

Specification for Fusion Welding for Aerospace Applications



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Specification for Fusion Welding for Aerospace Applications

4th Edition

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Prepared by the
American Welding Society (AWS) D17 Committee on Welding in the Aircraft and Aerospace Industries

Under the Direction of the
AWS Technical Activities Committee

Approved by the
AWS Board of Directors

Abstract

This specification provides the general welding requirements for welding aircraft and space hardware. It includes but is not limited to the fusion welding of aluminum-based, nickel-based, iron-based, cobalt-based, magnesium-based, and titanium-based alloys using electric arc and high energy beam processes. There are requirements for welding design, personnel and procedure qualification, fabrication, inspection, and acceptance criteria for aerospace, support, non-flight hardware, and crewed spaceflight hardware. Additional requirements cover repair welding of existing hardware. A commentary for the specification is included.



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This standard is subject to revision at any time by the AWS D17 Committee on Welding in the Aircraft and Aerospace Industries. It must be reviewed every five years, and if not revised, it must be either reaffirmed or withdrawn. Comments (recommendations, additions, or deletions) and any pertinent data that may be of use in improving this standard are requested and should be addressed to AWS Headquarters. Such comments will receive careful consideration by the AWS D17 Committee on Welding in the Aircraft and Aerospace Industries and the author of the comments will be informed of the Committee's response to the comments. Guests are invited to attend all meetings of the AWS D17 Committee on Welding in the Aircraft and Aerospace Industries to express their comments verbally. Procedures for appeal of an adverse decision concerning all such comments are provided in the Rules of Operation of the Technical Activities Committee. A copy of these Rules can be obtained from the American Welding Society, 8669 NW 36 St, # 130, Miami, FL 33166.

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This revision of AWS D17.1/D17.1M, *Specification for Fusion Welding for Aerospace Applications*, is respectfully dedicated to the memory of Jagdish (JT) Amin, who served on the AWS D17 Committee on Welding in the Aircraft and Aerospace Industry since 1995.

The Committee sadly misses his passion, wisdom, and friendship. His commitment and significant contributions to the advancement of the aerospace industry will live on through this new revision.

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Foreword

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

Prior to 1977, aviation welding specifications were primarily dependent on government standards for contract purchases and were based on welding technology from the 1950s. Those specifications were MIL-W-8611 (steel), MIL-W-8604 (aluminum), MIL-W-18326 (magnesium), and MIL-T-5021 for welder performance requirements. In 1977, the aviation and aerospace industry and government moved to update some of these standards by consolidating the welder's performance of MIL-T-5021 into MIL-STD-1595. MIL-STD-1595 was issued as a supplement to the ASME Section IX code in 1977. It was subsequently revised and superseded by MIL-STD-1595A in 1983. The first update to the 1950's welding process specifications came with the release of MIL-W-8604A in 1982, almost 30 years after its initial release. The material welding specifications MIL-W-8604, MIL-W-8611, and MIL-W-18326 were consolidated into MIL-STD-2219 in 1988 and represented the most significant change to aviation welding standards in more than 30 years.

After two unsuccessful attempts to change the military standards, the American Welding Society contacted the industry and proposed a meeting to develop a national specification. Interested welding personnel from the aviation industry gathered in the autumn of 1993 to lay the foundation for a national aviation and aerospace specification for fusion welding to replace MIL-STD-1595A and MIL-STD-2219. This meeting led to the formation of the AWS D17 Committee on Welding in the Aircraft and Aerospace Industries. The overriding theme the welding committee members brought to the table was that the aviation industry had changed. Those changes affected the welding processes and procedures, base metal and filler metal types, quality, and the inspection equipment, just to name a few. Since the 1950s, the welding specifications had not completely kept pace during the revision process to reflect those technology changes. The writing of this specification was a prime opportunity for the industry and government to create a document to include those changes. Through an industrial effort and committee consensus, this specification represents several years of work, bringing the aviation and aerospace industry together to acknowledge the technological advances of welding and materials. Included in this document is weld repair technology to enable the use of weld repair beyond those areas originally designated for a weld.

Changes to this fourth edition of D17.1 include the following:

In this fourth edition of D17.1, the committee made several fundamental changes to expand the use and applicability of the document for the dynamics within the industry. The criteria for welding procedure and welder qualification in Clause 5 were separated for clarity and to prevent mixing of elements. As part of this, Tables 5.1 through 5.7 were reworked for better organization and to isolate each of the requirements to a single element. Also, for qualification coupon configuration, figures were added to integrate the criteria more completely within the D17.1 specification; allowing for more independence from the external documents such as AWS B2.1.

For Non-Flight Hardware in Clause 9, the criteria for fluid service inspection was diverted to ASME B31.3.

Clause 10 is a new addition which addresses the unique criteria for Crewed Spaceflight Hardware.

Underlined areas in text indicate an addition and vertical lines adjacent to text, figures, tables, and equations indicate where changes (additions, modifications, corrections, deletions) from the 2017 edition were made.

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Table of Contents

	Page No.
<i>Personnel</i>	vii
<i>Foreword</i>	ix
<i>List of Tables</i>	xiii
<i>List of Figures</i>	xiii
1. General Requirements	1
1.1 Scope	1
1.2 Units of Measure	2
1.3 Safety	2
1.4 Classification	2
1.5 Approval	2
1.6 Mandatory Provisions and Authority	2
1.7 <u>Design Definition and Requirements</u>	2
1.8 <u>Exclusions</u>	2
2. Normative References	3
3. Terms and Definitions	3
4. Design of Welded Connections	5
4.1 Scope	5
4.2 Weldment Design Data	5
4.3 General Drawing Requirements	5
5. Welding Procedure and Performance Qualification	6
5.1 General	6
5.2 Welding Procedure Data and Qualification	6
5.3 Performance Qualification—General Requirements	13
5.4 Performance Qualification—Detailed Requirements	15
6. Fabrication	28
6.1 Scope	28
6.2 Welding Consumables	28
6.3 Welding Equipment	28
6.4 <u>Machine Welding Parameters</u>	29
6.5 Preweld Cleaning and Other Preparation	29
6.6 Preweld Joint Preparation and Fitup	30
6.7 Preheating and Interpass Temperature Control	31
6.8 Tack Welds	31
6.9 Weld Start and Run-Off Tabs	31
6.10 Weld Shielding for GTAW, GMAW, and PAW	31
6.11 Tungsten Electrodes	31
6.12 Filler Materials	31
6.13 Interpass Cleaning	31
6.14 Welding and Weldments	31
6.15 Postweld Cleaning	32
6.16 Postweld Processing	32
6.17 Weld Identification Requirements	32

6.18	Acceptance Inspection	33
6.19	Rework	33
6.20	Repair	33
7.	Inspection	33
7.1	Qualification of Inspection Personnel	33
7.2	Visual Weld Inspection	34
7.3	Nondestructive Examination	34
7.4	Acceptance Criteria	35
8.	Repair of Existing Structures	41
8.1	Scope	41
8.2	Design	41
8.3	Welding Procedures	42
8.4	Welder and Welding Operator Qualification	42
8.5	Welding Equipment	42
8.6	Weld Repair Inspection	42
8.7	Grounding and Bonding	42
8.8	Repair Documentation	42
9.	Nonflight Hardware	43
9.1	Scope	43
9.2	Exceptions and Additional Requirements	43
10.	<u>Crewed Spaceflight Hardware</u>	47
10.1	<u>Scope</u>	47
10.2	<u>General</u>	47
10.3	<u>Welding Processes</u>	47
10.4	<u>Approval of Engineering Authority</u>	47
10.5	<u>WPS & Qualification Requirements</u>	48
10.6	<u>Material Review Board</u>	48
10.7	<u>Titanium Welding</u>	48
	Annex A (<u>Informative</u>) — Guidelines for Design, Analysis, and Fabrication of Weld Joints	49
	Annex B (Normative) — Bend Testing Criteria	63
	Annex C (Informative) — Informative References	75
	Annex D (Informative) — Cross Referenced UNS Numbers to Proprietary Tradenames, ASTM, and AISI Designations	79
	Annex E (Informative) — Commentary	81
	Annex F (Informative) — Samples of Welding Forms for WPSs, PQRs, and Welder Performance Qualifications	93
	Annex G (Informative) — Qualified Positions for Production Welding	99
	Annex H (Informative) — Common Acronyms Used in this Standard	103
	Annex I (Informative) — <u>Recommended Shielding Gases and Filler Metals</u>	105
	Annex J (Informative) — Requesting an Official Interpretation on an AWS Standard	107
	List of AWS Documents on Welding in the Aircraft and Aerospace Industries	109

List of Tables

Table	Page No.
5.1	Welding Procedure Specification <u>Variables</u> 8
5.2	Procedure Qualification Variables 10
5.3	Procedure Qualification Test Requirements 13
5.4	Performance Qualification Variables 14
5.5	Thickness and Tube Diameter Limitations for Performance Qualification 16
5.6	Base Metal Groups for Qualification of Welders, Tack Welders, and Welding Operators 17
5.7	Welder Qualification – Positions and Base Metal Forms Qualified by Sheet or Tube Tests 18
6.1	Gas Requirements 29
6.2	Preheat and Interpass Temperatures 31
7.1	Acceptance Criteria (in [mm]) 36
9.1	Industrial Codes and Specifications Suggested for Welding Aerospace Nonflight Hardware 43
A.1	Equivalent Fillet Weld Size for Skewed T-Joints 61
B.1	Base Metals for Which Bend Testing is Not Applicable 64
B.2	Bend Specimen Thickness and Bend Radius (in) 65
B.2M	Bend Specimen Thickness and Bend Radius (mm) 66
B.3	Bend Specimens for Groove Welds in Tube (in) 67
B.3M	Bend Specimens for Groove Welds in Tube (mm) 68
I.1	Recommended Shielding Gases for Welding 105
I.2(a)	Filler Metal Guidelines for Welding Aluminum Alloys 106
I.2(b)	Recommend Shielding Gases for Welding Titanium Alloys 106
I.2(c)	Filler Metal Guidelines for Welding Stainless Steels and Heat-Resistant Alloys 106

