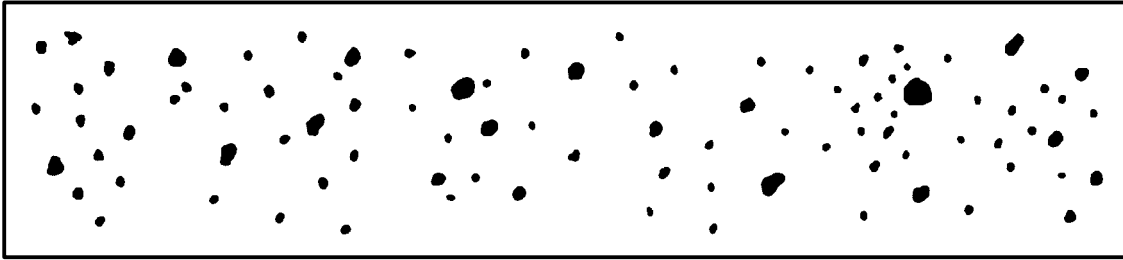
Adapted from ASME *Boiler and Pressure Vessel Code*, 2004 Section VIII, Division 1, Appendix 4, Figure 4.5 with permission from ASME.

Figure D.9—Charts for Thickness Over 3/8 in to 3/4 in [10 mm to 20 mm], Inclusive

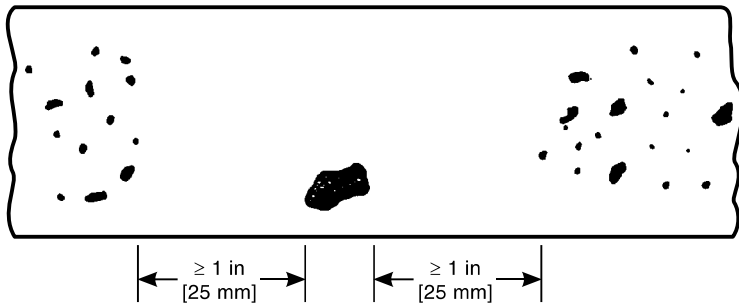


Adapted from ASME *Boiler and Pressure Vessel Code*, 2004 Section VIII, Division 1, Appendix 4, Figure 4.6 with permission from ASME.

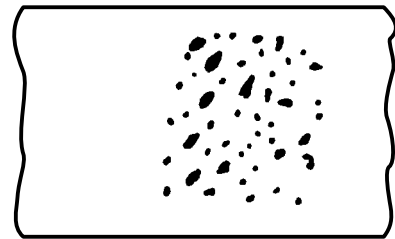
Figure D.10—Charts for Thickness Over 3/4 in to 2 in [20 mm to 50 mm], Inclusive

**A. RANDOM ROUNDED INDICATIONS**

TYPICAL CONCENTRATION AND SIZE PERMITTED IN ANY 6 in [150 mm] LENGTH OF WELD

**B. ISOLATED INDICATION**

MAXIMUM SIZE OF INDICATION PER D3.3.2.2 AND TABLE D.3

**C. CLUSTER**Adapted from ASME *Boiler and Pressure Vessel Code*, 2004 Section VIII, Division 1, Appendix 4, Figure 4.7 with permission from ASME.**Figure D.11—Charts for Thickness Over 2 in to 4 in [50 mm to 100 mm], Inclusive**

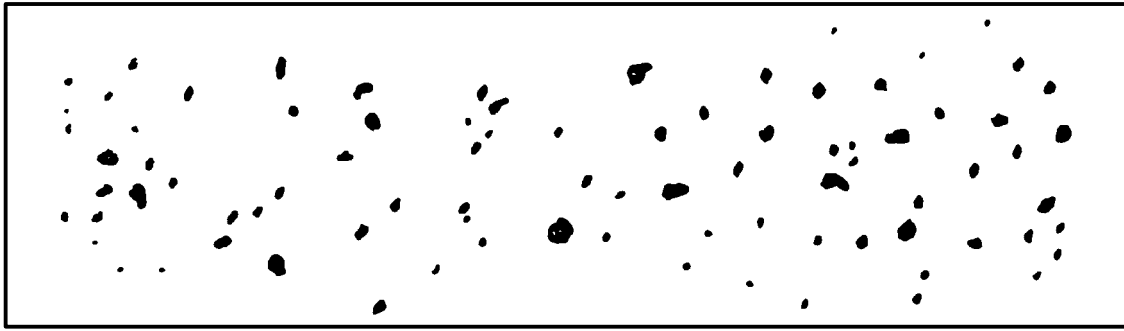
scale 6 in [150 mm] radiographs and shall not be enlarged or reduced. The distributions shown are not necessarily the patterns that may appear on the radiograph, but are typical of the concentration and size of indications permitted.

D3.3.2.7 Weld Thickness t less than 1/8 in [3 mm]. For t less than 1/8 in [3 mm], the maximum number of rounded indications shall not exceed twelve in a 6 in [150 mm] length of weld. A proportionally fewer number of indications shall be permitted in welds less than 6 in [150 mm] in length.

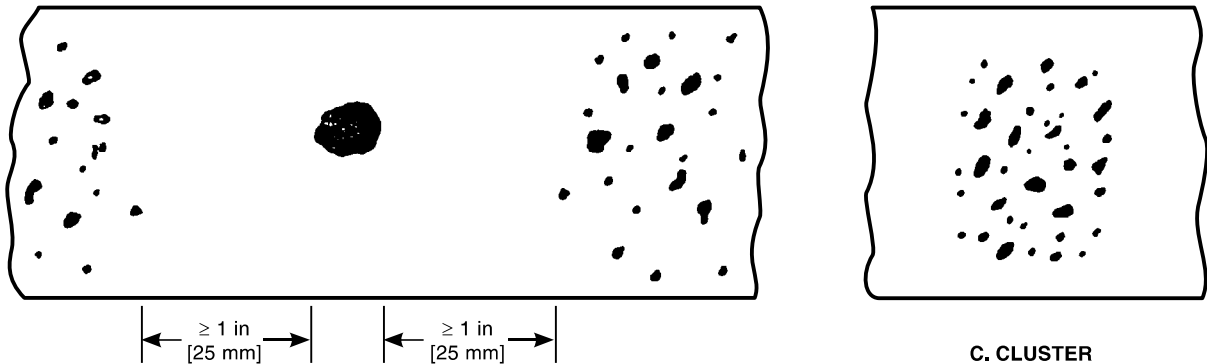
D3.3.2.8 Clustered Indications. The illustrations for clustered indications show up to four times as many indications in a local area as that shown in the illustrations for random indications. The length of an acceptable cluster shall not exceed the lesser of 1 in [25 mm] or $2t$. Where more than one cluster is present, the sum of the lengths of the clusters shall not exceed 1 in [25 mm] in a 6 in [150 mm] length weld.

