

Specification for Friction Stir Welding of Aluminum Alloys for Aerospace Applications



American Welding Society



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Specification for Friction Stir Welding of Aluminum Alloys for Aerospace Applications

1st Edition

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 covers the general requirements for the friction stir welding of aluminum alloys for aerospace applications. It includes the requirements for weldment design, qualification of personnel and procedures, fabrication, and inspection.



American Welding Society

550 N.W. LeJeune Road, Miami, FL 33126

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Advisors to the AWS D17J Subcommittee on Friction Stir Welding

H. Bushfield	<i>Bushfield Associates</i>
R. B. Maust, III	<i>Raytheon Integrated Defense Systems</i>

Foreword

This foreword is not part of AWS D17.3/D17.3M:2010, *Specification for Friction Stir Welding of Aluminum Alloys for Aerospace Applications*, but is included for informational purposes only.

In the fall of 1993, aerospace welding personnel gathered together under the auspices of the American Welding Society (AWS) to develop an aerospace fusion welding specification to replace MIL-STD-1595A, *Qualification of Aircraft, Missile, and Aerospace Fusion Welders*, and MIL-STD-2219, *Fusion Welding for Aerospace Applications*. The result of this initial meeting was the formation of the AWS D17 Committee on Welding in the Aircraft and Aerospace Industries. The overriding theme voiced by the committee members was that the aviation industry had changed and a new specification was needed. In 2001, after years of hard work by the committee members, the American Welding Society issued AWS D17.1:2001, *Specification for Fusion Welding for Aerospace Applications*.

Specifications used for aerospace welding deal primarily with fusion welding, except for the relatively few that deal with friction welding. Fusion welding is used to produce the vast majority of large, structural, welded components, as opposed to friction welding, which usually is used to join smaller, circular cross-section detail parts. In 1991, The Welding Institute, in England, patented a new welding process called Friction Stir Welding (FSW). The question soon arose as to which requirements were necessary to specify and control this new welding process. Fusion welding specifications could not adequately address FSW because it is a solid-state welding process. Friction welding specifications also could not adequately address FSW process because unlike friction welding, FSW process uses a third body, the welding tool.

The AWS D17 Committee on Welding in the Aircraft and Aerospace Industries determined that it was necessary to form a subcommittee to write a specification for friction stir welding. It was appropriate that the setting for the subcommittee's kickoff meeting was at the Kennedy Space Center in Florida. Kennedy Space Center is where the first friction stir welded commercial aerospace component, the fuel tank for the Delta launch vehicle, went into service. Representatives from industry, welding institutes, government agencies and universities met to dedicate themselves to form a specification for the friction stir welding of aluminum for aerospace applications. AWS D17.1:2001, *Specification for Fusion Welding for Aerospace Applications* served as the model for this specification.

Comments and suggestions for the improvement of this standard are welcome. They should be sent to the Secretary AWS D17 Committee on Welding in the Aircraft and Aerospace Industries, American Welding Society, 550 N.W. LeJeune Road, Miami, FL 33126.

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Specification for Friction Stir Welding of Aluminum Alloys for Aerospace Applications

1. Scope

This specification contains the requirements for designing, friction stir welding, and inspecting aluminum aerospace hardware. Friction stir welding (FSW) produces a weld between two abutting workpieces by the friction heating and plastic material displacement caused by a rotating tool that traverses along the weld joint.

1.1 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 shall be used independently. Consult AWS A1.1, *Metric Practice Guide for the Welding Industry*, for additional information.

1.2 Health and Safety. Safety and health issues and concerns are beyond the scope of this standard and therefore are not fully addressed herein. Safety and health information is available from other sources, including, but not limited to, ANSI Z49.1, *Safety in Welding, Cutting, and Allied Processes*, and applicable federal, state, and local regulations.

2. Normative References

The following standards contain provisions, which through reference in this AWS Standard constitute mandatory provisions of this AWS Standard. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

AIA/NAS document:¹

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

ANSI document:²

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

ASTM documents:³

ASTM B881-D5, *Standard Terminology Relating to Aluminum- and Magnesium-Alloy Products*

ASTM E 164, *Standard Practice for Ultrasonic Contact Examination of Weldments*;

ASTM E 1417, *Standard Practice for Liquid Penetrant Examination*;

ASTM E 1742, *Standard Practice for Radiographic Examination*.

AWS documents:⁴

AWS A1.1, *Metric Practice Guide for the Welding Industry*;

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

AWS A3.0, *Standard Welding Terms and Definitions*;

AWS B5.1, *Specification for the Qualification of Welding Inspectors*;

AWS QC1, *Standard for AWS Certification of Welding Inspectors*.

¹ AIA/NAS standards are published by the Aerospace Industries Association, 1000 Wilson Boulevard, Suite 1700, Arlington, VA 22209-3928.

² ANSI standards are published by the American Welding Society, 550 N.W. LeJeune Rd, Miami, FL 33126.

³ ASTM standards are published by the American Society for Testing and Materials, 100 Barr Harbor Drive, West Conshohocken, PA 19428.

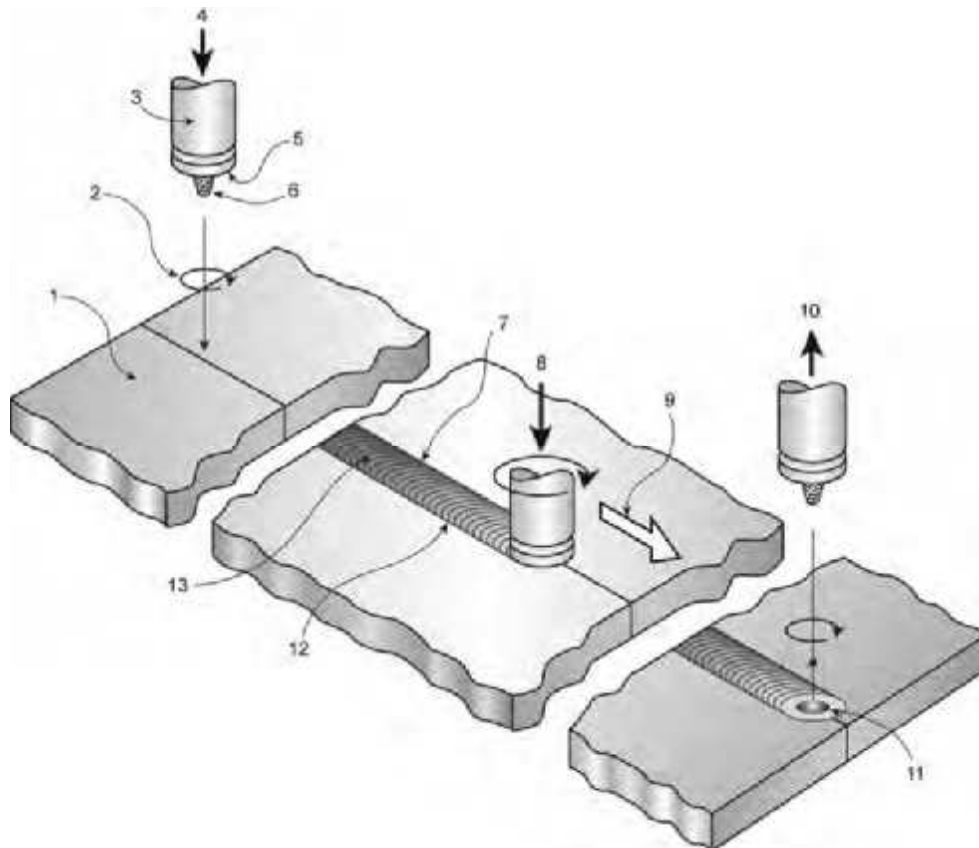
⁴ AWS documents are published by the American Welding Society, 550 N.W. LeJeune Rd, Miami, FL 33126.

3. Terms and Definitions

The welding terms used in this specification shall be interpreted in accordance with the definitions given in the latest edition of AWS A3.0, *Standard Welding Terms and Definitions*, and the following definitions. If there is a conflict between AWS A3.0 and Clause 3, Clause 3 shall take precedence.

For the purposes of this document, the following terms and definitions apply:

advancing side of weld. Side of the weld where the direction of tool rotation is the same as the direction of welding (see Figure 3.1).