List of Figures

Figure	Page No.
5.1	Groove Weld in Sheet: Positions 1G, 2G, 3G, and 4G 19
5.2	Fillet Weld in Sheet: Positions 1F, 2F, 3F, and 4F 20
5.3	Groove Weld in Tube: Positions 1G, 2G, 5G, and 6G 21
5.4	Fillet Weld in Tube: Positions 1F, 2F, 4F, and 5F 22
5.5	Groove Test Weld in Sheet 23
5.6	Fillet Test Weld in Sheet 24
5.7	Groove Test Weld in Tube 24
5.8	Fillet Test Weld in Tube 25
5.9	Blank Locations for Metallographic (M) Specimens in Fillet-Welded Sheet 25
5.10	Blank Locations for Metallographic (M) Specimens in Fillet-Welded Tube 26
5.11	<u>Fusion in Fillet Welds</u> 26
5.12	<u>Incomplete Fusion at the Root in Fillet Welds</u> 27
5.13	<u>Melt Through in Fillet Welds</u> 27
5.14	<u>Base Metal Thickness Reduction in Fillet Welds</u> 28
6.1	Joint Preparation in Joint Members of Unequal Thickness 30
7.1	<u>Fillet Weld Profiles</u> 39

7.2	Mismatch Between Joint Members After Welding	40
7.3	<u>Two- and Three-Piece T-Weld Joints – Melt Through Welds</u>	41
A.1(a)	Square Groove Butt Joints	50
A.1(b)	Single-Bevel-Groove Weld Joints	51
A.1(c)	Single-V-Groove Weld Joints	52
A.1(d)	Single-J-Groove Weld Joints	53
A.1(e)	Single-U-Groove Weld Joints	54
A.1(f)	Double-Bevel-Groove Weld Joints	55
A.1(g)	Double-V-Groove Weld Joints	56
A.1(h)	Double-J-Groove Weld Joints	57
A.1(i)	Double-U-Groove Weld Joints	58
A.2(a)	Flanged Joints	59
A.2(b)	Flanged <u>Parallel</u> Joints (Nonstandard)	59
A.3	Fillet Weld Details	60
B.1	Bend Specimens in Groove Welded Tube	69
B.2	<u>Typical Bottom Ejecting Guided Bend Test Fixture</u>	71
B.3	<u>Typical Bottom Guided Bend Test Fixture</u>	72
B.4	<u>Typical Wraparound Guided Bend Test Fixture</u>	73
E.1	Example of a Welding Procedure Specification	94
E.2	Example of a Procedure Qualification Record	95
E.3	Example of a Performance Qualification Test Record	97
G.1	Positions of Production Groove Welds	99
G.2	Positions of Production Fillet Welds	100
G.3	Production Welding Position Diagram for Groove Welds in Pipe or Tube	101

Specification for Fusion Welding for Aerospace Applications

1. General Requirements

1.1 Scope. This specification contains requirements for fusion welding and nondestructive examination (NDE) of aerospace flight hardware as well as for the welding and NDE of non-flight hardware. When this specification is stipulated in contract documents, conformance with all provisions of the specification shall be required, except for those provisions specifically exempted or modified by the Engineering Authority or contract documents.

The following is a summary of the specification clauses:

Clause 1. **General Requirements:** basic information on the scope and provisions of this specification.

Clause 2. **Normative References:** a listing of the documents that are required for the application of this specification.

Clause 3. **Terms and Definitions:** a list of technical terms and definitions of particular importance to this specification.

Clause 4. **Design of Welded Connections:** requirements and guidance information for the design of welded connections.

Clause 5. **Welding Procedure and Performance Qualification:** qualification requirements for welding procedures, welders, welding operators, and tack welders.

Clause 6. **Fabrication:** requirements for preparation, assembly, and workmanship when welding aerospace hardware.

Clause 7. **Inspection:** criteria for inspector qualification, responsibilities of inspectors, acceptance of production welds, and standard requirements for performing visual inspection and nondestructive examination (NDE).

Clause 8. **Repair of Existing Structures:** requirements for repair of existing aerospace flight hardware.

Clause 9. **Nonflight Hardware:** requirements for welding nonflight hardware.

Clause 10. **Crewed Spaceflight Hardware:** Requirements in addition to baseline flight hardware welding requirements addressing the fabrication and inspection of crewed spaceflight hardware and launch vehicles.

1.1.1 Flight Hardware. The purpose of this specification is to provide requirements for commonly used fusion welding processes, materials, and acceptance criteria for production welds. This specification also provides requirements for materials, processes, and acceptance criteria that are not listed in this specification when approved by the Engineering Authority.

1.1.1.1 Aircraft, Rotorcraft, and Engines Subject to Federal Aviation Administration (FAA) Regulation. When applying welding in the design, construction, and repair of aircraft, rotorcraft, or engines subject to FAA regulation, the Engineering Authority must perform the appropriate design analyses and impose process control measures that will ensure compliance with the applicable requirements of the Code of Federal Regulations, Title 14.

1.1.2 Nonflight Hardware. Nonflight hardware, tooling, ground support equipment, and related nonconventional aerospace facilities shall be designed and welded in accordance with the requirements of Clause 9.

1.1.3 Crewed Spaceflight Hardware. Crewed spaceflight hardware, including launch vehicles, shall be fabricated and inspected per the additional requirements found in Clause 10. This clause may be invoked for uncrewed missions if directed by the Engineering Authority.

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

1.3 Safety. Safety and health issues and concerns are beyond the scope of this standard and therefore are not addressed herein.

Safety and health information is available from the following sources:

American Welding Society:

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

Material or Equipment Manufacturers:

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

Applicable Regulatory Agencies

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

1.4 Classification. All welds produced in accordance with this specification shall be classified on the engineering drawings or contract. Weld classifications shall be as follows: Class A, Class B, or Class C. These classifications refer to the level of inspection required and to the applicable acceptance criteria. Alternate acceptance criteria and inspection methods shall be applied if specified on the engineering drawing. A weld joint may be zoned with multiple classifications.

1.5 Approval. All references to the need for approval shall be interpreted to mean approval by the Engineering Authority.

1.6 Mandatory Provisions and Authority. Nothing in this specification supersedes applicable laws and regulations unless a specific exemption has been obtained prior to the contract date or as a contract amendment.

1.6.1 Mandatory Provisions. Most provisions of this specification are mandatory when the use of this specification is invoked. Certain provisions are optional and apply only when specified in contractual documents for a specific project. Guidance information is indicated by the words “should” or “may.”

1.6.2 Drawing Authority. When requirements in this specification conflict with those on the engineering drawing, the requirements on the engineering drawing shall take precedence.

1.6.3 Specification Authority. In the event of a conflict between the text of this specification and the references cited herein, the text of this specification takes precedence.

1.7 Design Definition and Requirements. This specification recognizes that the Engineering Authority may convey its design definition and accompanying requirements for a weldment using one or a combination of recognized formats and media. Examples range from an engineering drawing, an engineering specification, digital engineering models, and the contract. When this specification invokes the engineering drawing(s) or contract, it is inclusive of these other recognized formats and media.

1.8 Exclusions. In-process welding of castings at the fabricating foundry is outside the scope of this specification. This exclusion covers the in-process welding, the qualification of the personnel performing those in-process welds, and the qualification of the procedures for those in-process welds.

2. Normative References

The documents listed below are referenced within this publication and are mandatory to the extent specified herein. For undated references, the latest edition of the referenced standard shall apply. For dated references, subsequent amendments or revisions of the publications may not apply since the relevant requirements may have changed.

American Welding Society (AWS) documents:

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

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

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

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

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

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

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

AWS B5.2, Specification for the Training, Qualification, and Company Certification of Welding Inspector Specialists and Welding Inspector Assistants;

AWS D1.1/D1.1M, Structural Welding Code — Steel;

AWS QC1, Specification for AWS Certification of Welding Inspectors.

Aerospace Industries Association (AIA) document:

NAS 410, NAS Certification & Qualification of Nondestructive Test Personnel.

American Society for Testing and Materials (ASTM) documents:

ASTM E164, Standard Practice for Ultrasonic Contact Testing of Weldments;

ASTM E1417/E1417M, Standard Practice for Liquid Penetrant Testing;

ASTM E1444/E1444M, Standard Practice for Magnetic Particle Testing;

ASTM E1742/E1742M, Standard Practice for Radiographic Examination;

ASTM E29, Standard Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications.

Society of Automotive Engineers (SAE) documents:

AMS-H-81200, Heat Treatment of Titanium and Titanium Alloys;

AMS2680, Electron Beam Welding for Fatigue Critical Applications;

AMS2801, Heat Treatment of Titanium Alloy Parts.