D3.3.2.9 Unacceptable Indications. Any type of crack, incomplete fusion, or incomplete joint penetration is not acceptable.

- (1) Any indication characterized as a crack or zone of incomplete fusion or penetration;
- (2) Any other elongated indication on the radiograph which has length greater than:
 - (a) 1/4 in [6 mm] for $t \leq 3/4$ in [20 mm];

**A. RANDOM ROUNDED INDICATIONS**

TYPICAL CONCENTRATION AND SIZE PERMITTED IN ANY 6 in [150 mm] LENGTH OF WELD

**B. ISOLATED INDICATION**

MAXIMUM SIZE OF INDICATION PER D3.3.2.2 AND TABLE D.3

C. CLUSTERAdapted from ASME *Boiler and Pressure Vessel Code*, 2004 Section VIII, Division 1, Appendix 4, Figure 4.8 with permission from ASME.**Figure D.12—Charts for Thickness Over 4 in [100 mm]**

- (b) $1/3t$ for $t > 3/4$ in [20 mm] to $\leq 2-1/4$ in [57 mm]; or
- (c) $3/4$ in [20 mm] for $t > 2-1/4$ in [57 mm]

where

t = the thickness of the weld excluding any allowable reinforcement. For butt weld joining two members having different thicknesses at the weld, t is the thinner of these two thicknesses. If a full penetration weld includes a fillet weld, the thickness of the throat of the fillet shall be included in t .

(3) Any group of aligned indications that have an aggregate length greater than t in a length of $12t$ except when the distance between the successive imperfections exceeds $6L$ where L is the length of the longest imperfection in the group.

(4) Rounded indications in excess of that specified by the acceptance standards given in Annex D.

D3.4 Defect Removal and Repair. Unacceptable imperfections shall be removed and re-examination made to assure the complete removal. Whenever a defect is removed and subsequent repair by welding is not required, the excavated area shall be blended into the surrounding surface so as to avoid sharp notches, crevices, or corners. Where welding is required after removal of a defect, the area shall be cleaned, and the welding shall be performed in conformance to a qualified welding procedure. Complete repairs shall be re-examined by the method originally used for detection of the defect. (See Clause 8, Modifications and Repair, for mandatory requirements.)

D3.5 Examination, Report, and Disposition of Radiographs

D3.5.1 The Manufacturer, Fabricator, or Repair Organization shall provide a suitable high intensity viewer with sufficient capacity to illuminate radiographs with a density of 4.0 without difficulty. (It is recommended that a two level or variable intensity illuminator be used.)

To aid in the proper interpretation of radiographs, details of the radiographic examination setup utilized shall accompany each group of radiographs as described below:

- (1) Contract Number/Component name/Drawing number
- (2) Weld seam identification and/or location
- (3) Serial number if applicable
- (4) Film density ranges, type of film and manufacture
- (5) Source to film distance
- (6) Focal spot size
- (7) Type of source or radiographic device

D3.5.2 Before a weld subjected to radiographic testing by the Manufacturer, Fabricator, or Repair Organization is accepted, all of its final radiographs and the report interpreting them shall be available to the Buyer's Inspector.

D3.5.3 A full set of final radiographs for welds subject to radiographic testing by the Manufacturer, Fabricator, or Repair Organization shall be delivered to the purchaser upon completion of the work, if required by contract.

D3.5.4 The Manufacturer, Fabricator, or Repair Organization shall maintain final radiographs for a minimum of five years after completion of contract.

D4. Ultrasonic Inspection of Groove Welds in Butt, T-, and Corner J Joints

D4.1 General Requirements

D4.1.1 The procedures and standards set forth in this clause govern the ultrasonic inspection of groove welds between the thicknesses of 5/16 in [8 mm] and 8 in [200 mm] inclusive. These procedures and standards shall not be used as a basis for rejection of the base metal.

D4.1.2 Variations in testing procedure, equipment, and acceptable standards not included in this clause may be used by agreement between the Manufacturer and Buyer. Such variations include other thicknesses, weld geometries, transducer sizes, frequencies, and couplants.

D4.1.3 Personnel performing ultrasonic examinations shall be qualified and certified by the American Society for Nondestructive Testing requirements (SNT-TC-1A), Level II minimum.

D4.1.4 Information furnished to bidders shall clearly identify the extent of ultrasonic testing required.

D4.1.5 Complete testing, when specified by contractual agreement, requires testing of the entire length of the weld in each designated joint.

D4.1.6 Spot testing, when specified by contractual agreement, requires that the number of spots in each designated category of weld or the number required to be made in a stated length of weld, be included in the information furnished to bidders. When spot testing reveals discontinuities that require repair, two adjacent spots shall be tested. If discontinuities requiring repair are revealed in either of these, the entire length of the weld in that joint shall be tested ultrasonically.

D4.1.7 Ultrasonic calibration blocks shall be manufactured from material similar to the production part under examination.

D4.2 Ultrasonic Testing Equipment and Calibration

D4.2.1 The apparatus for ultrasonic examination shall meet the requirements of ASTM E 164, *Recommended Practices for Ultrasonic Contact examination of Weldments*, and ASTM E 317, *Recommended Practices for Evaluating Performance Characteristics of Pulse-Echo Ultrasonic Testing Systems*. Refer to ASTM E 1316, *Terminology for Non-destructive Examinations*, for standard terminology regarding ultrasonic testing.

D4.2.2 Test instruments shall include internal stabilization so that, after warmup, no variation in response greater than ± 1 dB occurs with supply voltage changes of $\pm 15\%$ from nominal or, in the case of battery powered instruments, over the battery's charged operating endurance. There shall be an alarm or meter to signal a drop in battery voltage prior to instrument shutoff due to battery exhaustion.

D4.2.3 The test instrument shall have a calibration gain control (attenuator) adjustable in discrete 1 dB or 2 dB steps over a range of at least 60 dB.

D4.2.4 The dynamic range of the instrument's display shall be such that a difference of 1 dB of amplitude can be easily detected.

D4.2.5 Each search unit shall be marked to clearly indicate the frequency of the transducer, nominal angle of refraction, and index point.

D4.2.6 Preferred couplants are a cellulose gum-water mixture, and glycerine with a wetting agent. Where possible, avoid the use of oil or grease as the couplant for examination of welds. If oil or grease is used as a couplant, the requirements of 7.2.1 must be met before any repairs are made.

D4.2.7 The horizontal linearity of the test instrument shall be within $\pm 5\%$ over the linear range that includes 90% of the sweep length presented on the display for the longest sound path to be used. The horizontal linearity shall be measured by the techniques prescribed in 7.9 of ASTM E 317, except that the results may be tabulated rather than graphically represented. Horizontal linearity shall be checked after each 40 hours of instrument use.