Key

- 1 Base metal
- 2 Direction of tool rotation (clockwise is shown)
- 3 Weld tool
- 4 Downward movement of tool
- 5 Tool shoulder
- 6 Probe
- 7 Advancing side of weld
- 8 Axial force
- 9 Direction of welding
- 10 Upward movement of tool
- 11 Exit hole
- 12 Retreating side of weld
- 13 Weld face

Source: TWI, W. T. Thomas – WMT104/04Lr1

Figure 3.1—Friction Stir Welding Nomenclature

angular distortion of the joint. Distortion between two welded pieces such that their surface planes are not parallel or at the intended angle (see Figure 3.2).

anvil. Structure supporting the root side of the joint.

axial force. Force applied to the work piece along the axis of tool rotation (see Figure 3.1).

cavity. Void-type discontinuity within a solid-state weld (see Figure 3.3).

complex weld joint. Continuous weld joint with variations in section thickness and/or tapered thickness transitions.

direction of tool rotation. Rotation as viewed from the spindle that is rotating the tool (see Figure 3.1).

engineering drawing. Technical information, given on an information carrier, written and/or graphically presented in accordance with agreed rules and usually to scale.

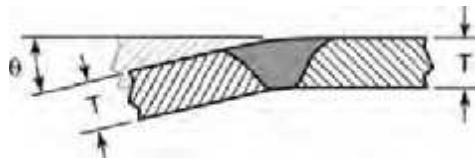
Engineering Authority. Contracting agency or corporate organization that acts for and on behalf of the Customer on all matters within the scope of this standard. The Engineering Authority has the responsibility for the structural integrity or maintenance of airworthiness of the hardware and compliance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

exit hole. Hole remaining at the end of a weld after the withdrawal of the tool (see Figure 3.1).

Fabricator. Person or organization responsible for production welding.

flash. Material expelled along the weld toe during FSW (see Figure 3.4).

friction stir welding methods. Methods include, but are not limited to, robotic, single spindle, multiple spindles, self-reacting tool, and simultaneous two-sided welding.

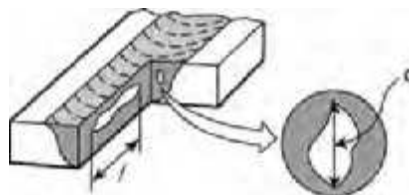


Key

T Thickness of base metal

θ Angle between original surface and postweld surface

Figure 3.2—Angular Distortion of the Joint



Key

d Maximum transverse cross-sectional dimension of the cavity

l Length of a cavity in the longitudinal direction of the weld

Note: A cavity can also break through the surface of the workpiece.

Figure 3.3—Cavity

heel. Part of the tool shoulder that is at the rear of the tool relative to its forward motion (see Figure 3.5).

heel plunge depth. Distance the heel extends into the workpiece (see Figure 3.5).

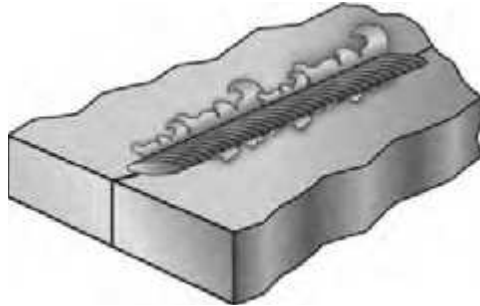
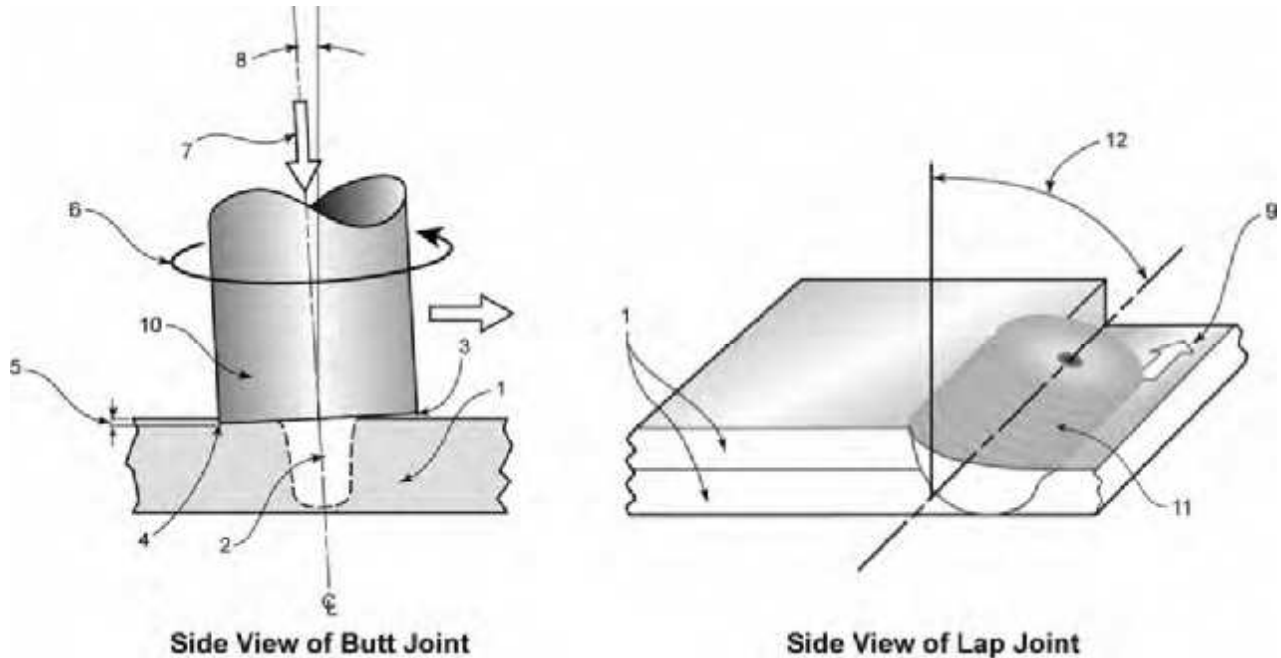


Figure 3.4—Flash



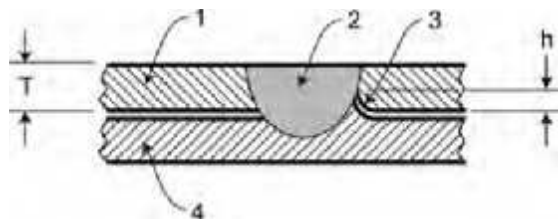
Key

- 1 Workpiece
- 2 Probe
- 3 Shoulder (leading edge)
- 4 Heel (shoulder trailing edge)
- 5 Heel plunge depth
- 6 Direction of tool rotation (counterclockwise)
- 7 Axial force
- 8 Tilt angle
- 9 Direction of welding
- 10 Tool
- 11 Weld face
- 12 Side tilt angle

Figure 3.5—Heel and Heel Plunge Depth

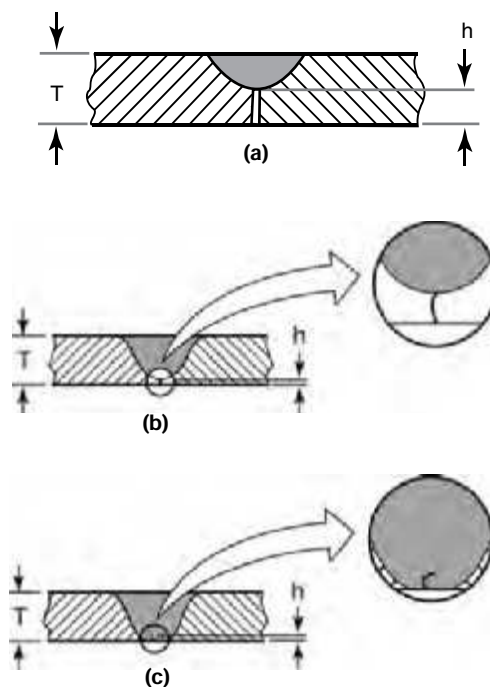
hook. Faying surface that curves upward or downward along the side of the weld metal in a friction stir welded lap joint (see Figure 3.6).

incomplete joint penetration. Discontinuity where the full thickness of the joint has not been welded (see Figure 3.7).



Key
 1 Upper workpiece
 2 Weld
 3 Hook
 4 Lower workpiece
 h Height of hook
 T Thickness of upper workpiece

Figure 3.6—Hook



Key
 T Nominal thickness of the base metal
 h Height of discontinuity

Note: There are three types of incomplete joint penetration. They include the original joint line with (1) no plastic deformation of the unfused edge of the joint, as shown in graphic "a," (2) minor plastic deformation of the unfused edge of the joint, as shown in graphic "b," and (3) severe plastic deformation of the unfused edge of the joint, as shown in graphic "c."