3. Terms and Definitions

AWS A3.0M/A3.0, *Standard Welding Terms and Definitions*, provides the basis for terms and definitions used herein. However, the following terms and definitions are included below to accommodate usage specific to this document. Refer to Annex H for a list of commonly used acronyms in this standard.

aerospace flight hardware. Any portion of a flight vehicle (e.g., aircraft, missile, spacecraft) or its payload.

complex weld joint. A continuous weld joint with variations in section thickness and tapered transitions that may require changes in welding position or direction, weld deposition rates, and heat inputs during the execution of a weld. A complex weld joint cannot be defined on the engineering drawing by a single welding symbol.

critical structure. A structure or component in which a single failure would cause significant danger to personnel, loss of system, loss of major component, loss of control, unintentional release of critical stores, inability to release armament stores, result in an operating penalty or loss of the aerospace system, or abortion of the mission.

customer. The individual or organization which established the mission or design requirements of a product and provides some form of compensation for the delivery of the product. The product could be an engineering design, a structure, a system, or a weldment.

Engineering Authority. The Engineering Authority is the contracting agency or corporate organization that acts for and on behalf of the customer on all matters within the scope of this standard. The Engineering Authority has the responsibility for the structural integrity or maintenance of airworthiness of the hardware and compliance with all contract documents.

fabricator. The organization responsible for producing weldments that satisfy the design and contract requirements.

fail safe. A part is defined as fail safe if it can be shown by analysis or test that, due to structural redundancy, the structure remaining after failure of the one part can sustain the new limit loads with an ultimate factor of safety equal to or greater than 1.0, and the remaining structure has sufficient fatigue life to complete the mission.

filler metal alloy. A recognized designation of a nominal alloy composition from a recognized industry organization (examples AA4043, ER321, Ti-6Al-4V).

fracture critical. A part which, by fracture mechanics analysis, has a service life factor of less than an engineering-defined factor times the vehicle life cycle requirements and failure of which would cause loss of the mission, vehicle, or crew. Also, a part that is a pressure vessel or a rotating machinery component.

in-process welding of casting. Welding performed in the foundry on castings. Generally, this type of welding applies to the correction of casting discontinuities.

Material Review Board (MRB). A customer or Engineering Authority activity to review and formally disposition non-conforming hardware. MRB typically has the authority to take exception to engineering requirements, which includes authorizing repairs.

nonconventional aerospace facilities. Nonconventional aerospace facilities are program-oriented or experimental in nature and may include, but not be limited to, launch complexes, test stands, wind tunnels, operational or research facilities, towers, and similar special purpose facilities whose structures are characterized by unusual or inadequately defined loading conditions, a lack of design precedent, or frequent modifications to support changes in the operational requirements.

noncritical structure. A structure or component which is noncritical and is contained so that failure will not affect other flight elements or personnel.

nonstandard materials. Base metals and/or filler metals not covered by industrial welding codes or specifications.

qualification variable. One of a set of elements that define the qualification limits of a welding procedure specification or of welders, welding operators, or tack welders.

safety critical item. A component whose failure will result in probable loss of the aircraft or hazard to personnel due to direct part failure or by causing other progressive part failures.

sheet. A generic product form and descriptor used in this specification for planar metal products typically described in the market as sheet metal when thinner and plate when thicker.

semicritical structure. A structure or component, the single failure of which would reduce the overall efficiency of the system, but a loss of the system or danger to personnel would not be experienced.

structures. Structures are defined by the Engineering Authority according to accepted practices and shall have the same meaning herein.

tube. A generic product form and descriptor used in this specification for cylindrical metal products with a hollow centerline. These metal products are typically described in the market as tube when possessing a thinner wall and pipe when possessing a thicker wall.

UNS number. The Unified Numbering System (UNS) is a composition-based system of commercial materials. Each metal is indicated by a letter that is followed by five numbers.

4. Design of Welded Connections

4.1 Scope. The Engineering Authority shall design the weldment and define the requirements to ensure compliance with all mission and system requirements. The engineering documentation shall clearly define special requirements, such as fracture critical, or safety critical, imposed over and above the general requirements. Further, the Engineering Authority shall define process controls and substantiate that all design requirements can be met by welds produced in accordance with specified procedure, fabrication, and inspection requirements. Annex A contains further guidance on the weld joint design and analysis.

4.2 Weldment Design Data. The Engineering Authority shall develop or obtain appropriate material property data to support the weldment design. In addition, the Engineering Authority is responsible to account for the residual stresses resulting from the welding process or providing a method for controlling/minimizing residual stresses, such as annealing or aging after welding.

4.3 General Drawing Requirements

4.3.1 Drawing Information. Essential information for all welds shall be completely described in the engineering drawing or in referenced supporting documentation. When necessary, the engineering drawing shall show the profile (cross section) of a complex weld joint with sufficient detail for the fabricator to determine essential features at any position along the length of the weld.

4.3.2 Groove Welds. All groove welds, including those in flanged butt and corner joints, shall be full penetration (complete joint penetration) unless otherwise specified on the engineering drawing or in the referenced supporting documentation.

4.3.3 Fillet Welds. Fillet weld size shall be specified on the engineering drawing. Unless otherwise indicated, the specified size is a minimum with the default maximum size listed in Table 7.1. Fillet weld root penetration shall not be included in weld strength calculations unless a combination groove and fillet weld is specified for the joint.

4.3.4 Essential Information. For all welds, the engineering drawing or referenced supporting documents shall specify this specification and the following:

- (1) base metal alloy and condition at the time of welding (e.g., annealed, normalized)
- (2) filler metal alloy, classification, or composition or autogenous weld (without filler)
- (3) postweld thermal treatment, method, or heat treatment cycles (including tensile strength or hardness values as applicable)
- (4) welding symbols per AWS A2.4
 - (a) weld location and extent of welding
 - (b) final weld contour and weld finishing requirements (as welded or subsequently finished)
 - (c) Special conditions shall be fully explained by added notes or details on the engineering drawing
- (5) weld classifications (Class A, B, or C)
- (6) weld sequence and technique when necessary to control shrinkage stresses and distortion
- (7) dimensional controls required to assure final drawing dimensions
- (8) alternate inspection methods and acceptance criteria where applicable

NOTE: Unless indicated otherwise, dimensions on the weldment drawing indicate the final dimensions of the weldment and do not include allowances for shrinkage.

4.3.5 Inspection Requirements. The engineering drawings shall define weld inspection requirements. Clause 7 specifies default inspection requirements based on classification, which may be modified as appropriate by the Engineering Authority. A single weld may utilize more than one set of inspection requirements through the use of separate zones applied to the weld.

5. Welding Procedure and Performance Qualification

5.1 General. This clause establishes the requirements for welding procedure specification data, welding procedure qualification, and qualification, requalification, and maintenance requirements for welders, welding operators, and tack welders.

5.1.1 Qualification Responsibility. The fabricator shall be responsible for the qualification of welding procedures and personnel. Qualifications, certifications, requalifications, and recertifications given under this specification do not transfer from one fabricator to another. Properly documented welding procedure specifications (WPSs), procedure qualification records (PQRs), and personnel qualifications qualified under the provisions of this specification by a company that later has a name change due to voluntary action, separation from, or consolidation with a parent company may utilize the new name on its WPS, PQR, and personnel qualification documents while maintaining the supporting qualification records with the old company name.

5.1.2 Content and Format of Welding Documents. The WPS, PQR, and performance qualification record shall contain all the required data to appropriately characterize the welding procedure, record procedure qualification, and record welder or welding operator qualification. The specific format is optional. Sample forms are shown in Annex F. In all cases, it is the responsibility of the fabricator to ensure that all required data and welding information is included on all welding documents and records.

5.1.3 Previously Qualified Welding Procedures and Welders/Welding Operators. WPSs, PQRs, and performance qualifications that were written and qualified to previous editions of this specification need not be revised or requalified, within the limits specified herein.

5.1.4 Referee Interpretation of NDE Results. When NDE indications in test welds are indeterminate (i.e., neither clearly acceptable nor clearly rejectable), a referee examination path is available as approved by the Engineering Authority. Referee examination may include supplementary testing consisting of metallographic examination, bend testing, or both, at the indeterminate indication location, regardless of material group. The Engineering Authority shall define the test method(s) and acceptance criteria for the referee examination.

5.2 Welding Procedure Data and Qualification.

5.2.1 Written WPS. All welds produced to the requirements of this specification shall be accomplished in accordance with a written WPS. A WPS shall include the welding data shown in Table 5.1 for the relevant welding process.

NOTE: The WPS may list variables recorded on the PQR within the full range permitted for a qualification variable and practical limits determined by the fabricator for non-qualification variables.

5.2.2 Qualification of Welding Procedures. WPSs for Class A and B welds shall have a supporting PQR. WPSs for Class C welds and tack welds do not require a supporting PQR. Welders or welding operators that successfully complete the procedure qualification, as stated in 5.3.3, shall concurrently be given their performance qualification for that activity. With the approval of the Engineering Authority, AWS B2.1 may be used for welding procedure qualification. WPSs qualified to a higher weld class may also be used to produce welds at a lower weld class within the limitations of Table 5.2

5.2.2.1 Standard Method of Welding Procedure Qualification. Unless otherwise specified by the Engineering Authority, WPSs for Class A and Class B welds shall be qualified by performing a welding procedure qualification test weld and recording the actual values on a PQR. The qualification variables for a welding procedure qualification test weld are as shown in Table 5.2 for each of the welding processes. A change in a welding procedure variable beyond the limits shown in Table 5.2 requires a new procedure qualification.