D4.2.8 Internal reflections from the search unit, with a screen presentation higher than the horizontal reference line, appearing on the screen to the right of the sound entry point shall not occur beyond $1/2$ in [13 mm] equivalent distance in steel when the sensitivity is as follows: 20 dB more than that required to produce a maximized horizontal reference-line height indication from the 0.060 in [1.5 mm] diameter hole in the International Institute of Welding (IIW) reference block (see ASTM E 164, *Recommended Practices for Ultrasonic Contact Examination of Weldments*, and ASTM E 317, *Practice for Evaluating Performance Characteristics of Pulse-Echo Ultrasonic Testing Systems Without the Use of Electronic Measurement Instruments*). Refer to ASTM E 1316, *Terminology for Nondestructive Examinations*.

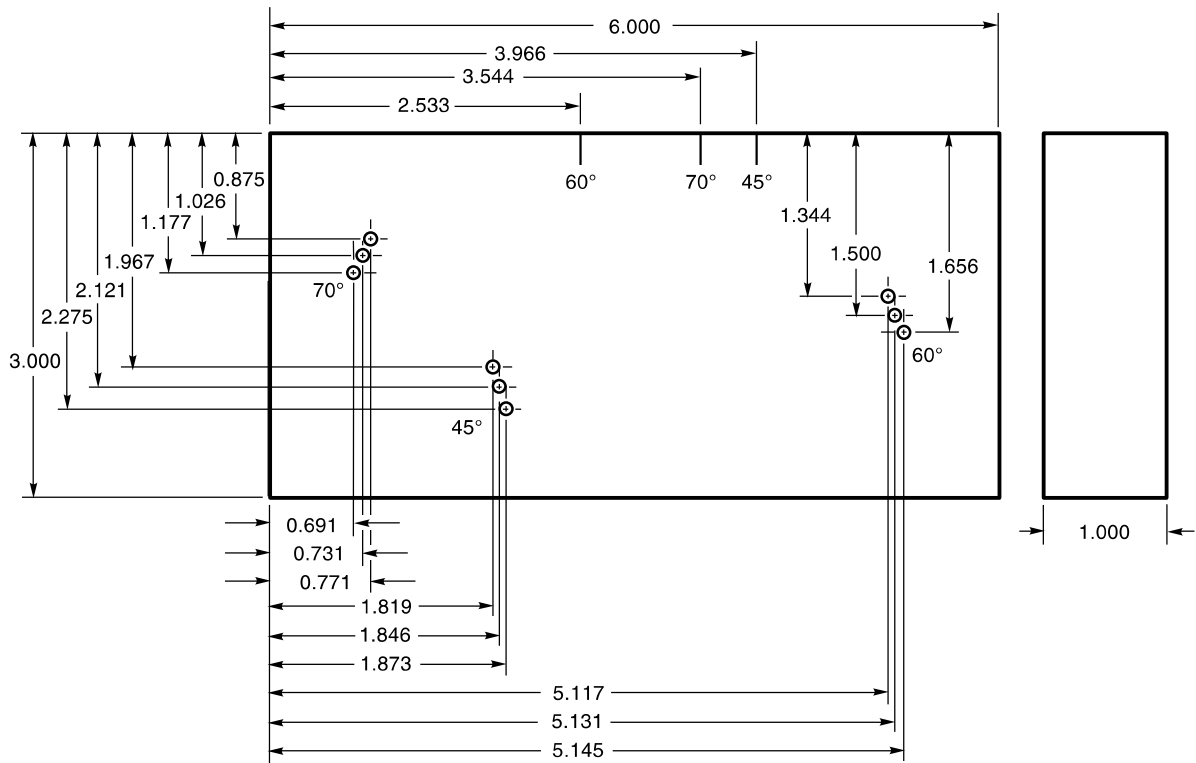
D4.2.9 The dimensions of search unit shall be such that the minimal allowable distance, X, between the toe of the search unit and the edge of the IIW block, shall be as follows:

- (1) 70° transducer, X = 2 in [50 mm]
- (2) 60° transducer, X = $1-7/16$ in [37 mm]
- (3) 45° transducer, X = 1 in [25 mm]

The search unit shall be positioned for maximum indication from the 0.060 in [1.5 mm] diameter hole in the IIW calibration block.

D4.2.10 Resolution

D4.2.10.1 For shear waves, the combination of search unit and instrument shall resolve the appropriate three holes in the resolution test block shown in Figure D.13. For a 70° angle, the transducer should be set in position Q on the resolution block. The resolution shall be evaluated with the instrument controls set at normal test settings, and with indications from the holes brought to midscreen height. Resolution shall be sufficient to distinguish at least the peaks of indication from the three holes.



Note: All holes are 0.060 inch in diameter.

DIMENSIONS IN INCHES

RC – RESOLUTION REFERENCE BLOCK

Source: Adapted from AWS D1.1/D1.1M:2010, *Structural Welding Code—Steel*, Figure 6.20.

Figure D.13—RC-Resolution Reference Block in Inches and Millimeters

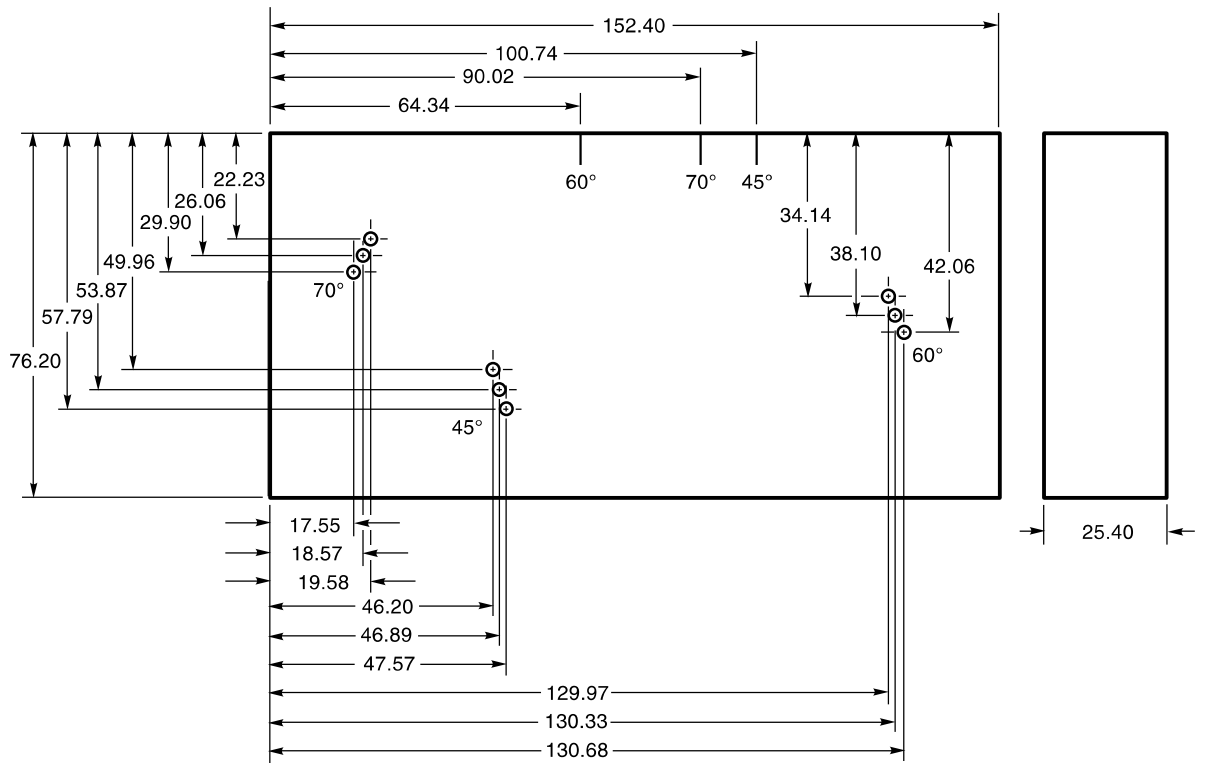
D4.2.10.2 To determine longitudinal wave resolution, the instrument controls must be at normal settings with indication from the holes brought to midscreen height (see Figure D.14).