Figure 3.7—Incomplete Joint Penetration

linear mismatch across joint. Misalignment between two welded pieces such that while their surface planes are parallel, they are not in the required plane (see Figure 3.8).

pipe. Tube in standardized combination of outside diameter and wall thickness.⁵

Note: In this standard, the term pipe will be used for pipe and tube.

plate. Rolled, extruded, cast, forged, or deposited products other than pipe in any thickness greater than 0.006 inches [0.152 mm].

Note: In this specification, the term plate is being used to describe all metal products, other than pipe.

probe. Part of the welding tool that extends into the workpiece to make the weld (see Figure 3.1).

preliminary welding procedure specification (pWPS). Document containing the required variables of the welding procedure which has to be qualified.

procedure qualification variable. Controllable detail, which, if changed beyond the limitations of the welding procedure specification, requires requalification of the WPS.

Referencing Document. Fabrication code, specification, contract document, or internal document such as the engineering drawing, quality control, or quality assurance manuals, which invoke this specification.

retreating side of weld. Side of the weld where the direction of tool rotation is opposite to the welding direction (see Figure 3.1).

self-reacting tool. Tool with two shoulders separated by a fixed length probe or an adjustable length probe.

test piece. Weldment which is used for testing purposes.

test specimen. Portion cut from a test piece in order to perform a specified destructive test.

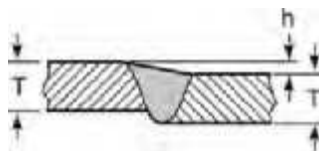
test specimen blank. Portion of a test piece removed for the production of a destructive test specimen.

Note: In some cases, the test specimen blank is also the test specimen.

tool offset. The shortest distance from the tool axis to the joint (see Figure 3.9).

tool shoulder. Surface of the tool that contacts the workpiece surface during welding (see Figures 3.1 and 3.10).

tube. Hollow, wrought product that is long in relation to its cross section, which is symmetrical and is round, elliptical, a regular hexagon or octagon, or square or rectangular with sharp or rounded corners, and has uniform wall thickness except as affected by corner radii.⁶



Key

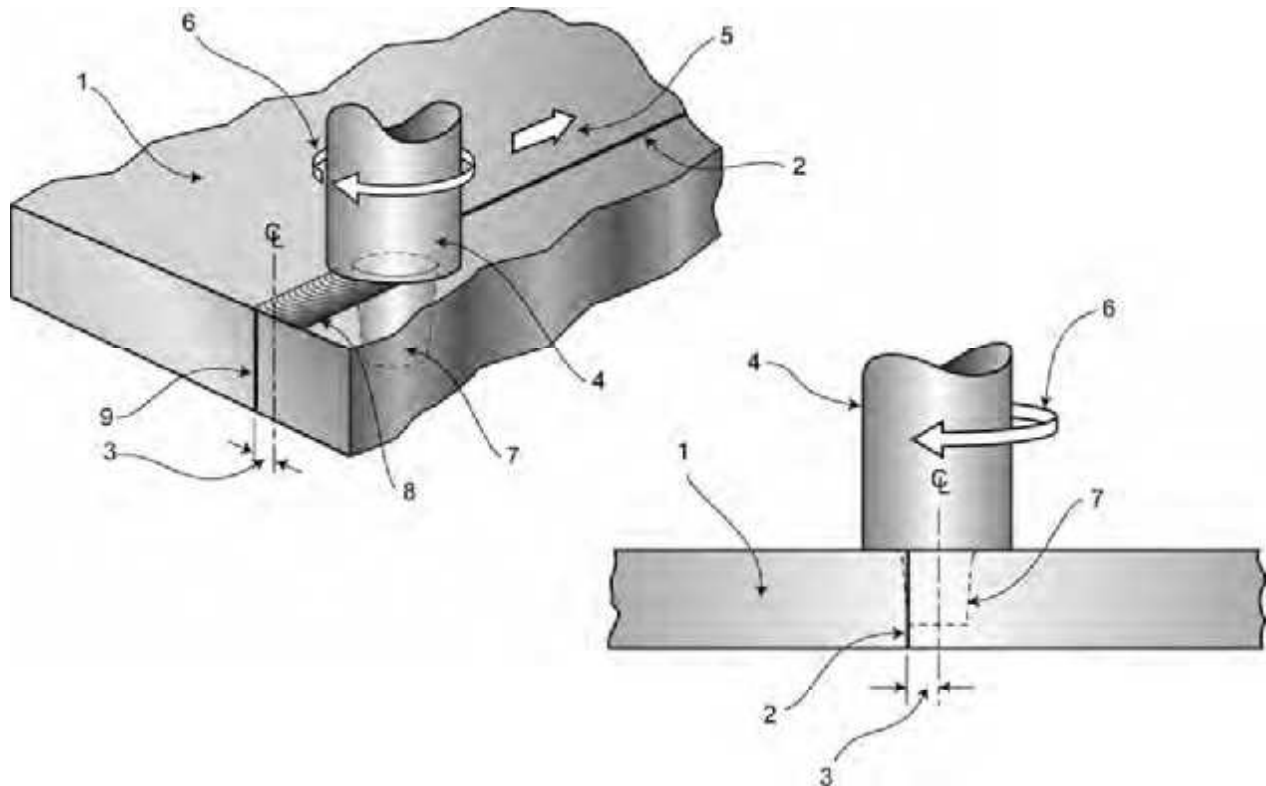
T Nominal thickness of the base metal

h Height of mismatch

Figure 3.8—Linear Mismatch Across Joint

⁵ ASTM B 881-05 Standard terminology relating to aluminum and magnesium alloy products.

⁶ ASTM B 881-05 Standard terminology relating to aluminum and magnesium alloy products.



Key

- 1 Workpiece
- 2 Joint
- 3 Tool offset
- 4 Tool
- 5 Direction of welding
- 6 Direction of tool rotation (clockwise)
- 7 Probe
- 8 Weld face
- 9 Location of joint before welding

Figure 3.9—Tool Offset

test weldment. Workpieces joined by welding to qualify welding procedures or welding operators.

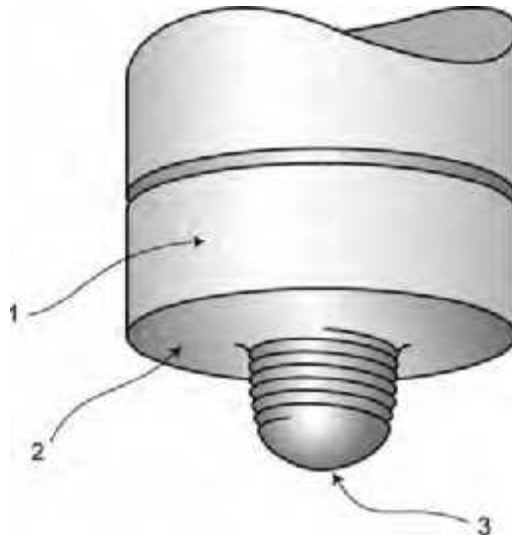
tool rotation speed. Angular speed of the welding tool in revolutions per minute.

travel speed. Rate at which the welding operation progresses in the direction of welding.

welding tool. Rotating component that passes entirely through or partially through the workpiece, and may or may not have a shoulder.

4. General Requirements

4.1 Classification. All welds produced in accordance with this specification shall be classified as Class A, Class B, or Class C. Classification is based on the function and the use of the welded joint. The Engineering Authority shall consider material and process aspects that affect mission or systems requirements. A weld joint may be zoned with multiple classifications.



Key

- 1 Tool
- 2 Shoulder
- 3 Probe

Figure 3.10—Components of Tool

Class A – Critical application. A welded joint whose failure would cause significant danger to personnel, loss of the flight vehicle, loss of control, loss of a system, loss of a major component, unintentional release of critical stores, inability to release armament stores, abortion of the mission, or an operating penalty.

Class B – Semicritical application. A welded joint whose failure would reduce the overall strength of the equipment or system or preclude the intended functioning or use of equipment, but loss of the system or the endangerment of people would not occur.

Class C – Noncritical application. A welded joint whose failure would not affect the efficiency of the system or endanger people.

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

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

4.4. Specification Precedence. In the event of a conflict between the text of this specification and the references cited herein, the text of this specification shall take precedence.

5. Design of Weld Joints

5.1 Weldment Design Data. The Engineering Authority shall develop or obtain appropriate material property data to support the weldment design. In addition, the Engineering Authority shall either account for the residual stresses resulting from the welding process or provide a method for controlling or minimizing those residual stresses (e.g., annealing, aging after welding).