5.2.2.2 Test Methods for Welding Procedure Qualification. The tests listed in Table 5.3 are required for welding procedure qualification. When mechanical testing is required by the Engineering Authority, the test coupon shall be of sufficient size to yield the necessary test specimens. Multiple test coupons may be produced if necessary to yield the required test specimens.

(1) See Figures 5.5, 5.6, 5.7, and 5.8 for test coupon configuration.

(a) Figure 5.5 for groove test welds in sheet

(b) Figure 5.6 for fillet test welds in sheet

(c) Figure 5.7 for groove test welds in tube

(d) Figure 5.8 for fillet test welds in tube

(2) All test results shall be recorded on the PQR.

(3) Test welds shall be inspected in accordance with the test methods and acceptance criteria for the applicable weld class per Table 7.1. A 0.5 in [13 mm] discard may be taken at the ends of groove and fillet weld coupons in sheet.

(4) Metallographic examination of fillet welds shall be performed using a magnification of 5X – 100X. All required surfaces shall be evaluated to the relevant acceptance criteria in accordance with Table 7.1 and Figures 5.11, 5.12, 5.13, and 5.14.

5.2.2.3 Alternative Methods of Procedure Qualification. In lieu of Clause 5.2.2.1, alternative procedure qualification shall be accomplished. The Engineering Authority shall specify the test weldment configuration, the test methods, and acceptance criteria for the test weldments to be used when qualifying welding procedures using these alternative methods. The following provides examples of alternative configurations for procedure qualification:

- (1) A simulated weld joint sample.
- (2) An actual part.
- (3) An applicable qualification test weld.
- (4) A special test weldment.
 - (a) Simulated service test weldment.
 - (b) Prototype structural special test weldments.
 - (c) Non-loaded special test weldments.

Table 5.1
Welding Procedure Specification Variables

JOINT DESIGN	F C A W	G M A W	G T A W	P A W	O F W	S M A W	E B W	L B W
(1) Joint type(s) qualified, including dimensions, and fitup requirements	X	X	X	X	X	X	X	X
(2) Treatment of backside, including method of gouging/preparation	O	O	O	O	O	O	O	O
(3) Backing material, if used	O	O	O	O	O	O	O	O
BASE METAL	F C A W	G M A W	G T A W	P A W	O F W	S M A W	E B W	L B W
(4) Base metal alloy	X	X	X	X	X	X	X	X
(5) Thickness range qualified	X	X	X	X	X	X	X	X
(6) Diameter range qualified (tubular only)	X	X	X	X	X	X	X	X
(7) Coating description or type, if present	O	O	O	O	O	O	O	O
FILLER METAL	F C A W	G M A W	G T A W	P A W	O F W	S M A W	E B W	L B W
(8) Specification, classification, alloy, or nominal composition	X	X	O	O	O	X	O	O
(9) Filler metal size or diameter	X	X	O	O	O	X	O	O
(10) Supplemental filler metal, including specification and size	O	O	O	O	–	–	O	O
(11) Filler metal feed rate	–	–	O	O	–	–	O	O
(12) Consumable insert, including material and type	O	O	O	O	O	O	O	O
(13) Hot filler metal amperage	–	–	O	O	–	–	O	O
(14) For cladding and hardfacing: the minimum surfacing thickness	O	O	O	O	–	O	O	O
POSITION	F C A W	G M A W	G T A W	P A W	O F W	S M A W	E B W	L B W
(15) Welding positions(s) allowed	X	X	X	X	X	X	X	X
(16) Progression for vertical welding	O	O	O	O	O	O	O	O
PREHEAT AND INTERPASS TEMPERATURE	F C A W	G M A W	G T A W	P A W	O F W	S M A W	E B W	L B W
(17) Minimum preheat temperature	X	X	X	X	–	X	X	X
(18) Method of preheat maintenance	X	X	X	X	–	X	X	X
(19) Interpass temperature maximum, if applicable	O	O	O	O	O	O	O	O
POST WELD HEAT TREATMENT	F C A W	G M A W	G T A W	P A W	O F W	S M A W	E B W	L B W
(20) PWHT including specification or temperature, time, method, and heating/cooling rates when applicable	O	O	O	O	O	O	O	O
SHIELDING GAS	F C A W	G M A W	G T A W	P A W	O F W	S M A W	E B W	L B W
(21) Torch shielding gas, including composition and flow rate range	X	X	X	X	–	–	–	X
(22) Backing gas, including composition and flow rate range	O	O	O	O	–	–	–	O
(23) Supplemental shielding gas, including composition and flow rate range	–	O	O	O	–	–	–	O
(24) Environmental shielding (i.e. purge chamber, gas composition, purity)	–	O	O	–	–	–	–	O
(25) Vacuum pressure	–	–	–	–	–	–	X	O

(Continued)

Table 5.1 (Continued)
Welding Procedure Specification Variables

ELECTRICAL	F C A W	G M A W	G T A W	P A W	O F W	S M A W	E B W	L B W
(26) Welding current (not required for manual welding), including type and polarity	—	—	X	X	—	X	—	—
(27) Accelerating voltage, beam current, beam focusing current, and filament type, size, and shape	—	—	—	—	—	—	X	—
(28) Beam power, beam distribution, and optical configuration	—	—	—	—	—	—	—	X
(29) Wire feed speed and voltage range, or control variables for synergic processes	X	X	—	—	—	—	—	—
(30) Beam pulsing characteristics	—	—	—	—	—	—	O	O
(31) Voltage range (except not required for manual welding)	—	—	X	X	—	X	—	—
(32) Specification, classification, diameter, and electrode preparation/geometry of tungsten electrode	—	—	X	X	—	—	—	—
(33) Metal Transfer mode (short circuit, globular, or spray)	X	X	—	—	—	—	—	—
(34) Pulsed welding power parameters	O	O	O	O	—	O	—	—
(35) Contact tube to work distance	X	X	—	—	—	—	—	—
OTHER WELDING PROCESS VARIABLES	F C A W	G M A W	G T A W	P A W	O F W	S M A W	E B W	L B W
(36) Working distance and angle (gun/optic to work piece)	—	—	—	—	—	—	X	X
(37) Welding process and whether manual, semiautomatic, mechanized or automatic	X	X	X	X	X	X	X	X
(38) For mechanized and automatic applications: number of electrodes and their spacing, if applicable	X	X	X	X	—	—	—	—
(39) Single or multipass weld	X	X	X	X	X	X	X	X
(40) Method of initial and interpass cleaning	X	X	X	X	X	X	X	X
(41) Peening, including method	O	O	O	O	—	O	—	—
(42) Conventional or keyhole technique	—	—	X	X	—	—	X	X
(43) Standoff distance for mechanized and automatic welding	—	—	X	X	—	—	—	—
(44) Stringer or weave bead, including weave parameters	X	X	X	X	—	X	X	X
(45) Travel speed range for mechanized or automatic welding and manual applications requiring heat input calculations	X	X	X	X	—	—	X	X
(46) Fuel gas and flame type (oxidizing, neutral, carburizing)	—	—	—	—	X	—	—	—
(47) Beam oscillation pattern and parameters (e.g., length and width)	—	—	—	—	—	—	X	X

Legend:

Fusion Welding Processes:

OFW—Oxyfuel welding

SMAW—Shielded metal arc welding

SAW—Submerged arc welding

GTAW—Gas tungsten arc welding

GMAW—Gas metal arc welding

FCAW—Flux cored arc welding

PAW—Plasma arc welding

EBW—Electron beam welding

LBW—Laser beam welding

WPS Variables:

X—Data that shall be included in a WPS.

O— Include this data when this variable gets used in the welding procedure.

Table 5.2
Procedure Qualification Variables

JOINT DESIGN	F C A W	G M A W	G T A W	P A W	O F W	S M A W	E B W	L B W
(1) For mechanized and automatic welds: a change in the groove weld type (V-groove, U-groove, square groove, etc.)	Q	Q	Q	Q	–	–	Q	Q
(2) A change from a fillet to a groove weld	Q	Q	Q	Q	Q	Q	Q	Q
(3) The addition or deletion of non-fusing metal or non-metallic backing or backing gas	–	–	Q	Q	–	–	–	Q
(4) An increase in the fitup gap beyond that used in the qualification test	–	–	–	–	–	–	Q	Q
(5) A change in the nominal part geometry adjacent to the joint	–	–	–	–	–	–	Q	Q
BASE METAL	F C A W	G M A W	G T A W	P A W	O F W	S M A W	E B W	L B W
(6) A change from one base metal alloy to a different base metal alloy	Q	Q	Q	Q	Q	Q	Q	Q
(7) A change in the base metal thickness beyond the range specified below: A test weld with a base metal thickness of (t) shall qualify welds in base metals with a thickness range of 1/2t to 2t, except when the test weld base metal thickness is equal to or greater than 1 in [25 mm], the qualification range is 1/2t to unlimited. Two test welds shall qualify welds with all intermediate base metal thicknesses	Q	Q	Q	Q	Q	Q	–	–
(8) A change in the nominal thickness (t) of the base metal	–	–	–	–	–	–	Q	Q
(9) For mechanized or automatic welds: A change exceeding ±10% of base metal thickness (t) qualified	–	–	Q	Q	–	–	–	–
FILLER METAL	F C A W	G M A W	G T A W	P A W	O F W	S M A W	E B W	L B W
(10) A change in the filler metal alloy	Q	Q	Q	Q	Q	Q	Q	Q
(11) A change in the chemical composition of the weld metal. Each layer shall be considered independent of other layers	C H	C H	C H	C H	–	C H		C H
(12) A change in the diameter of filler metal of ±20%	–	–	–	–	–	–	Q	Q
(13) The addition or deletion of filler material	–	–	Q	Q	–	–	Q	Q
(14) A decrease of the applied surfacing thickness below that qualified	C H	C H	C H	C H	–	C H	–	C H
(15) A change of filler metal/electrode nominal size/shape in the first layer	C H	C H	–	–	–	C H	–	–
(16) The addition or deletions of supplementary filler metal (powder or wire)	Q	Q	Q	Q	Q	Q	Q	Q
(17) A change exceeding ±10% of the amount of supplementary filler metal (powder or wire)	Q	Q	Q	Q	Q	Q	Q	Q
(18) A change from single to multiple supplementary filler metals or vice versa	C H	C H	C H	C H	C H	C H	–	–
POSITION	F C A W	G M A W	G T A W	P A W	O F W	S M A W	E B W	L B W
(19) The addition of a welding position, except those positions other than flat also qualify for flat	C H	C H	C H	C H	–	C H	–	C H