- (1) Set the transducer in position F on the IIW block.
- (2) Transducer and instrument should resolve all three distances.

D4.2.11 The IIW ultrasonic reference block, shown in ASTM E 164, shall be the standard used for both distance and sensitivity calibration. More portable reference blocks of other designs may be used, provided they meet the requirements of this specification and are referenced back to the IIW block. Approved designs are shown in ASTM E 164. See Figure D.14 for application.

D4.2.12 Using a corner reflector for calibration purposes is prohibited.

D4.2.13 The gain control (attenuator) of the instrument shall meet the requirements of D4.2.3 and shall be checked for correct calibration at three month intervals in accordance with a procedure approved by the manufacturer of the instrument.



Note: All holes are 1.5 mm in diameter.

DIMENSIONS IN MILLIMETERS

RC – RESOLUTION REFERENCE BLOCK

Source: Adapted from AWS D1.1/D1.1M:2010, *Structural Welding Code—Steel*, Figure 6.20.

Figure D.13 (Continued)—RC-Resolution Reference Block in Inches and Millimeters

D4.2.14 With the use of an approved calibration block, each angle-beam search unit shall be checked after each eight hours of use to determine the following:

- (1) The contact face is flat.
- (2) The sound entry point is correct.
- (3) The beam angle is within the permitted $\pm 2^\circ$ tolerance.

Search units that do not meet these requirements shall be corrected or replaced.

D4.2.15 Calibration for sensitivity and horizontal sweep (distance) shall be made at the location of testing by the ultrasonic operator just prior to examination of each weld and at intervals of 30 minutes during examination. Recalibration shall be made when:

- (1) There is a change of operators,
- (2) Transducers are changed,
- (3) New batteries are installed, or

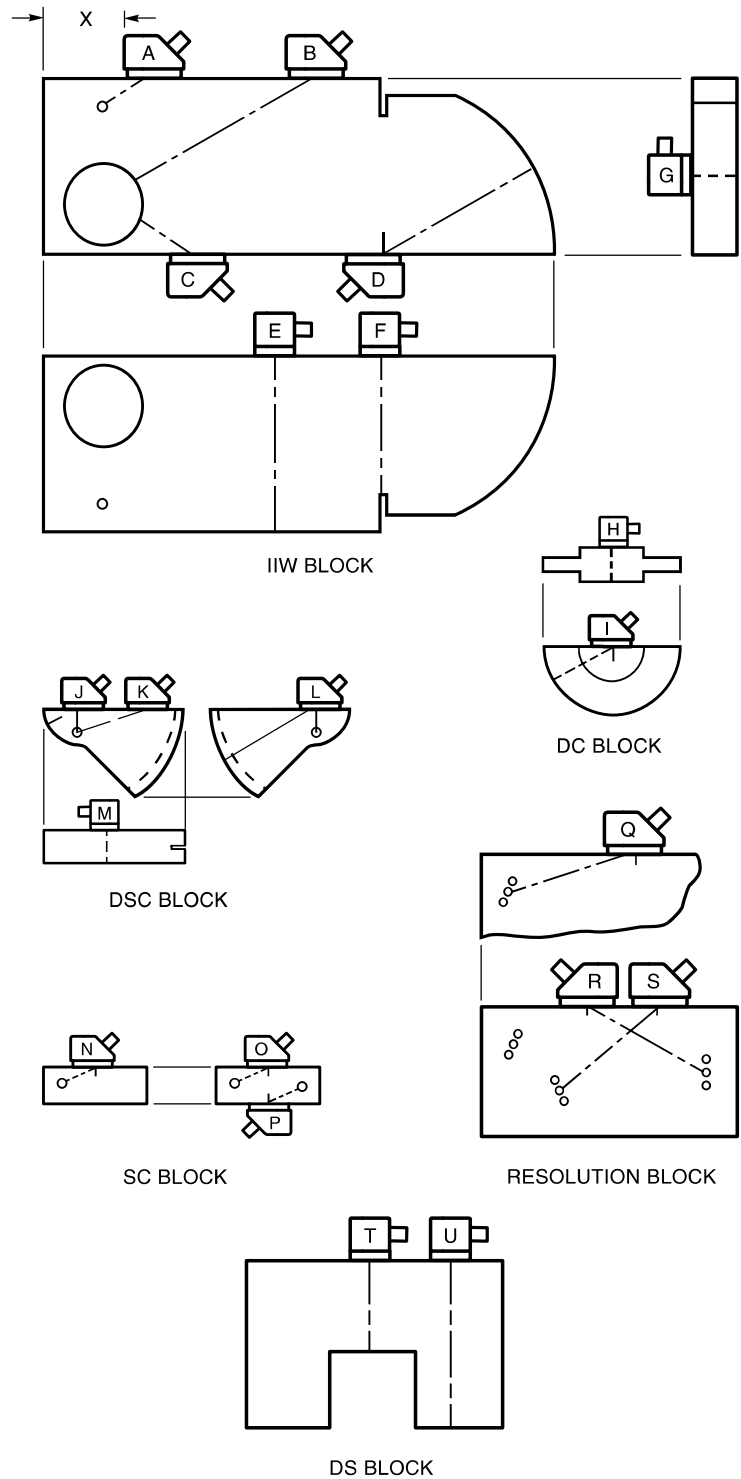


Figure D.14—Typical Transducer Positions

(4) Equipment operating from a 110 V source is connected to a different power outlet.