5.1.1 Butt Joint. A weld in a butt joint shall have complete joint penetration, except when a partial joint penetration weld is explicitly required.

5.1.2 Lap Joint. The distance from the centerline of the tool to the edge of each overlapping member shall be a minimum of two times the diameter of the tool's shoulder (see Figure 7.1).

5.1.3 Hook. The acceptability or the extent of a hook that is allowed in a seam weld is dependent on the fatigue and static load requirements for the weld. Therefore, the size of a hook that is allowed in the seam weld shall be defined by the Referencing Document (see Figure 3.5 for an illustration of a hook).

5.2 Drawing Information Requirements. The engineering drawing shall show the profile (transverse cross-section) of a complex weld joint. Welding terminology shall be in accordance with AWS A3.0, *Standard Welding Terms and Definitions*. Welding symbols shall be in accordance with AWS A2.4, *Standard Symbols for Welding, Brazing, and Nondestructive Examination*. Special conditions shall be fully explained by adding notes or details on the engineering drawing.

5.2.1 Essential Information. For all welds, the engineering drawing or referenced supporting documents shall specify the following:

- (1) Aluminum alloy and the temper at the time of welding
- (2) Preweld preparation
- (3) Weld location and extent of welding
- (4) Final weld contour and weld finishing requirements (as-welded or subsequently finished)
- (5) Weld classification in accordance with 4.1
- (6) Postweld heat treatment

5.2.2 Weld Dimensions. Dimensions on the drawing shall indicate the final dimensions and dimensional tolerances of the weldment.

5.2.3 Inspection Requirements. A single weld may employ more than one set of inspection requirements through the use of separate zones applied to the weld. Table 9.1 provides acceptance levels for discontinuities. The weld acceptance levels given in Table 9.1 are based on the classifications given in 4.1.

6. Development and Qualification of a Welding Procedure

6.1 General. Prior to production welding, the Fabricator shall develop and qualify a welding procedure, in accordance with the sequence shown in Table 6.1.

Table 6.1
Sequence for Qualifying a Welding Procedure Specification

Activity	Result	Party Involved
Development of the procedure	Preliminary Welding Procedure Specification (pWPS)	Fabricator
Qualification by any method	Welding Procedure Qualification Record (WPQR) including the range of validity based on the relevant standard of qualification	Fabricator and, if applicable, examiner/ examining body
Finalization of the procedure	Welding Procedure Specification (WPS) based on this WPQR	Fabricator
Release for production	Copy of WPS or work instruction	Fabricator

Figure 6.1 contains a flow diagram that illustrates the steps required for the development and qualification of a welding procedure.

6.1.2 Previous Welding Procedure Specification. A WPS used previously by a Fabricator to meet other codes or specifications may be used by the Fabricator to support a WPS in accordance with this specification, if approved by the Engineering Authority. A WPS used by one Fabricator is not transferable to another Fabricator.

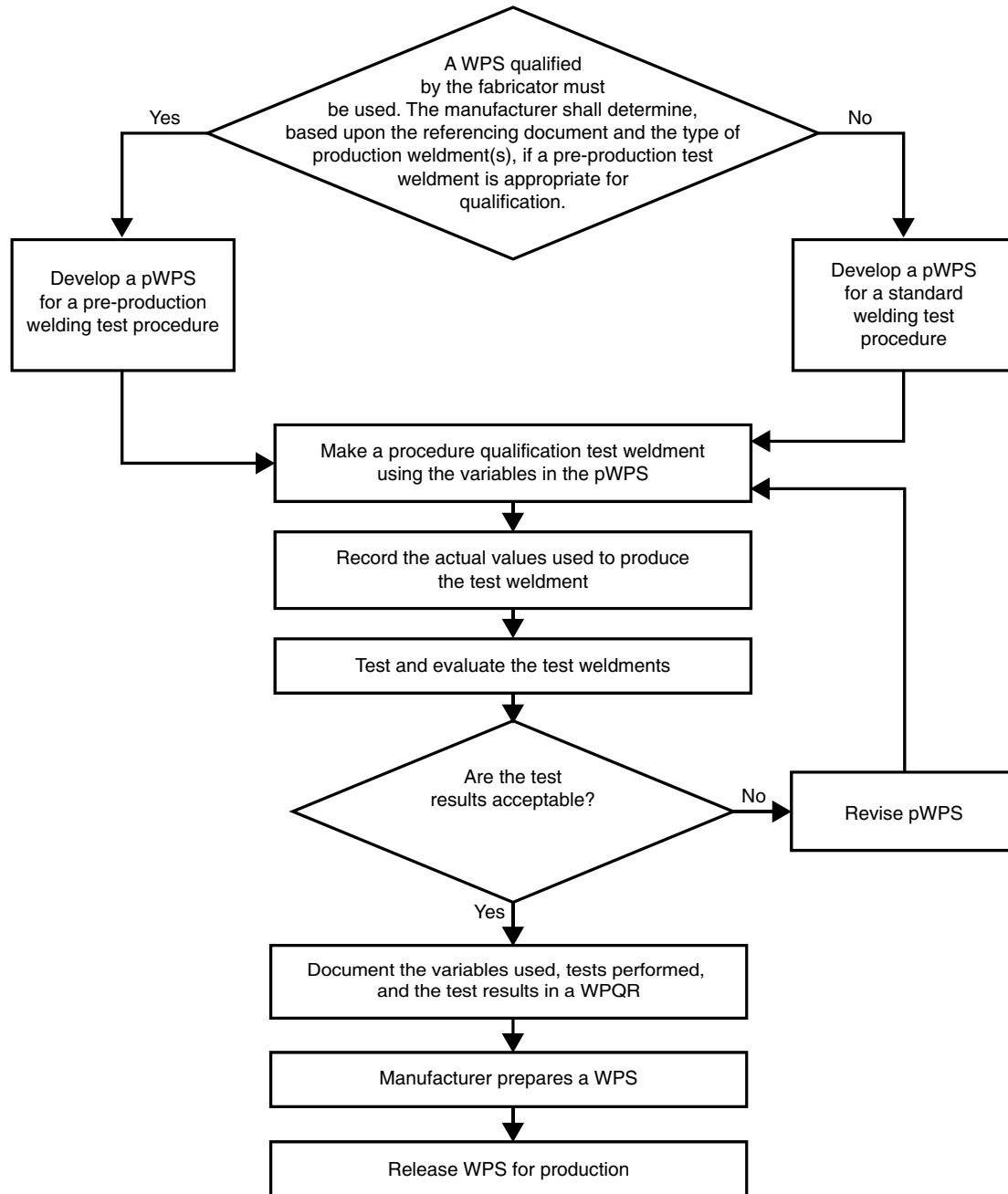


Figure 6.1—Flow Diagram for the Development and Qualification of a Welding Procedure

6.1.3 Identification of a WPS and a WPQR. WPSs and WPQRs shall be identified in accordance with a system that allows permanent traceability from the WPS to its supporting WPQRs.

6.2 Selection of a Welding Procedure Qualification Method. The two methods for qualifying a welding procedure are shown in Table 6.2.

6.2.1 Qualification Based on a Standard Welding Procedure Test. This method specifies how a welding procedure can be qualified by welding and testing a standardized test piece. A standard test weldment of a square groove weld in pipe is illustrated in Figure 6.2. A standard test weldment of a square groove weld in plate is illustrated in Figure 6.3. A standard test weldment of a fillet weld is illustrated in Figure 6.4. A standard test weldment of a seam weld test is illustrated in Figure 6.5.

Table 6.2
Methods for Qualifying a Welding Procedure

Method Based on	Application
Standard welding procedure test (see 6.2.1)	Can always be applied, unless the procedure test does not adequately correspond to the joint geometry, restraint, or accessibility of the actual welds.
Preproduction welding procedure test (see 6.2.2)	Can always be applied in principle, but requires a test piece be manufactured under production conditions. Suitable for mass production.

6.2.2 Qualification Based on a Preproduction Welding Procedure Test. When the production joint geometry requirements are not represented by the standardized test pieces shown in Figures 6.2 through 6.5, then the preproduction qualification test method shall be required. One or more preproduction test pieces shall be made to simulate the production joint in all essential features. The preproduction test piece shall be welded prior to, and under the conditions to be used in production.