(Continued)

Table 5.2 (Continued)
Procedure Qualification Variables

PREHEAT AND INTERPASS TEMPERATURE	F C A W	G M A W	G T A W	P A W	O F W	S M A W	E B W	L B W
(20) A decrease in preheat of more than 100°F [56°C]	Q	Q	Q	Q	–	Q	Q	Q
(21) For all materials, an increase in the preheat or interpass temperature exceeding 100°F [56 °C]	Q	Q	Q	Q	–	Q	Q	Q
POST WELD HEAT TREATMENT	F C A W	G M A W	G T A W	P A W	O F W	S M A W	E B W	L B W
(22) The addition or deletion of a post weld heat treatment (PWHT)	Q	Q	Q	Q	Q	Q	Q	Q
(23) A decrease exceeding 20% of the aggregate time at temperature (i.e., soak time)	Q	Q	Q	Q	Q	Q	Q	Q
SHIELDING GAS	F C A W	G M A W	G T A W	P A W	O F W	S M A W	E B W	L B W
(24) The addition or deletion of backing gas	–	Q	Q	Q	–	–	–	Q
(25) Addition or deletion of torch shielding gas	Q	Q	Q	Q	–	–	–	Q
(26) A change in the specified nominal composition of the shielding gas	Q	Q	Q	Q	–	–	–	Q
(27) The addition or deletion of a purge chamber	–	Q	Q	Q	–	–	–	Q
(28) A change of shielding environment from vacuum to an inert gas or vice versa	–	–	–	–	–	–	Q	Q
(29) A change of vacuum pressure exceeding ± 1 decade (order of magnitude, i.e., 10E-4 to 10E-5)	–	–	–	–	–	–	Q	–
(30) For titanium and zirconium base metals: a change in the nominal composition of the root shielding gas	–	Q	Q	Q	–	–	–	Q
(31) For titanium and zirconium base metals: a decrease exceeding 15% of the root shielding flow rate setting	–	Q	Q	Q	–	–	–	Q
(32) For titanium and zirconium base metals: a change in the nominal composition of the trailing gas	–	Q	Q	Q	–	–	–	Q
(33) For titanium and zirconium base metals: a decrease exceeding 10% of the trailing gas flow rate setting	–	Q	Q	Q	–	–	–	Q
(34) For aluminum base metals: an increase exceeding 50%, or a decrease exceeding 20% of the shielding gas flow rate setting	–	Q	Q	Q	–	–	–	Q
(35) A change exceeding $\pm 5\%$ of the flow rate setting change for any gas used in the process (the addition or deletion of gas exceeds a 5% change)	–	–	–	–	–	–	–	Q
(36) A change in the orientation of the plasma plume removing gas jet relative to the workpiece (e.g., coaxial to transverse to the beam)	–	–	–	–	–	–	–	Q
(37) The addition or deletion of plasma plume removing gas jets	–	–	–	–	–	–	–	Q
ELECTRICAL CHARACTERISTICS	F C A W	G M A W	G T A W	P A W	O F W	S M A W	E B W	L B W
(38) A change from DC to AC and vice versa	–	Q	Q	Q	–	Q	–	–
(39) A change from DCEN to DCEP and vice versa	–	–	Q	–	–	Q	–	–
(40) A change in the mode of metal transfer from short circuiting to globular, spray, or vice versa; or the addition or removal of pulsing	Q	Q	–	–	–	–	–	–
(41) A change of accelerating voltage exceeding $\pm 1\%$	–	–	–	–	–	–	Q	–
(42) A change of beam current amperage exceeding $\pm 1\%$	–	–	–	–	–	–	Q	–
(43) A change of beam focus current amperage exceeding $\pm 0.5\%$	–	–	–	–	–	–	Q	–
(44) A change exceeding $\pm 3\%$ in the average or CW laser power from that qualified	–	–	–	–	–	–	–	Q
(45) Any nominal change in beam (energy) pulse characteristics	–	–	–	–	–	–	Q	Q
(46) A change in filament type, size, or shape	–	–	–	–	–	–	Q	–

(Continued)

Table 5.2 (Continued)
Procedure Qualification Variables

OTHER VARIABLES	F C A W	G M A W	G T A W	P A W	O F W	S M A W	E B W	L B W
(47) A change in the welding process	Q	Q	Q	Q	Q	Q	Q	Q
(48) A change from multi-passes per side to a single pass per side	Q	Q	Q	Q	–	Q	–	Q
(49) A change from a stringer bead to a weave bead for manual welding	C H	C H	C H	C H	–	C H	–	–
(50) For heat-treatable aluminum metals: a change from a stringer to a weave bead, but not vice versa	–	Q	Q	Q	–	–	–	–
(51) A change in the type of fuel gas	–	–	–	–	Q	–	–	–
(52) A change in the type of welding flame	–	–	–	–	Q	–	–	–
(53) A change in working distance exceeding $\pm 0.5\%$ or ± 0.040 in [1.0 mm], whichever is less	–	–	–	–	–	–	–	Q
(54) Any change in the optic configuration (e.g. final focus lens, fiber diameter)	–	–	–	–	–	–	–	Q
(55) A change in working distance exceeding $\pm 5\%$ (e.g., gun to workpiece)	–	–	–	–	–	–	Q	–
(56) A change in working angle exceeding $\pm 2^\circ$ (e.g., gun to workpiece)	–	–	–	–	–	–	Q	Q
(57) A change exceeding $\pm 20\%$ in oscillation length or width from that qualified	–	–	–	–	–	–	Q	Q
(58) A change in oscillation pattern	–	–	–	–	–	–	Q	Q
(59) The addition of a cosmetic cover pass	–	–	–	–	–	–	Q	–
(60) A change from single-sided welds to double-sided or vice versa	–	–	–	–	–	–	Q	Q
OTHER MECHANIZED AND AUTOMATED WELDING VARIABLES	F C A W	G M A W	G T A W	P A W	O F W	S M A W	E B W	L B W
(61) A change exceeding $\pm 10\%$ of the distance between the welding head and the workpiece	Q	Q	Q	Q	–	–	–	–
(62) A change of travel speed exceeding $\pm 5\%$ or ± 0.5 in [13 mm] per minute, whichever is greater	–	–	Q	Q	–	–	Q	Q
(63) A change of travel speed exceeding $\pm 10\%$ or ± 1.0 in [25 mm] per minute, whichever is greater	Q	Q	–	–	–	–	–	–
(64) A change in amperage exceeding $\pm 5\%$ or ± 5 amps, whichever is greater	–	–	Q	Q	–	–	–	–
(65) A change in amperage exceeding $\pm 10\%$ or ± 10 amps, whichever is greater	Q	Q	–	–	–	–	–	–
(66) A change in arc voltage exceeding $\pm 5\%$ or ± 0.5 volts, whichever is greater	–	–	Q	Q	–	–	–	–
(67) A change exceeding $\pm 10\%$ wire feed speed	–	–	Q	Q	–	–	Q	Q
(68) A change in the number of electrodes in the same weld pool	Q	Q	Q	–	–	–	–	–
(69) A change in the spacing of multiple electrodes, if applicable	Q	Q	Q	–	–	–	–	–
(70) A change from a keyhole welding mode to a non-keyhole welding mode and vice versa; or the inclusion of both modes, unless each has been individually qualified	–	–	Q	Q	–	–	Q	Q
(71) A change exceeding $\pm 20\%$ in the oscillation variables	Q	Q	Q	Q	–	–	–	–

Legend:

Fusion Welding Processes:

OFW—Oxyfuel welding

SMAW—Shielded metal arc welding

SAW—Submerged arc welding

GTAW—Gas tungsten arc welding

GMAW—Gas metal arc welding

FCAW—Flux cored arc welding

PAW—Plasma arc welding

EBW—Electron beam welding

LBW—Laser beam welding

Qualification Variables:

Q—Qualification variable for all applications

C—Qualification variable for weld cladding applications

H—Qualification variable for hardfacing applications

Table 5.3
Procedure Qualification Test Requirements

	Required	When specified by the Engineering Authority	Number of destructive test specimens
Groove Welds			
Visual Inspection ^a	X	—	—
Penetrant Testing ^a	X	—	—
Radiographic Testing ^a	Class A	Class B & C	—
Magnetic Particle Examination ^a	—	X	—
Tension Test ^b	—	X	2
Bend Test ^{d, e}	—	X	4
Fracture Toughness Test ^b	—	X	1
Metallographic Examination ^a	—	X	2 ^f
Fillet Welds			
Visual Inspection ^a	X	—	—
Penetrant Testing ^a	X	—	—
Radiographic Testing ^a	—	X	—
Magnetic Particle Examination ^a	—	X	—
Tension Test ^b	—	X	4
Bend-Break Test ^{c, d}	—	X	2
Metallographic Examination ^{a, c}	X	—	2 ^f
Weld Cladding			
Visual Inspection ^a	X	—	—
Penetrant Testing ^a	X	—	—
Radiographic Testing ^a	—	X	—
Magnetic Particle Examination ^a	—	X	—
Chemical Analysis	—	X	1

^a Visual, NDE, and metallographic examinations shall be performed and evaluated in accordance with Clause 7.