D4.2.16 Calibration for straight beam testing shall be performed as follows:

(1) The horizontal sweep shall be adjusted for distance calibration to present the equivalent of at least two plate thicknesses on the display.

(a) Set the transducer in position G on the IIW block, position H on the DC block, or position M on the DSC block (see Figure D.14).

(b) Adjust instrument to produce indications at 1 in [25 mm], 2 in [50 mm], 3 in [75 mm], 4 in [100 mm], etc. on the display.

(2) The sensitivity (gain) shall be adjusted at a location free of indications so that the first back reflection from the far side of the plate will be 50% to 70% of full screen height. For this purpose, the reject (clipping) control shall be turned off.

D4.2.17 Calibration for angle beam testing shall be performed as follows:

(1) The horizontal sweep shall be adjusted to represent the actual sound-path distance by using acceptable distance calibration blocks shown in Figure D.14. This distance calibration shall be made using either the 5 in [125 mm] scale or the 10 in [250 mm] scale on the display, whichever is appropriate, unless joint configuration or thickness prevents full examination of the weld at either of these settings.

(a) Set the transducer in position D on the IIW block (any angle).

(b) Adjust the instrument to obtain indications on the display at 4 in [100 mm] and 9 in [230 mm] from a Type 1 block, or at 4 in [100 mm] and 8 in [200 mm] from a Type 2 block.

(c) Set the transducer in position J or L on the DSC block (any angle).

(d) Adjust the instrument to obtain indications on the display at 1 in [25 mm], 5 in [125 mm], 9 in [230 mm] in the J position, or at 3 in [75 mm], and 7 in [175 mm] in L position.

(e) Set the transducer in position I on the DC block (any angle).

(f) Adjust the instrument to obtain indications on the display at 1 in [25 mm], 2 in [50 mm], 3 in [75 mm], 4 in [100 mm], and so forth.

(2) With the unit adjusted to conform with the requirements of D4.2.1 through D4.2.10 the sensitivity shall be adjusted by the use of the gain control (attenuator) so that a horizontal reference-level trace deflection results on the display with the maximum indication from the 0.060 in [1.5 mm] diameter hole in the IIW block or from the equivalent references reflector in other acceptable calibration blocks. This basic sensitivity then becomes the zero reference level for discontinuity evaluation and shall be recorded on the ultrasonic test reports under reference level. See Annex B for a sample ultrasonic test report form.

(a) Set the transducer in position A on the IIW block (any angle).

(b) Adjust the maximized signal from the 0.060 in [1.5 mm] hole to attain a horizontal reference-line height indication of 50% to 80%.

(c) Set the transducer in position L on the DSC block (any angle).

(d) Adjust the maximized signal from the 1/32 in [0.8 mm] slot to attain a horizontal reference-line height indication of 50% to 80%.

(e) Set the transducer on the SC block in position N for 70° angle, position O for 45° angle, or position P for 60° angle.

(f) Adjust the maximized signal from the 0.060 in [1.5 mm] hole to attain a horizontal reference-line height indication of 50% to 80%.

(g) The decibel reading obtained in (f) shall be used as the reference level, b, reading on the report sheet (see Annex B).

D4.3 Ultrasonic Testing Procedure, Acceptance Criteria, and Reports

D4.3.1 The letter Y accompanied by a weld identification number shall be clearly marked on the base metal adjacent to the weld at the left end of each weld that is ultrasonically examined. This identification number serves as an orientation direction for weld discontinuity location and as the report number on the report form (see Annex B for suggested report form).

D4.3.2 All surfaces to which a search unit is applied shall be free of weld spatter, dirt, grease, oil, (other than that used as a couplant) and loose scale and shall have a contour permitting intimate coupling. Tight layers of paint need not be removed unless their combined thickness exceeds 0.010 in [0.25 mm].

D4.3.3 A couplant shall be used between the search unit and the metal. The couplant should be either glycerine with a wetting agent, if needed, or a cellulose gum and water mixture of a suitable consistency.

D4.3.4 The entire base material through which ultrasonic sound must travel to test the weld shall be examined for laminar reflectors by utilizing a straight beam search unit conforming to the requirements of D4.2. If the base material exhibits a total loss of back reflection or an indication equal to or greater than the original back reflection height is noted and located in a position that would interfere with the normal shear wave scanning procedures, then the following applicable alternate weld scanning procedures in D4.3.4.1 through D4.3.4.4, shall be utilized as necessary to attain full weld inspection coverage. Alternate weld procedure inspection may also be conducted in accordance with ASTM E 164.

D4.3.4.1 The area of the laminar reflector and its depth from the surface shall be determined and reported on the ultrasonic test report.

D4.3.4.2 Weld surface(s) shall be ground flush.

D4.3.4.3 Testing from faces A and B shall be performed.

D4.3.4.4 Other search unit angles shall be utilized.

D4.3.5 Scanning Patterns (See Figure D.15)

(1) Longitudinal Discontinuities. Scanning patterns shall consist of the following combined movements:

(a) Scanning movement A—Rotation angle, a , equals 10° .

(b) Scanning movement B—Scanning distance, b , shall be sufficient to ensure that the section of weld being examined is covered.

(c) Scanning movement C—Progression distance, c , shall be approximately one-half of the transducer width.

(2) Transverse Discontinuities

(a) Scanning pattern D—when welds are ground flush.

(b) Scanning pattern E—when weld is not ground flush.

(c) Scanning angle $e = 15^\circ$ maximum.

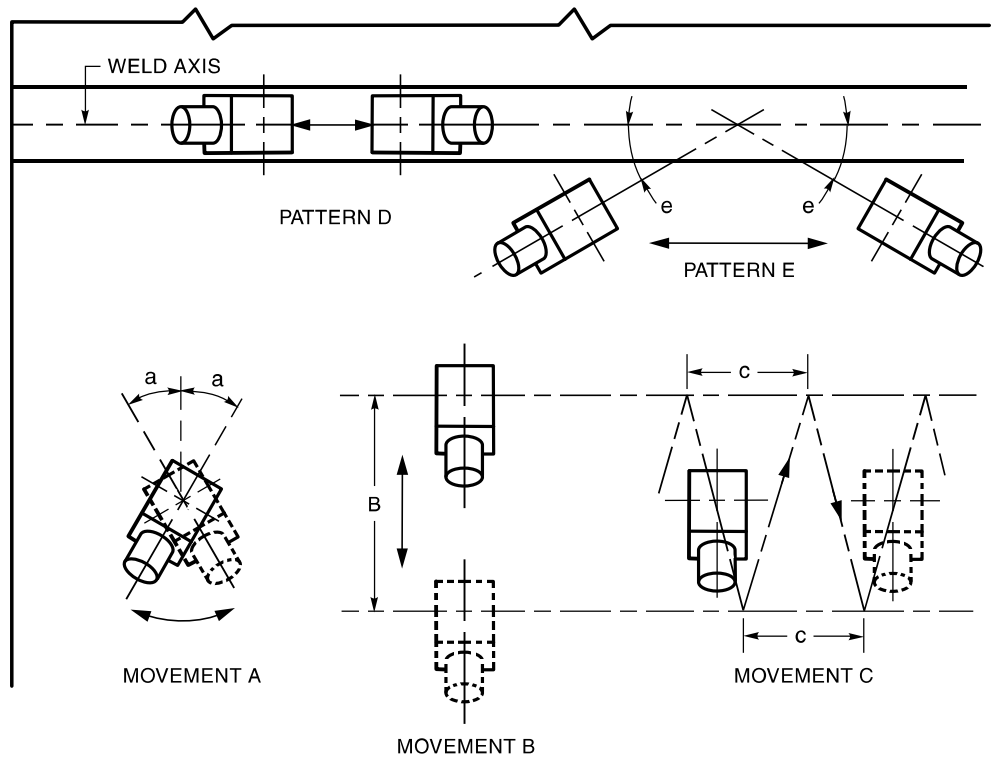
(d) Scanning pattern shall ensure the full weld section is covered.