6.3 Preparation of a Preliminary Welding Procedure Specification (pWPS). The Fabricator shall prepare a preliminary welding procedure specification (pWPS). The pWPS shall provide all of the information required to make a weld. The minimum information required in a pWPS is given below in Points 1–12. An example of a pWPS form is given in Annex D, Figure D.1. A pWPS may be presented in any format, in either written or electronic, provided all applicable information is recorded. The pWPS shall list the variables to be recorded on the WPQR.

1. Fabricator's information

- (1) Identification of the Fabricator, and
- (2) Identification of the pWPS.

2. Base metal type(s), base metal temper(s), and reference standard(s)

3. Base metal dimensions

- (1) Thickness of the members composing the welded joint, and
- (2) Outside diameter of pipe.

4. Equipment identification

- (1) Model number,
- (2) Serial number, and
- (3) Equipment manufacturer.

5. Tool identification

- (1) Material, and
- (2) Engineering drawing or drawing number.

6. Clamping arrangement

- (1) The method and type of fixtures, rollers, and anvil, and
- (2) Friction stir tack welding and fusion tack welding.

7. Joint design

- (1) A sketch of the weld joint design and dimensional tolerances,
- (2) Weld run sequence and welding direction given on the sketch, if applicable, and
- (3) Placement of the exit hole.

8. Joint and surface preparation

- (1) Maximum allowable root opening,
- (2) Maximum allowable weld joint mismatch,
- (3) Dimensions of starting weld tab and runoff weld tab plates, aluminum alloy type and reference standard, and
- (4) Cleaning procedure.

9. Welding details

- (1) Tool motion (e.g., rotation in either the clockwise or counter-clockwise direction, rotation speed including ramp-up/ramp-down rotation speeds),

- (2) Heel plunge depth, axial force, as applicable,
- (3) Tilt angle,
- (4) Side tilt angle,
- (5) Dwell time,
- (6) Lap joint: lapped length between start and end of weld,
- (7) Lap joint: advancing or retreating side near the edge of the sheet against which the tool is in contact,
- (8) Lap joint: direction of welding, and
- (9) Primary control method: force control or position control.

10. Travel speed

- (1) Ramp-up/ramp-down, upslope/downslope speeds, and
- (2) Travel speed.

11. Preheating

- (1) Base metal and other items that shall be preheated and to what temperature, and
- (2) Location or zone to which preheat should be applied.

12. Postweld processing and heat treatment

- (1) Solution heat treatment, natural and artificial aging, stress relieving (or the methods to correct distortion and straighten distorted parts), removal of flash, or any other post-weld processing of the weldment.

6.4 Welding. When welding the procedure qualification test pieces, the welding operator shall be under the full control and supervision of the Fabricator.

6.5 Evaluation of Test Welds

6.5.1 Visual Inspection. Prior to removing test specimen blanks from the completed test piece, the weld shall be visually inspected for cracks, incomplete penetration, cavities open to the surface, linear and angular mismatch across the joint, overlap, underfill, and weld flash. These discontinuities shall be evaluated in accordance with the acceptance criteria defined in Table 9.1.

6.5.2 Destructive Tests

6.5.2.1 Standard Test Weld. The test weld shall be evaluated using the tests required, as depicted in Figures 6.2 through 6.5, as a minimum. Test specimen blanks shall be removed from the locations shown in Figure 6.2 for square groove welds in pipe, Figure 6.3 for square groove welds in plate, Figure 6.4 for fillet welds in lap joints, or Figure 6.5 for seam welds. The preparation and dimensions of test specimens shall be in accordance with Annex A. The test results shall be recorded on or appended to a WPQR containing the actual variables used for welding the welding procedure qualification test piece.

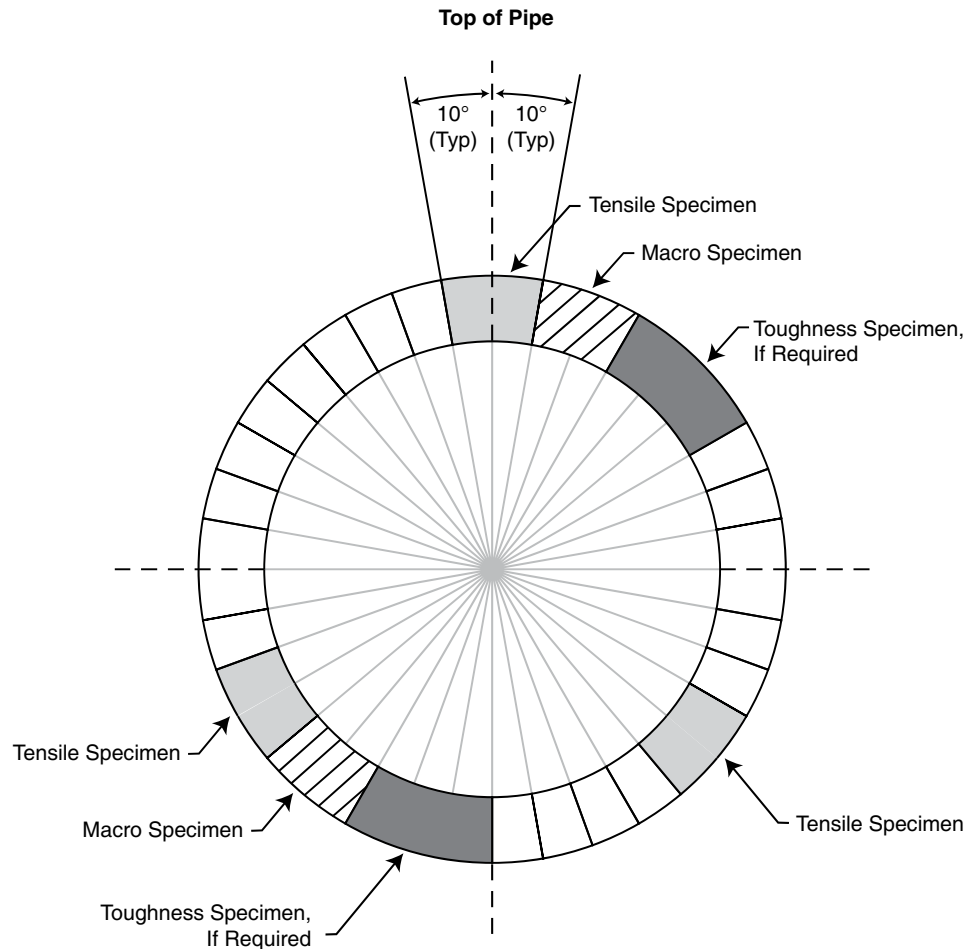
6.5.2.2 Preproduction Test Weld. The preproduction test welds shall be subjected to the applicable destructive tests listed in Table 6.3. The type, quantity, and location of the test specimens shall be as given in the Referencing Document.

Table 6.3
Destructive Tests Required for Qualifying a Welding Procedure

Type	Groove Weld	Fillet and Lap Welds
Tension tests	Yes	[Note (2)]
Macro-examination	Yes	Yes
Fracture toughness tests	[Note (1)]	[Note (2)]
Bend tests	[Note (1)]	[Note (2)]
Shear tests	[Note (2)]	Yes

Notes:

- 1. When specified in the Referencing Document.
- 2. No test is required.



Notes:

1. The base metal thickness shall be determined in accordance with 6.7.2(1).
2. The dimensions for test specimen blanks and details are given in Annex A.

Source: Adapted from AWS B2.1:2000, *Specification for Welding Procedure and Performance Qualification*, Figure 2.2.