^b Acceptance criteria shall be determined by the Engineering Authority.

^c When base metal thickness (t) > 0.063 in [1.6 mm], bend-break testing of fillet welds is optional to metallographic examination. When base metal thickness (t) ≤ 0.063 in [1.6 mm], break-bend testing is not permitted and metallographic examination is required.

^d Bend test and bend-break test acceptance criteria shall be per Annex B.

^e The use of bend testing in lieu of radiography shall be permitted only if the requirements of Annex B, Clause B.2 are met.

^f Two non-adjacent specimens are required. One face of each specimen shall be evaluated.

5.3 Performance Qualification—General Requirements

5.3.1 Welder, Welding Operator, and Tack Welder Functional Descriptions. The definitions and functional descriptions for welder, welding operator, and tack welder are as defined in AWS A3.0.

5.3.2 Vision Requirements. Welders, welding operators, and tack welders shall meet the vision requirements of 5.3.2.1 and 5.3.2.2. The requirements for test administrators are given in 5.3.2.3.

5.3.2.1 Visual Acuity Testing Requirements.

- (1) Welders, welding operators, and tack welders shall demonstrate near vision acuity of 20/30 or better.
- (2) Test method shall be one of the following:
 - a. Snellen
 - b. A tumbling E chart
 - c. An alternate vision test recognized to provide a measure of acuity equivalent to 20/30 near vision.

(3) Visual acuity shall be demonstrated in at least one eye.

(4) Corrected or uncorrected vision may be used, however if corrected vision is used to pass the eye exam, it shall be recorded on the test report or qualification record.

(5) Minimum testing frequency is once every two years.

5.3.2.2 Color Perception Requirements.

(1) Color perception testing is only required when deemed necessary by the fabricator.

(2) When required, the fabricator will specify both the level of color perception and the recognized test method to assess if the color perception requirement is met.

5.3.2.3 Test Administration Requirements.

(1) All vision tests shall be administered by appropriately trained personnel designated by the fabricator or by qualified medical personnel.

(2) The test administrator is responsible for determining appropriate test parameters except for those specified in 5.3.2.1 and 5.3.2.2.

5.3.3 Qualification Requirements. To achieve qualified status, welders, welding operators, and tack welders shall demonstrate their skill by the following:

(1) Welders and welding operators shall produce acceptable test welds per the requirements of 5.4.6 using a WPS per 5.2.1, except welder or welding operator qualification may be performed concurrently with procedure qualification as noted in 5.2.2.

(2) Tack welders shall produce acceptable test welds per 5.4.8.

5.3.3.1 Welder, Welding Operator, and Tack Welder Performance Qualification Variables. A change to the performance qualification variables as identified in Table 5.4 shall require qualification.

5.3.3.2 Concurrent Qualification of Tack Welders. Welders qualified in accordance with the requirements of this specification are also qualified as tack welders within the limits of Table 5.5.

5.3.3.3 Concurrent Qualification of Welding Operators. Welders qualified in accordance with the requirements of this specification are also qualified as welding operators within the limits of Table 5.5, provided that the fabricator has documented evidence the welder has been trained to operate the automated or mechanized equipment.

Table 5.4
Performance Qualification Variables

Qualification Variables	Welder	Welding Operator	Tack Welder
(1) Welding process (5.4.1)	X	X	X
(2) Base metal group (5.4.2)	X	X	X
(3) Type of weld, groove or fillet (Table 5.5)	X	—	—
(4) A change from a double welded groove weld to a single welded groove weld	X	—	—
(5) A change from a partial joint penetration (PJP) weld to a complete joint penetration weld (CJP)	X	—	—
(6) Base metal thickness (5.4.3 and Table 5.5)	X	X	—
(7) Base metal form, sheet or tube (5.4.5 and Table 5.5)	X	—	—
(8) Pipe or tube diameter (5.4.3 and Table 5.5)	X	—	—
(9) Welding position (5.4.4 and Table 5.7)	X	—	—
(10) Addition of filler metal	X	—	X
(11) Deletion of backing material	X	—	—
(12) A change from AC to DC and vice versa	X	—	—

5.3.4 Qualification/Certification Validity

5.3.4.1 Initial Validity. A welder, welding operator, or tack welder who has successfully completed performance qualification shall be certified for a period of two years.

5.3.4.2 Extended Validity. The fabricator may extend the initial certification period indefinitely provided an auditable record is maintained, from the date of initial qualification, documenting that the welder, welding operator, or tack welder has used the qualified process without periods of inactivity exceeding 6 months.

5.3.4.3 Disqualification. The certification of a welder, welding operator, or tack welder shall be revoked if any of the following conditions are met:

- (1) The initial certification period of 5.3.4.1 has been exceeded and was not extended in accordance with 5.3.4.2.
- (2) The welder, welding operator, or tack welder has failed to meet or maintain the visual acuity requirements in accordance with 5.3.2
- (3) There is a specific reason to question the ability of a welder, welding operator, or tack welder to meet the requirements for qualification.

5.3.4.4 Reinstatement. The individual disqualified may be retested for the qualification/certification sought. Reinstatement of certification shall require the individual to demonstrate ability and skills to the same or the current qualification test. The final authority for granting of certification or reinstatement of certification and retest frequency, training requirements, and overall evaluation of the individual's qualification in accordance with this document rests with the fabricator.

5.3.5 Identification. The fabricator shall assign a unique number or other identification to each welder, welding operator, or tack welder upon certification.

5.3.6 Test Records. The fabricator shall complete a performance qualification test record containing the qualification variables listed in Table 5.4 through Table 5.7, detailing the limits of the welder, welding operator, or tack welder qualification. These records shall be retained for the period of time specified in the contract or, if no retention time is specified, the period of record retention shall be for the duration of the qualification. (See Annex F for examples of forms.)

5.4 Performance Qualification—Detailed Requirements

5.4.1 Welding Process. For welders, welding operator, and tack welders, a test weld made with a given welding process qualifies only that welding process.

5.4.2 Base Metals. For welders, welding operators, and tack welders, a test weld made in a base metal included on one of the base metal groups of Table 5.6 qualifies only that base metal group, except as modified in 5.4.2.1.

5.4.2.1 Group Qualification. Qualification in a base metal group with a “B” designator also qualifies base metals with the same Roman numeral designator and an “A” designator. For example, a welder, welding operator, or tack welder qualified using Base Metal Group IIIB material for the test sample also qualifies for Base Metal Group IIIA.

5.4.2.2 Dissimilar Materials Welds. Welders, welding operators, and tack welders may also weld dissimilar alloy joints provided that they are qualified to weld each base metal alloy group represented in the joint.

5.4.3 Qualification Ranges for Thickness and Tube Diameter.

- (1) Thickness and tube diameter qualification ranges shall be in accordance with Table 5.5.
- (2) Where a joint involves members with different thicknesses, qualification shall be based on the thinner member.
- (3) Tube fillet weld qualifications are based on tube thickness only, not mating sheet thickness.
- (4) These limits apply to both groove welds and fillet welds.

5.4.4 Welding Position.

5.4.4.1 Welders. The welding positions qualified by a given test weld position are denoted in Table 5.7. The welding position designations are identified and illustrated in Figures 5.1, 5.2, 5.3, and 5.4.

Table 5.5
Thickness and Tube Diameter Limitations for Performance Qualification

Test Weldment			Qualified Range		
Metal Form	Type of Weld	Thickness	Thickness ^a		Tube OD
			Groove	Fillet	
Sheet	Groove	< 1 in [25.4 mm]	0.67t to 4t	0.67t to 4t ^b	≥ 1 in [25.4 mm]
		≥1 in [25.4 mm]	0.67t to unlimited	0.67t to unlimited	
	Fillet	≤ 0.063 in [1.6 mm]	—	0.67t to 4t	
		> 0.063 in [1.6 mm]		0.67t to 4t ^b	
Tube	Groove	< 1 in [25.4 mm]	0.67t to 4t	0.67t to 4t ^b	Size tested and larger
		≥ 1 in [25.4 mm]	0.67t to unlimited	0.67t to unlimited	
	Fillet	≤ 0.063 in [1.6 mm]	—	0.67t to 4t	
		> 0.063 in [1.6 mm]		0.67t to 4t ^b	

^a Two successful test welds may be used to qualify for all welds of intermediate thickness.

^b Not qualified for material thicknesses 0.063 in. [1.6 mm] or less.

5.4.4.2 Welding Operators. A test weld made in any position qualifies for all welding positions.

5.4.5 Base Metal Form and Weld Type.

5.4.5.1 Welders. The base metal forms and weld types qualified by a given test weld are denoted in Table 5.7. Welders qualified to perform groove welds are also qualified to perform plug and slot welding in the qualified position.