D4.3.6 Welds shall be examined using an angle beam search unit conforming to the requirements of D4.2 and ASTM E 164. Following calibration and during testing, the only instrument adjustment permitted is in the sensitivity-level adjustment with the calibrated gain control or attenuator. Sensitivity shall be increased from the reference level for weld scanning in accordance with Table D.5.

D4.3.6.1 If mechanically possible, all welds shall be scanned from both sides on the same face for longitudinal and transverse discontinuities. The applicable scanning pattern, or patterns, shown in Figure D.15 shall be used.

D4.3.6.2 The testing angle shall be as shown in Table D.4.

D4.3.6.3 When a discontinuity indication appears on the screen, the maximum attainable indication from the discontinuity shall be adjusted to produce a horizontal reference level trace deflection on the display. This adjustment shall be made with the calibration gain control or attenuator, and the instrument reading in decibels shall be recorded on the ultrasonic test report under the heading Indication Level, a .



Notes:

1. Testing patterns are all symmetrical around the weld axis with the exception of pattern D, which shall be conducted directly over the weld axis.
2. Testing from both sides of the weld axis shall be made wherever mechanically possible.

Source: AWS D1.1/D1.1M:2010, *Structural Welding Code—Steel*, Figure 6.21.

Figure D.15—Plan View of UT Scanning Patterns

D4.3.6.4 The attenuation factor, c , on the test report is attained by subtracting 1 in [25 mm] from the sound-path distance and multiplying the remainder by 2.

D4.3.6.5 The indication rating, d , on the test report is the difference between the reference level and the indication level after the indication level has been corrected by the attenuation factor.

Instruments with gain in dB: $a - b - c = d$

Instruments with attenuation in dB: $b - a - c = d$

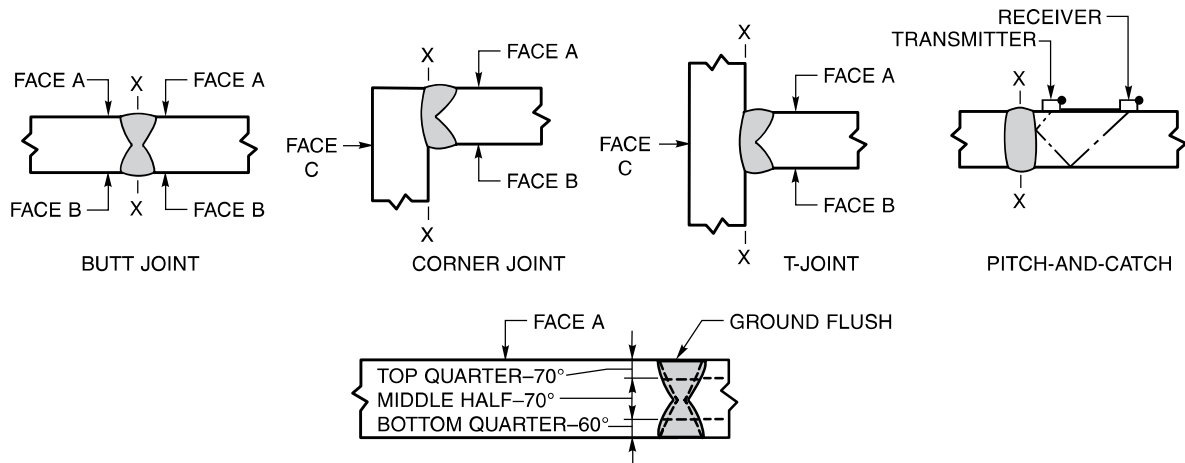
D4.3.6.6 The length of a discontinuity, as entered under indication length on the test report, shall be determined by locating the points at each end at which the indication amplitude drops 6 dB (50%) and measuring between the center-lines of those transducer locations.

D4.3.6.7 Each weld discontinuity shall be accepted or rejected on the basis of its indication rating and its length in accordance with Table D.5. Only those discontinuities which are rejectable need be recorded on the test report.

D4.3.7 Each rejectable discontinuity shall be indicated on the weld by a mark directly over the discontinuity for its entire length. The depth from the surface and type of discontinuity shall be noted on nearby base metal.

Table D.4
Ultrasonic Procedure Testing Angle

Procedure Chart																		
Material Thickness, in [mm]																		
Weld Type	5/16 [8] to ≤ 1-1/2 [38]		> 1-1/2 [38] to ≤ 1-3/4 [45]		> 1-3/4 [45] to ≤ 2-1/2 [60]		> 2-1/2 [60] to ≤ 3-1/2 [90]		> 3-1/2 [90] to ≤ 4-1/2 [110]		> 4-1/2 [110] to ≤ 5 [130]		> 5 [130] to ≤ 6-1/2 [160]		> 6-1/2 [160] to ≤ 7 [180]		> 7 [180] to ≤ 8 [200]	
	Prim.	Sec.*	Prim.	Sec.*	Prim.	Sec.*	Prim.	Sec.*	Prim.	Sec.*	Prim.	Sec.*	Prim.	Sec.*	Prim.	Sec.*	Prim.	Sec.*
Butt Joint	1	0	1	F	1G or 4	F	1G or 5	F	6 or 7	F	8 or 10	F	9 or 11	F	12 or 13	F	12	F
T-Joint	1	0	1	F or XF	4	F or XF	5	F or XF	7	F or XF	10	F or XF	11	F or XF	13	F or XF	—	—
Corner Joint	1	0	1	F or XF	1G or 4	F or XF	1G or 5	F or XF	6 or 7	F or XF	8 or 10	F or XF	9 or 11	F or XF	13 or 14	F or XF	—	—
Electrogas & Electroslag	1	0	1	0	1G or 4	1**	1G or 3	P1 or P3	6 or 7	P3	11 or 15	P3	11 or 15	P3	11 or 15	P3	11 or 15**	P3