Figure 6.2—Location of Square Groove Weld Test Specimens—Pipe

6.5.2.3 Acceptance Criteria

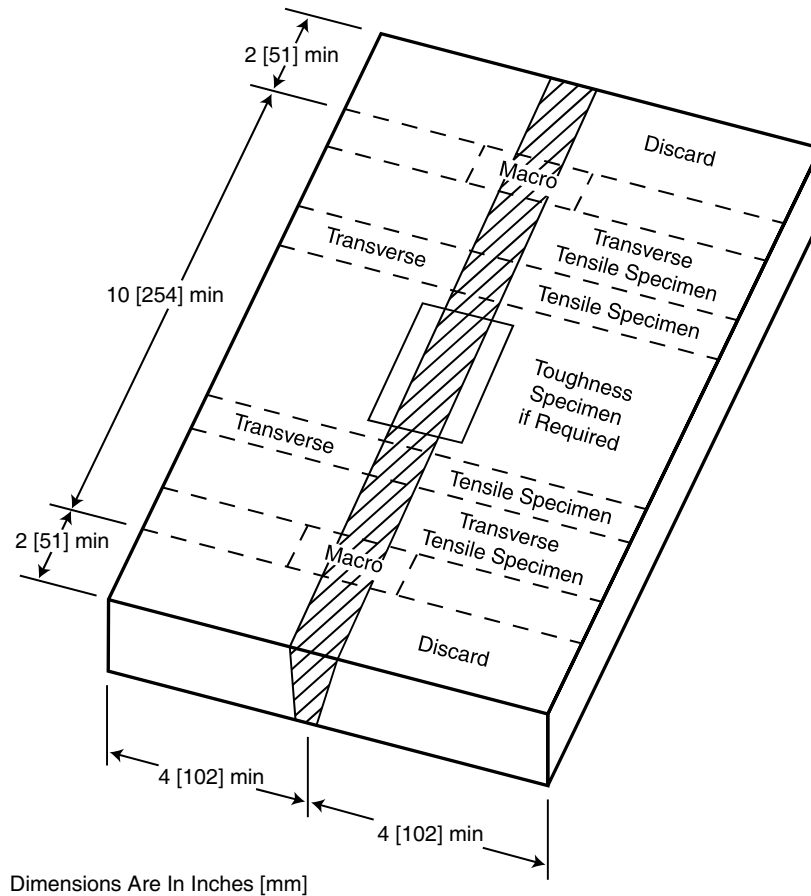
Macroetch Test. The macroetch test specimens shall meet the requirements of Table 9.1, except where partial joint penetration weld joints are specified in the Referencing Document.

Tensile Test. Each transverse-weld tensile test specimen shall meet the requirements of Table 6.4.

Shear Test. The shear strength of the fillet weld or seam weld test specimen shall not be less than 60% of the minimum specified tensile strength of the base metal (see Figure 6.4).

6.6 Welding Procedure Qualification Record (WPQR). The welding procedure qualification record (WPQR) is a statement of the test results of each test specimen. The WPQR shall contain the actual welding procedure qualification test variables, the items listed in the pWPS, and the acceptance test results of Clause 9. If no rejectable features or unacceptable test results are found, a WPQR detailing the welding procedure test piece results is qualified and shall be signed and dated by the examiner or the examining body.

See Figures D.1 and D.2 in Annex D for two examples of WPQR forms.



Notes:

1. The base metal thickness shall be determined in accordance with 6.7.2(1).
2. The dimensions for test specimen blanks and details are given in Annex A.
3. The test plate length shall be sufficient for the required number and type of specimens.

Source: Adapted from AWS B2.1:2000, *Specification for Welding Procedure and Performance Qualification*, Figure 2.5.

Figure 6.3—Location of Square Groove Weld Test Specimens—Plate

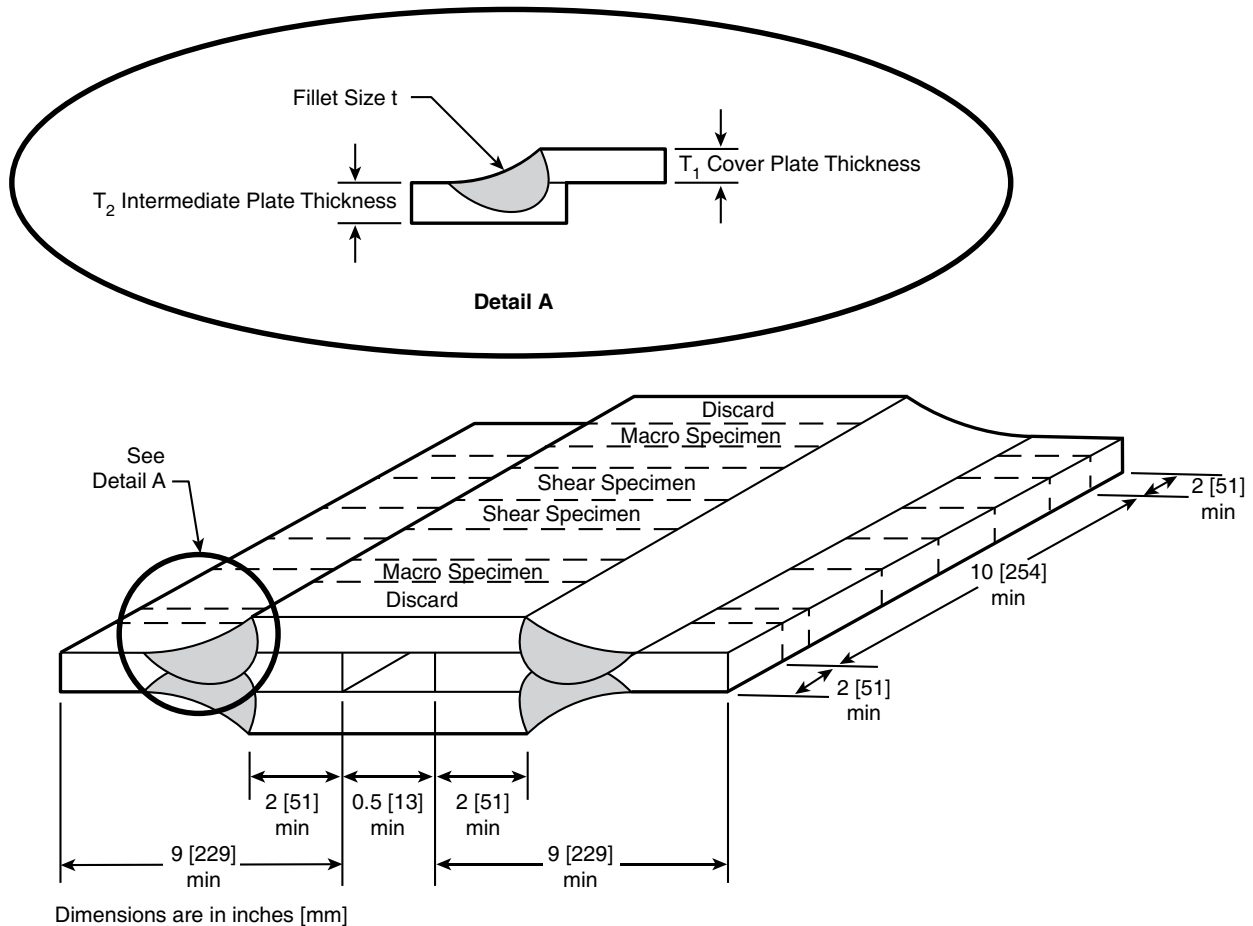
6.7 Welding Procedure Qualification Variables. Subclauses 6.7.1 through 6.7.5 list the welding procedure qualification test variables to be recorded on the WPQR. The values of the actual variables used shall be listed on the WPQR. A change in a welding procedure qualification test variable requires requalification of the welding procedure.

6.7.1 Joint Design

- (1) A change from a fillet to a groove weld,
- (2) The addition or deletion of backing, and
- (3) An increase in the root opening beyond that used in the qualification test.

6.7.2 Base Metal

- (1) A change in base metal thickness beyond $\pm 5\%$,
- (2) A change from uncoated aluminum to coated aluminum (e.g., conversion coat, anodize) unless the coating is removed from the weld area prior to welding, but not vice versa,



Notes:

1. The base metal thickness shall be determined in accordance with 6.7.2(1).
2. The dimensions for test specimen blanks and details are given in Annex A.
3. The test plate length shall be sufficient for the required number and type of specimens.

Source: Adapted from AWS B2.1:2000, *Specification for Welding Procedure and Performance Qualification*, Figure 2.6.

Figure 6.4—Location of Fillet Weld Test Specimens—Plate

(3) A change to clad aluminum from bare aluminum or vice versa, or a change in cladding type, unless the cladding is removed from the weld area prior to welding, and

(4) A change in alloy type, preweld temper, or postweld temper, whether it is in a single-alloy weld or a multi-alloy weld.