5.4.5.2 Welding Operators. A test weld of any base metal form of any weld type shall qualify for all base metal forms and all weld types.

5.4.6 Test Welds. Multiple test welds may be required to expand qualifications beyond the limits of Clause 5.3.3.1. Test welds shall be made in accordance with a WPS.

5.4.6.1 Groove Test Weld in Sheet. The test weld is a butt joint in sheet as described in Figure 5.5.

5.4.6.2 Fillet Test Weld in Sheet. The test weld is a T-joint in sheet as described in Figure 5.6.

5.4.6.3 Groove Test Weld in Tube. The test weld is a butt joint in tube as described in Figure 5.7.

5.4.6.4 Fillet Test Weld in Tube. The test weld is a tube to sheet joint as described in Figure 5.8.

5.4.6.5 Special Applications. When none of the test welds described above are applicable to a given production weld, a special welder, tack welder, or welding operator qualification limited to the specific application may be achieved with a test weld consisting of the given production weld or a test weld representative of the given production weld. The qualification is limited to the welding conditions of the test weld with regard to welding process, base metal composition, base metal thickness, welding position, base metal form, type of weld, and the other welding conditions of Table 5.4. The required inspection, examination, and acceptance criteria shall be consistent with 5.4.7 or with production part criteria.

5.4.7 Inspection and Examination Requirements.

5.4.7.1 Inspection. Test welds shall be accepted or rejected in accordance with the criteria for Class A welds in Table 7.1, except a 0.5 in [13 mm] section may be discarded at each end of the weld coupon in sheet. Fillet welds shall conform to Figures 5.11 through 5.14. Inspection methods shall be performed as follows:

- (1) External weld quality shall be evaluated using visual inspection in the as-welded condition.
- (2) Internal weld quality shall be evaluated using radiographic testing methods for groove welds and metallographic examination for fillet welds.

5.4.7.2 Metallographic Examination.

(1) Blanks shall be removed in accordance with Figures 5.9 and 5.10 for fillet welds in sheet or tube. The four sections “M” to be evaluated (8 surfaces) shall be separated by blanks. If these sections cannot be separated by blanks, additional test weldments shall be used to create the required number of specimens to be evaluated.

(2) Metallographic examination shall be performed using magnification of 5X–100X.

(3) All required surfaces shall be evaluated to the relevant acceptance criteria per Table 7.1, Figures 5.11, 5.12, 5.13, and 5.14.

5.4.7.3 Bend Testing. Bend testing, in accordance with Annex B, may be substituted for radiographic examination of groove welds and metallographic examination of fillet welds.

5.4.8 Tack Welding. Tack welder performance qualification for tack welding operations may be accomplished by performing tack welding on a production part or by producing a test coupon using a WPS. The tack welds shall be visually examined as welded, requiring a nominal 7X to 10X magnification for cracks, inclusions, and surface contamination to the Class A visual acceptance criteria. Once this initial tack welding performance qualification is complete and documented, subsequent production tack welds need only be examined to the production welding requirements.

Table 5.6
Base Metal Groups for Qualification of Welders, Welding Operators, and Tack Welders^a

Group	Materials
IA	Carbon and Alloy Steels: • Wrought Carbon Steel: (bar, sheet, plate, and shapes): A36, A53, A106, A131, A139, A283, A284, A441, A515, A516, A570, A572, A588, and the AISI carbon steels with a nominal carbon of 0.40 weight percent or less (1005–1040) • Cast Carbon Steels: A216, A352, A389, A487 • Cast Low Alloy Steels: A217, A389, A 487 • Low Alloy Structural Steel^b: A514, A517, A537, A633^c • High Strength Boiler Plate and Forgings^a: A302, A508, A533 • Ultra High Strength Steels: 18 Ni Maraging steels, 9 Ni-4 Co steels
IB	Heat Treatable Alloy Steels: • UNS G41300^c, G41350, G41400, G43400, G86300, K22925, K44220, H11
IIA	Stainless Steels: • UNS S20100, S20200, S21900, S30100, S30200, S30300, S30400, S30800, S30900, S31000, S31600 • UNS N08330, S31700, S32100, S34700, S34800, S63198, S631989, S21900 • UNS S40500, S40900, S42900, S43000, S43400, S43600, S43035, S44100, S44200, S44600 • UNS S40300, S41000, S41400, S41600, S42000, S42200, S43100, S44002, S44003, S44004
IIB	Precipitation Hardenable Stainless Steels: • UNS S13800, S15500, S15700, S17400, S17700^c, S35000, S35500, S45000, S45500, S66286
IIIA	Nickel and Nickel-Based Alloys: • UNS N02200, N02201 • UNS N04400 • UNS N06002, N06007, N06455, N06600, N06625^c, N06975 • UNS N08020, N08320, N08800, N08810, N08825 • UNS N10001, N10002, N10003, N10276, N10665
IIIB	Precipitation Hardening Nickel and Nickel-Based Alloys: • UNS N05500, N06601, N07041, N07718^c, N07750, N09706, N09901, N19903, N19907, N19909 • Rene 77, 80 • Udimet 700
IV	Non Heat Treatable Aluminum Alloys: • UNS A91060, A91100, A93003, A93004, A95052, A95083, A95086^c, A95154, A95254, A95454, A95456, A95652 Heat Treatable Aluminum Alloys: • UNS A03550, A03560, A03570, A92014, A92219, A96061^c, A96063

(Continued)

Table 5.6 (Continued)
Base Metal Groups for Qualification of Welders, Welding Operators, and Tack Welders^a

Group	Materials
V	Magnesium Alloys: • UNS M10100, M11311^c, M11610, M11800, M11910, M11920, M12330, M13210, M13310, M13312 • UNS M13320, M14141, M16620, M18220
VI	Titanium Alloys: • UNS R50250, R50400, R50550 • UNS R54520, R54620, R54810, R56210, R56260, R56320, R56400^c, R56620, R58640 • Ti-6Al-2Sn-3Zr-2Cr-2Mo • Ti-15V-3Cr-3Mo-3Sn
VII	Cobalt-Based Alloys: • UNS R30006, R30106, R30021, R30023, R30027, R30030, R30031 • UNS R30188^c, R30605, R30816
VIII	Alloys that do not conform to Groups I–VII: ^d • Refractory alloys (Cb, Mo, W) • Reactive alloys (Zr) • Magnet alloys • Copper alloys

^a These are sample alloys. Tradenames may be provided for some common alloys without a UNS number. These tradenames are provided for information only; without regard for trademark status.

^b These materials shall be considered as a separate subgroup. Qualification with an alloy identified with this symbol will also qualify for welding materials in the basic group not identified by the symbol.

^c Recommended alloy for qualification of this alloy group.

^d Each alloy in this group requires separate qualification.

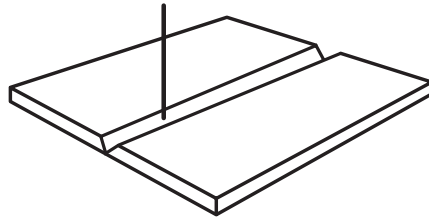
Table 5.7
Welder Qualification – Positions and Base Metal Forms Qualified by Sheet or Tube Tests

Qualification Test ^a			Positions Qualified ^b			
			Sheet		Tube	
Base Metal Form	Weld Type	Test Position	Groove	Fillet	Groove	Fillet
Sheet	Groove	1G	F	F, H	F ^c	F, H ^c
		2G	F, H	F, H	F, H ^c	F, H ^c
		3G	F, V	F, H, V	F, V ^c	F, H, V ^c
		4G	F, O	F, H, O	F, O ^c	F, H, O ^c
	Fillet	1F	—	F	—	F ^c
		2F		F, H		F, H ^c
		3F		F, H, V		F, H, V ^c
		4F		F, H, O		F, H, O ^c
Tube	Groove	1G	F	F, H	F	F, H
		2G	F, H	F, H	F, H	F, H
		5G	F, V, O	All	F, V, O	All
		6G	All	All	All	All
	Fillet	1F	—	F	—	F
		2F		F, H		F, H
		4F		F, H, O		F, H, O
		5F		All		All

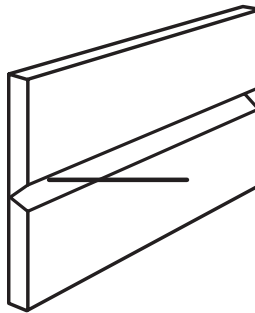
^a Use of heat sinks is optional.

^b Qualified positions for production welding are defined in AWS A3.0 as Flat (F), Horizontal (H), Vertical (V), Overhead (O). All = Flat, Horizontal, Vertical and Overhead.

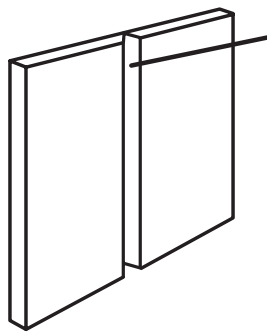
^c For qualified thickness and tube diameter range see Table 5.5.

**1G**

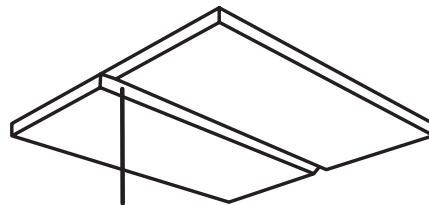
Flat position. The welding position used to weld from the upper side of the joint; the face of the weld is approximately horizontal.