Notes:

- Where possible, all examinations shall be made from Face A and in Leg 1, unless otherwise specified in this table.
- Root areas of single groove weld joints which have backing not requiring removal by contract, shall be tested in Leg 1, where possible, with Face A being that opposite the backing. (Grinding of the weld face or testing from additional weld faces may be necessary to permit complete scanning of the weld root.)
- Examination in Leg II or III shall be made only to satisfy provisions of this table or when necessary to test weld areas made inaccessible by an unground weld surface, or interference with other portions of the weldment, or to meet the requirements of 6.26.6.2.
- A maximum of Leg III shall be used only where thickness or geometry prevents scanning of complete weld areas and HAZs in Leg I or Leg II.
- On tension welds in cyclically loaded structures, the top quarter of thickness shall be tested with the final leg of sound progressing from Face B toward Face A, the bottom quarter of thickness shall be tested with the final leg of sound progressing from Face A toward Face B; i.e., the top quarter of thickness shall be tested either from Face A in Leg II or from Face B in Leg I at the contractor's option, unless otherwise specified in the contract documents.
- The weld face indicated shall be ground flush before using procedure 1G, 6, 8, 9, 12, 14, or 15. Face A for both connected members shall be in the same plane.

(See Legend on next page)

Table D.4 (Continued)
Ultrasonic Procedure Testing Angle

Legend:

X — Check from Face “C.”

G — Grind weld flush.

O — Not required.

A Face — The face of the material from which the initial scanning is done (on T- and corner joints follow the appropriate sketches).

B Face — The face opposite the “A” face of the same plate.

C Face — The face opposite the weld on the connecting member or a T- or corner joint.

* — Required only where reference level indication of discontinuity is noted in fusion zone while searching at scanning level with primary procedures selected from first column.

** — Use 15 in [380 mm] or 20 in [510 mm] screen distance calibration.

P — Pitch and catch shall be conducted for further discontinuity evaluation in only the middle half of the material thickness with only 45° or 70° transducers of equal specification, both facing the weld.

(Transducers should preferably be held in a fixture to control positioning—see sketch.) Amplitude calibration for pitch and catch is normally made by calibrating a single search unit. When switching to dual search units for pitch and catch inspection, there should be assurance that this calibration does not change as a result of instrument variables.

F — Further evaluate fusion zone indication with either 70°, 60°, or 45° transducer—whichever sound path is nearest to being perpendicular to the suspected fusion surface.

Procedure Legend			
No.	Location in Weld Thickness		
	Top Quarter	Middle Half	Bottom Quarter
1	70°	70°	70°
2	60°	60°	60°
3	45°	45°	45°
4	60°	70°	70°
5	45°	70°	70°
6	70° G A	70°	60°
7	60° B	70°	60°
8	70° G A	60°	60°
9	70° G A	60°	45°
10	60° B	60°	60°
11	45° B	70°**	45°
12	70° G A	45°	70° G B
13	45° B	45°	45°
14	70° G A	45°	45°
15	70° G A	70° A B	70° G B

D4.3.8 Welds found unacceptable by ultrasonic testing shall be repaired by methods permitted in Clause 9, Weld Repairs, of this specification. Repaired welds shall be reexamined ultrasonically, and an additional report form shall be completed.

D4.3.9 A report form which clearly identifies the work and the area of inspection shall be completed by the ultrasonic inspector at the time of the inspection. The report form for the welds that are unacceptable need only contain sufficient information to identify the weld, the Inspector (by his signature), and the acceptability of the weld. An example of such a form is shown in Annex B.

D4.3.10 All report forms pertaining to a weld that is subject to contractual ultrasonic testing by the Manufacturer for the Buyer, including those that show unacceptable quality prior to repair, shall be available for review by the Buyers representative before the weld is accepted.

D4.3.11 A full set of completed report forms of welds that are subject to contractual ultrasonic testing by the Manufacturer for the Buyer, including those that show unacceptable quality prior to repair, shall be delivered to the Buyer upon completion of the work. The Manufacturer's obligation to retain ultrasonic reports shall cease (1) upon delivery of this full set to the Buyer or (2) at the end of one full year after completion of the Manufacturer's work, in the event that delivery of these reports is not required or as otherwise provided in the contract.

Table D.5
Ultrasonic Acceptance and Rejection Criteria

Flaw Class	Weld Thickness ^a (in [mm]) and Search Unit Angle										
	≥ 5/16 [8] to ≤ 3/4 [20]	> 3/4 [20] to 1-1/2 [38]	> 1-1/2 [38] to ≤ 2-1/2 [65]			> 2-1/2 [65] to ≤ 4 [100]			> 4 [100] to ≤ 8 [200]		
	70°	70°	70°	60°	45°	70°	60°	45°	70°	60°	45°
Class A	+10 & lower	+8 & lower	+4 & lower	+7 & lower	+9 & lower	+1 & lower	+4 & lower	+6 & lower	-2 & lower	+1 & lower	+3 & lower
Class B	+11	+9	+5 +6	+8 +9	+10 +11	+2 +3	+5 +6	+7 +8	-1 0	+2 +3	+4 +5
Class C	+12	+10	+7 +8	+10 +11	+12 +13	+4 +5	+7 +8	+9 +10	+1 +2	+4 +5	+6 +7
Class D	+13 & up	+11 & up	+9 & up	+12 & up	+14 & up	+6 & up	+9 & up	+11 & up	+3 & up	+6 & up	+8 & up

^a Weld thickness shall be defined as the nominal thickness of the thinner of the two parts being joined.

Notes:

- Class B and C flaws shall be separated by at least 2L. L being the length of the longer flaw, except that when two or more flaws are not separated by at least 2L, but the combined length of flaws and their separation distance is equal to or less than the maximum allowable length under the provisions of Class B or S, the flaw shall be considered a single acceptable flaw.
- Class B and C flaws shall not begin at a distance less than 2L from the end of the weld, L being the flaw length.
- Flaws detected at "scanning" level in the root face area of complete penetration double groove weld joints shall be evaluated using an indicating rating 4 dB more sensitive than described in D4.3.6.5 when such welds are designated as "tension welds" on the drawing (subtract 4 dB from the indication rating "d").

Class A (large flaws)
Any indication in this category shall be rejected (regardless of length).

Class B (medium flaws)
Any indication in this category having a length greater than 3/4 in [20 mm] shall be rejected.

Class C (small flaws)
Any indication in this category having a length greater than 2 in [50 mm] in the middle half or 3/4 in [20 mm] length in the top or bottom quarter of weld thickness shall be rejected.