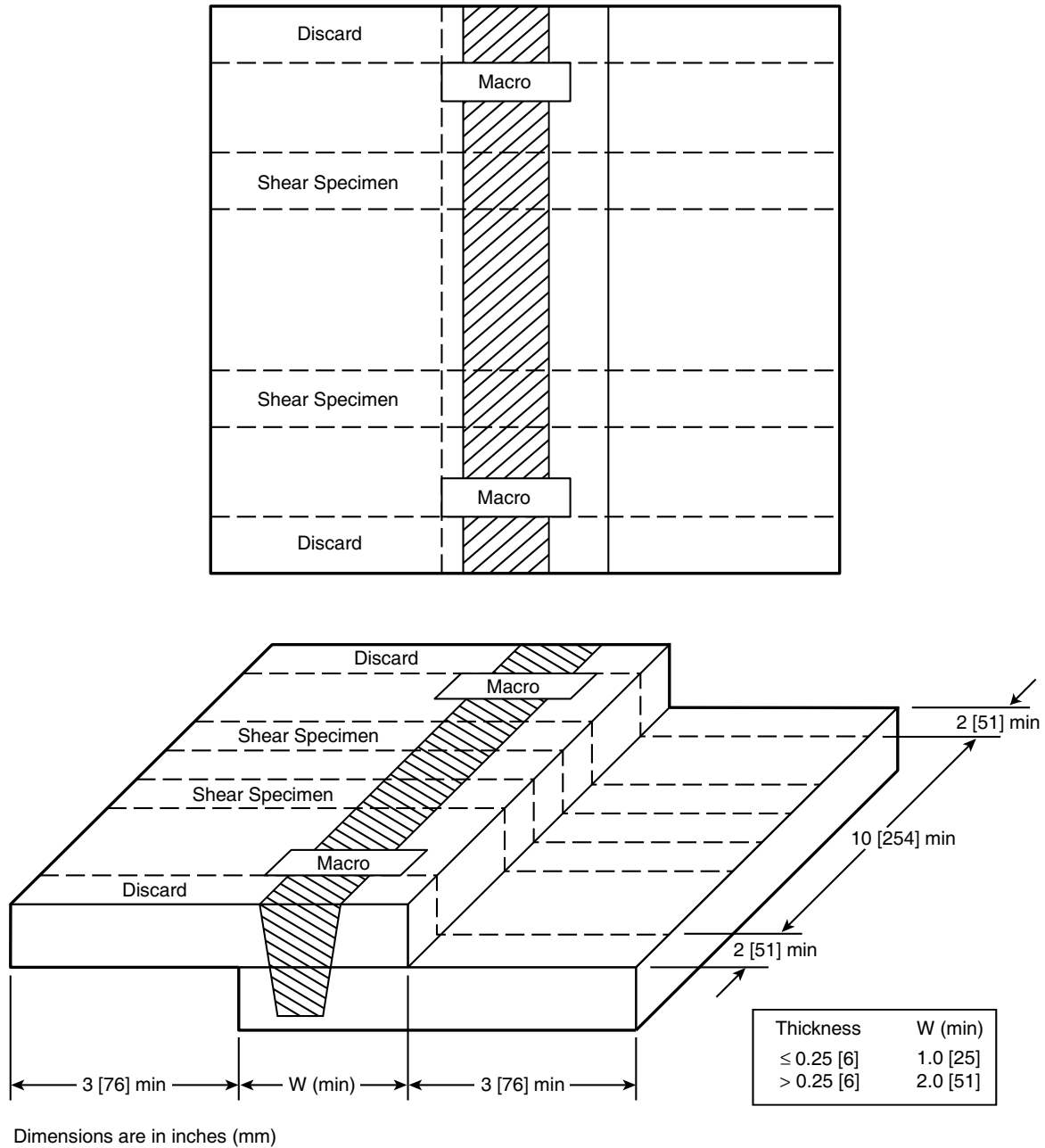
6.7.3 Preheat Temperature

(1) A decrease in preheat temperature of more than 100°F [55°C] from that qualified, and

(2) For heat treatable alloys, an increase in the preheat temperature of more than 100°F [55°C] from that qualified.

6.7.4 Postweld Heat Treatment (PWHT)

(1) A change from PWHT to no PWHT, and vice versa.



Notes:

1. The base metal thickness shall be determined in accordance with 6.7.2(1).
2. The dimensions for test specimen blanks and details are given in Annex A.
3. The test plate length shall be sufficient for the required number and type of specimens.

Figure 6.5—Location of Seam Weld Test Specimens—Plate

Table 6.4^a
Efficiency Requirements for Welded Butt Joint Tensile Strength

Material Type	Temper Condition of Base Metal before Welding ^b	Postweld Condition ^c	Joint Efficiency Factor ^{d, e}
Pure aluminum	All tempers	As welded	1.0 ^f
Non heat treatable alloys	All tempers	As welded	1.0 ^f
Heat treatable alloys ^h	T4	Natural aging	0.7
	T4	Artificial aging	0.7 ^g
	T5 and T6	Natural aging	0.6
	T5 and T6	Artificial aging	0.7 ^g

^a The data in this Table was taken from fusion welding specifications because no A-basis friction stir weld data were available.

^b For base metal in other tempers not shown in this Table, the ultimate tensile strength of the welded test specimen shall be in accordance with the Referencing Document.

^c Aging conditions shall be in accordance with the Referencing Document.

^d Joint efficiency factor = ultimate tensile strength of the welded test specimen after all postweld heat treatments have been conducted divided by the specified minimum tensile strength of the parent material required in the relevant specification.

^e For combinations between different alloys, the lowest individual efficiency factor value shall be achieved.

^f The ultimate tensile strength of the base metal is based on the specified minimum ultimate tensile strength of the “O” (annealed) condition, irrespective of the actual base metal temper used for the test.

^g Higher properties may be achieved, if a full postweld heat treatment is applied. The ultimate tensile strength of the welded test specimen shall be in accordance with the Referencing Document.

^h Only applies to 6000 series alloys. For 2000 series and 7000 series alloys, the temper of the base metal before welding and the postweld aging conditions shall be in accordance with the Referencing Document.

6.7.5 Other Variables

- (1) A change in welding method,
- (2) A change in the anvil design or material, and
- (3) A change in any of the variables identified in 6.3, or by the Referencing Document.

6.8 Welding Procedure Specification (WPS). The Fabricator shall prepare the WPS for production welding based on the entries in the WPQR. The WPS shall contain all of the information that is in the pWPS. Each WPS shall specify a minimum and maximum value or a single value for each welding variable identified in 6.7. A WPS shall include a statement acknowledging the validity of the data, and certifying that the weldments were made and tested, in accordance with the requirements of this specification. An example of a WPS form is given in Annex C, Figure C.2. A pWPS form and a WPS form are interchangeable except for the title.

6.8.1 Application of a WPQR. A WPS may require the support of more than one WPQR. One WPQR may support more than one WPS.

6.9 Revising a WPQR or WPS. Revisions to WPQRs and WPSs shall be permitted where procedures and process information have been incorrectly documented, omitted, or new information is available. New information includes information that was not available when the WPQR was prepared, e.g., the fatigue test results when only static test results were required for qualification. All revisions shall be authorized, identified, traceable, and dated on the WPQR and WPS.

7. Welding Operator Qualification

7.1 Qualification Requirements. To become qualified, the welding operator shall demonstrate his skill by producing an acceptable test weld in accordance with an approved WPS. Qualifications, certifications, requalifications, and recertifications given under this document do not transfer from one Fabricator to another.

7.1.1 Vision Test. The welding operator shall have vision acuity of 20/30 or better in either eye and shall be able to read the Jaeger No. 2 Eye Chart at 16 inches [406 mm]. Corrected or uncorrected vision may be used to achieve eye test requirements. Vision shall be tested to these requirements at least every two years.

7.1.2 Test Weld. One of the test pieces in Figures 7.1–7.4 shall be used for the welding operator qualification test. The test piece shall be welded in accordance with a WPS. When none of the test pieces described above are applicable to a given

production weld, then a special welding operator qualification that is limited to the specific application may be achieved with a test piece consisting of the given production weld or a test weld representative of the given production weld.

7.1.3 Inspection. The test weld shall be inspected in accordance with the class specified in the WPS, except a two inch long discard may be taken at the ends of groove and fillet weld coupons in plate. Visual inspection shall be accomplished in the as-welded condition.

7.2 Qualification Limitations

7.2.1 FSW Methods. A test weld made with any type of FSW method qualifies only for that FSW method.

7.2.2 Base Metals. A test weld made in any aluminum alloy qualifies for all aluminum alloys.

7.2.3 Base Metal Form and Weld Type. A successful qualification of any (Figures 7.1–7.4) test weld qualifies the welding operator to weld all base metal forms (plate or pipe), groove welds, and fillet welds. A successful qualification of a preproduction test weld, as described in 7.1.2, qualifies the welding operator to weld that particular production weld joint and all base metal forms (plate or pipe) and groove and fillet welds.