**2G**

Horizontal position. The position of welding in which the axis of the weld lies in an approximately horizontal plane and the face of the weld lies in an approximately vertical plane.

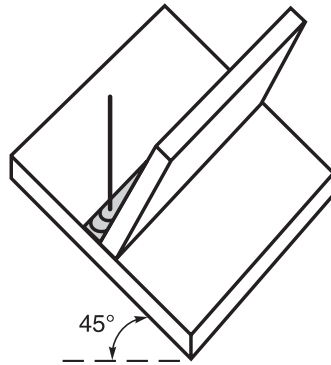
**3G**

Vertical position. The position of welding in which the axis of the weld is approximately vertical.

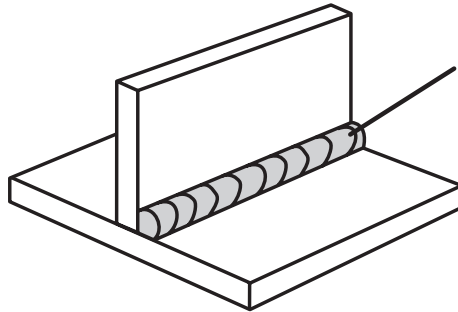
**4G**

Overhead position. The position in which welding is performed from the underside of the joint.

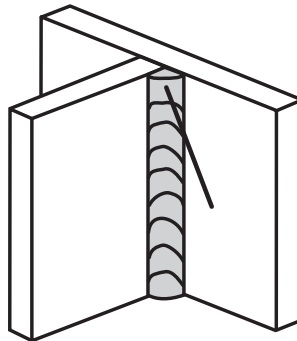
Figure 5.1—Groove Weld in Sheet: Positions 1G, 2G, 3G, and 4G

**1F**

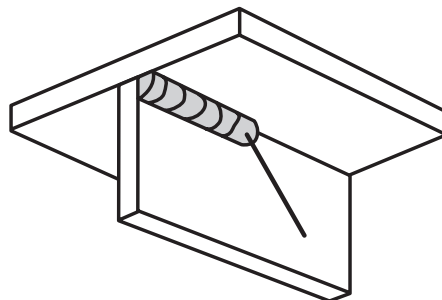
Flat position. The welding position used to weld from the upper side of the joint; the face of the weld is approximately horizontal.

**2F**

Horizontal position. The position in which welding is performed on the upper side of an approximately horizontal surface and against an approximately vertical surface.

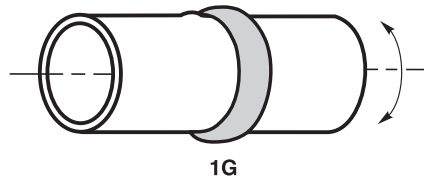
**3F**

Vertical position. The position of welding in which the axis of the weld is approximately vertical.

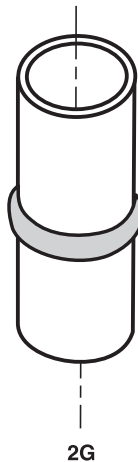
**4F**

Overhead position. The position in which welding is performed from the underside of the joint.

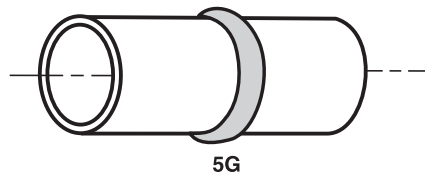
Figure 5.2—Fillet Weld in Sheet: Positions 1F, 2F, 3F, and 4F



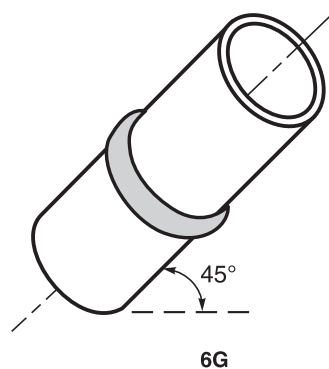
Horizontal rolled position. The position of a pipe joint in which the axis of the pipe is approximately horizontal, and welding is performed in the flat position by rotating the pipe.



Vertical position. The position of a pipe joint in which welding is performed in the horizontal position and the pipe is not rotated during welding.

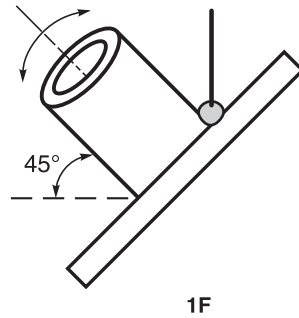


Horizontal fixed position. The position of a pipe joint in which the axis of the pipe is approximately horizontal and the pipe is not rotated during welding.

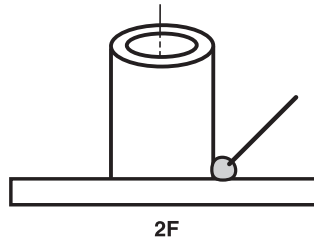


Inclined position. The position of a pipe joint in which the axis of the pipe is approximately at an angle of 45 degrees to the horizontal and the pipe is not rotated during welding.

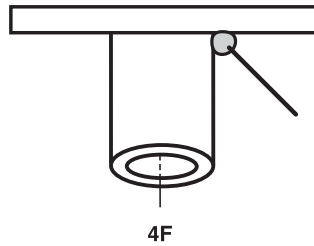
Figure 5.3—Groove Weld in Tube: Positions 1G, 2G, 5G, and 6G



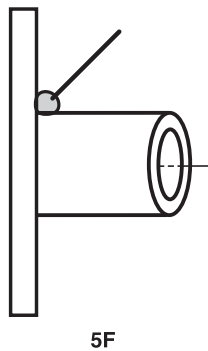
Flat position. The welding position used to weld from the upper side of the joint; the face of the weld is approximately horizontal and the pipe is rotated during welding.



Horizontal position. The position in which welding is performed on the upper side of an approximately horizontal surface and against an approximately vertical surface and the pipe is not rotated during welding.

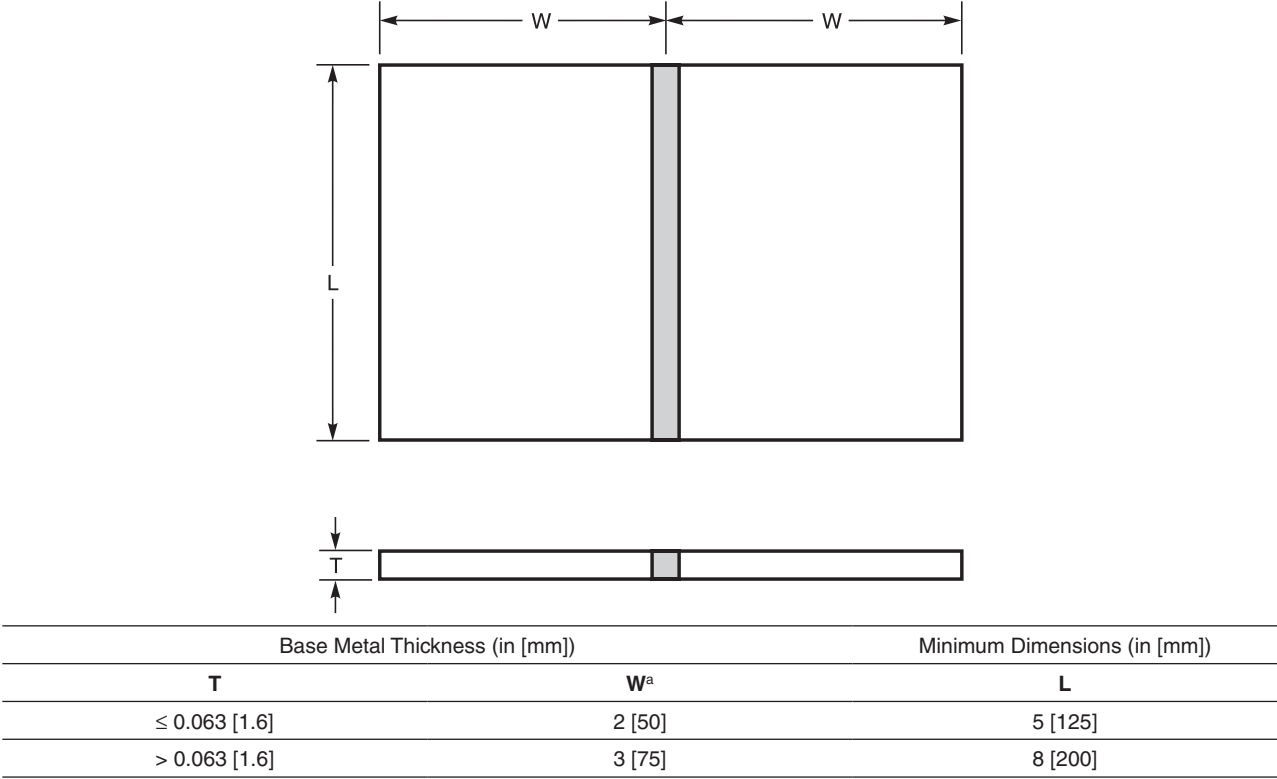


Overhead position. The position in which welding is performed from the underside of the joint and the pipe is not rotated during welding.



Multiple Position. The position in which the axis of the pipe is approximately horizontal and the pipe is not rotated during welding.

Figure 5.4—Fillet Weld in Tube: Positions 1F, 2F, 4F, and 5F



^a Suggested Dimension

Figure 5.5—Groove Test Weld in Sheet