Class D (minor flaws)
Any indication in this category shall be accepted regardless of length or location in the weld.

Scanning Levels	
Sound path ^b in [mm]	Above Zero Reference, dB
through 2-1/2 [65 mm]	20
> 2-1/2 [65] to ≤ 5 [130]	25
> 5 [130] to ≤ 10 [255]	35
> 10 [255] to ≤ 15 [380]	45

^b This column refers to sound path distance; NOT material thickness.

Annex E (Informative)

UT Examination of Welds by Alternative Techniques

This annex 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.

E1. General

The purpose of this annex is to describe alternative techniques for UT examinations of welds. The alternative techniques described within the latest edition of AWS D1.1 are proven methods currently being utilized for other industry applications but not presently detailed within this specification. The alternative techniques presented within AWS D1.1 require items such as qualified and specific written procedures, special UT operator qualifications, and special calibration methods needed to obtain the required accuracy in discontinuity sizing.

The use of this annex which references AWS D1.1 alternative techniques, the resulting procedures developed, including the applicable acceptance criteria, are subject to approval by the engineer.

This annex is informative unless specifically specified in the contract documents and specifically reference Annex E. When so specified, the entire requirements contained within the AWS D1.1 (*Alternative Technique UT Examination*) (as applicable) shall be considered mandatory unless specifically modified within the contract documents.

It is not intended that the above mentioned alternate UT inspection techniques be utilized to supplement the existing Annex D requirements of AWS D14.6 since the procedures and techniques specified therein are complete and represent a different and acceptable approach for the UT examination of welds.

When contract documents reference UT examinations per AWS D14.6 guidelines, the requirements of Annex D shall be utilized unless approved otherwise.

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Annex F (Informative)

Stud Welding

This annex 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.

F1. General

For information regarding the stud welding process or for the qualification of procedures or personnel using stud welding, refer to the most current version of AWS B2.1/B2.1M, *Specification for Welding Procedure and Performance Qualification*, and AWS C5.4, *Recommended Practices for Stud Welding*.

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Annex G (Informative)

Roadmap for Welding Procedure Specification (WPS) Development

This annex 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.

Table G.1 provides a guide to the user for decisions required in the preparation of a Welding Procedure Specification (WPS) and the applicable AWS standard references describing each of the variables or options. Use of this annex does not remove the responsibility of the Manufacturer to assure that the WPS meets all the requirements of this specification.

Table G.1
Roadmap for Development of Welding Procedure Specifications (WPSs)

WPS Variable or Option ^a	AWS Standard	Location
1. Qualification Method		
a. Procedure Qualification Tests	D14.6/D14.6M:2012	6.5
b. Performance	D14.6/D14.6M:2012	6.7
2. Base Material		
a. Specification and Grade	D14.6/D14.6M:2012	4.1
b. M-No. Group No.	B2.1:2009	Annex D
c. Thickness	D14.6/D14.6M:2012	6.13.2
3. Welding Process		
a. Process	D14.6/D14.6M:2012	5
b. Technique	D14.6/D14.6M:2012	6.13.9(11)
4. Welding Consumables		
a. Welding Electrode Filler Metals	D14.6/D14.6M:2012	4.2
b. F-No. and A-No.	B2.1:2009	Annex C
c. Classification	D14.6/D14.6M:2012	6.13.6 (Table 6)
d. Size / Diameter	D14.6/D14.6M:2012	6.13.3(3)
e. Shielding Gas Composition and Flow	D14.6/D14.6M:2012	6.13.7
f. Trailing Gas Composition and Flow	D14.6/D14.6M:2012	6.13.7
g. Flux	D14.6/D14.6M:2012	6.13.3
5. Joint Design		
a. Joint Type	D14.6/D14.6M:2012	6.13.1
b. Preparation of Base Metal	D14.6/D14.6M:2012	7.2
6. Electrical Characteristics		
a. Current Type	D14.6/D14.6M:2012	6.13.8
b. Amperage	D14.6/D14.6M:2012	6.13.8
c. Voltage	D14.6/D14.6M:2012	6.13.8
d. Travel Speed	D14.6/D14.6M:2012	6.13.8
7. Welding Conditions		
e. Heat Input	D14.6/D14.6M:2012	7.7.11
f. Bead Width	D14.6/D14.6M:2012	7.4
g. Preheat	D14.6/D14.6M:2012	6.13.5 and 7.7
h. Interpass Temperature	D14.6/D14.6M:2012	6.13.6 and 7.7
i. Post Heat and PWHT	D14.6/D14.6M:2012	6.13.9
j. Backgouging	D14.6/D14.6M:2012	6.13.9
k. Single or Multiple Arc	D14.6/D14.6M:2012	6.13.9
l. Welding Procedure Variables	D14.6/D14.6M:2012	Table 1
m. Welding Performance Variables	D14.6/D14.6M:2012	Table 3
8. Shielding Gas		
a. Gas	D14.6/D14.6M:2012	6.7.7
9. Position		
a. Position	D14.6/D14.6M:2012	6.7.4, Table 2
b. Progression	D14.6/D14.6M:2012	6.7.4
c. Weld Positions	B2.1/B2.1M:2009	Annex B
10. Test Fixtures and Specimens	B2.1/B2.1M:2009	Annex B
11. Inspection Methods	D14.6/D14.6M:2012	Annex D
12. Sample Forms	B2.1/B2.1M:2009	Annex F
13. Macroetch Procedure	B2.1/B2.1M:2009 D14.6/D14.6M:2012	Annex G 6.5.5.4
14. Mechanical Tests		
a. Procedure Qualification	B2.1/B2.1M:2009 D14.6/D14.6M:2012	Clause 4 6.5.5.1
b. Performance Qualification	B2.1/B2.1M:2009 D14.6/D14.6M:2012	Clause 5 6.8.1 and Table 4

^a Refer to AWS B2.1/B2.1M:2009, *Specification for Welding Procedure and Performance Qualification*, 2.13, for WPS data.

List of AWS Documents on Arc Welding and Cutting

Designation	Title
D14.1	<i>Specification for Welding of Industrial and Mill Cranes and Other Material Handling Equipment</i>
D14.3	<i>Specification for Welding Earthmoving, Construction, and Agricultural Equipment</i>
D14.4	<i>Specification for Welded Joints in Machinery and Equipment</i>
D14.5	<i>Specification for Welding of Presses and Press Components</i>
D14.6	<i>Specification for Welding of Rotating Elements of Equipment</i>
D14.7	<i>Recommended Practices for Surfacing and Reconditioning of Industrial Mill Rolls</i>
D14.8	<i>Standard Methods for the Avoidance of Cold Cracks</i>
D14.9	<i>Specification for the Welding of Hydraulic Cylinders</i>

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