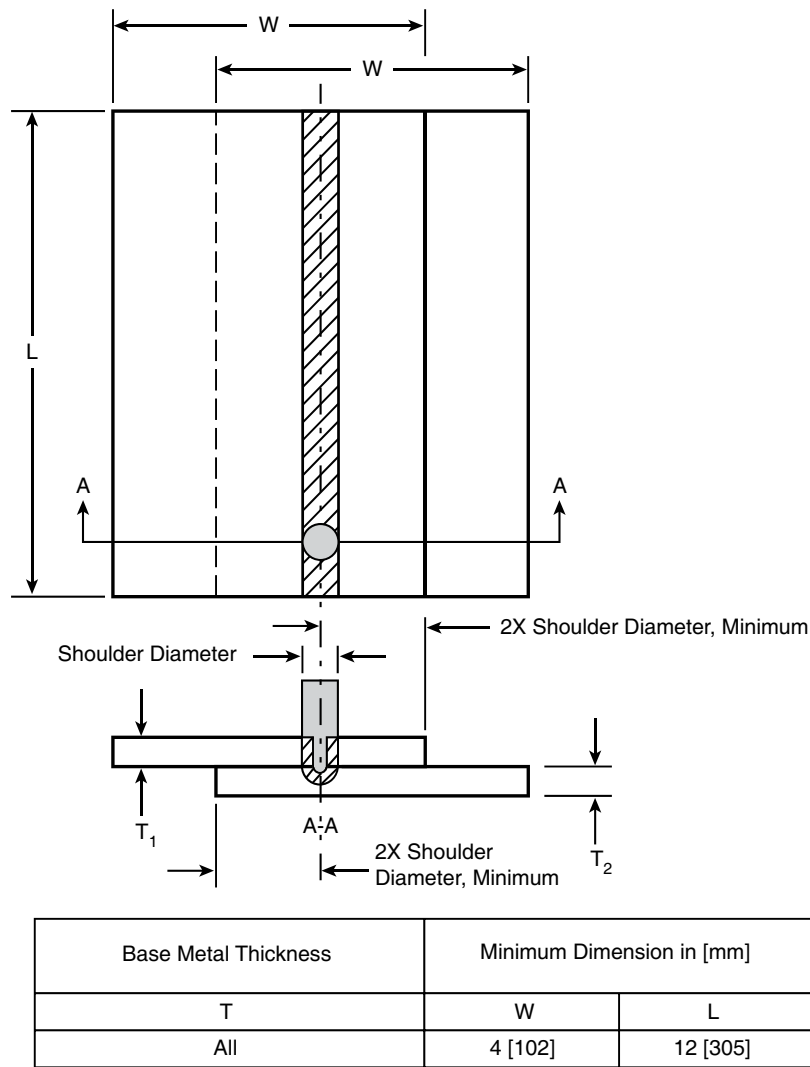
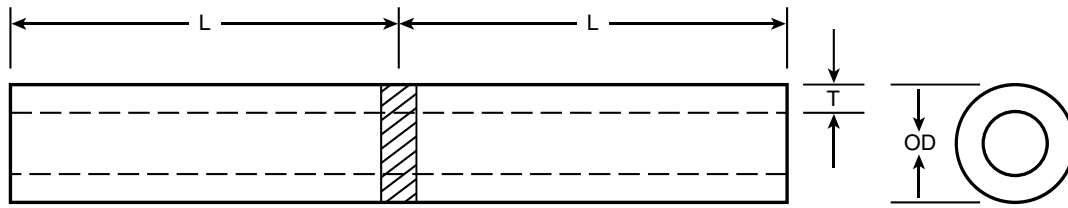
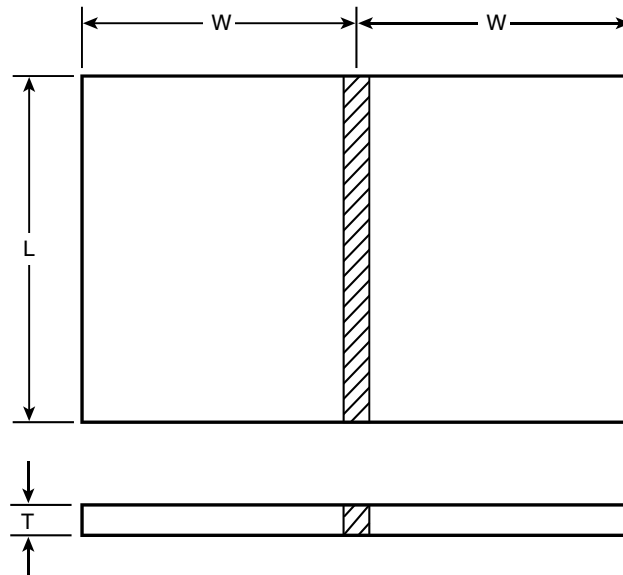


Figure 7.1—Seam Weld Test in Plate



Base Metal Thickness	Suggested Minimum Dimension in [mm]
T	L
All	3 [76]

Figure 7.2—Square Groove Weld Test in Pipe



Base Metal Thickness	Minimum Dimension in [mm]	
T	W	L
All	4 [102]	12 [305]

Figure 7.3—Square Groove Weld Test in Plate

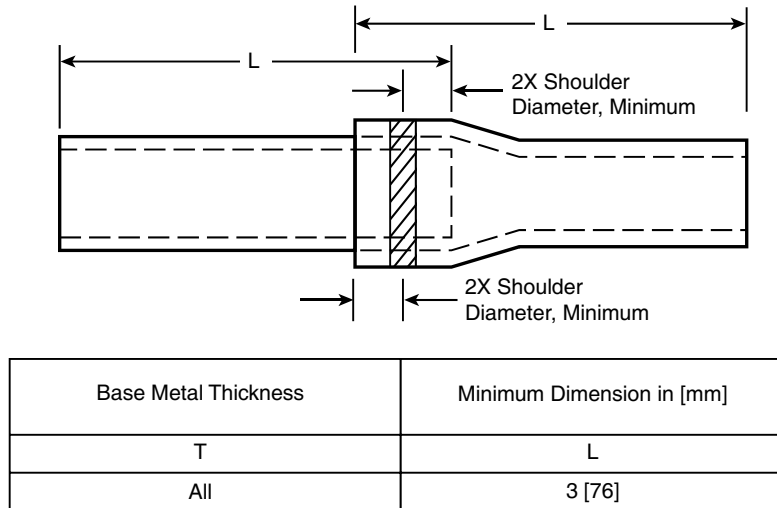


Figure 7.4—Seam Weld Test in Pipe

7.2.4 Qualified Thickness Range. A test weld made with any base metal thickness shall qualify the welding operator to weld any base metal thickness.

7.3 Qualification/Certification Validity

7.3.1 Initial Certification. Successful completion of welding operator qualification tests shall be justification for issuance of a certification valid for a period of two years from the acceptance date of the qualification test results.

7.3.2 Extended Certification. A welding operator's certification may be extended indefinitely, provided an auditable record is maintained from the date of the initial qualification that verifies the welding operator has used the process within the previous six-month period.

7.3.3 Disqualification. Disqualification and revocation of a welding operator's certification shall result under any one or more of the following conditions:

- (1) The welding operator failed the vision test or has not passed the required vision test within the previous two years, as required by 7.1.1.
- (2) The welding operator qualification tests were not performed successfully within the previous two years, as required in 7.3.1.
- (3) An auditable record of the welding operator's performance was not maintained by the Fabricator, as required in 7.3.2.
- (4) There is a specific reason to question the ability of the welding operator to meet the welding operator qualification requirements.

7.3.4 Reinstatement. An individual who has been disqualified shall be recertified by meeting the requirements of 7.1.

7.3.5 Identification. The Fabricator shall assign a unique number or other identification to each welding operator upon certification.

7.4 Test Records. The Fabricator shall complete a test record containing the essential information required as evidence of welding operator certification. An example of a test record form, entitled *Welding Operator Qualification Test Record for All Aluminum Alloys*, is given in Annex B, Figure B.1.

8. Fabrication

8.1 Welding Equipment Requirements

8.1.1 Equipment Capabilities and Performance. Welding equipment (e.g., welding machines and FSW tools) shall be capable of producing welds that meet the acceptance criteria specified in Clause 9. Welding equipment shall not be used without needed repairs or adjustments when a welding operator, inspector, welding operator's supervisor, or welding engineer has concern about the capability of the equipment to operate satisfactorily. The welding equipment shall be capable of maintaining weld quality and consistency.

8.1.2 Calibration. Meters, gages, and dials installed on automatic, mechanized, or robotic welding apparatus shall be calibrated using an established procedure. The Fabricator shall establish and document applicable calibration procedures. Required calibrations shall be performed at an interval of two years or less. Required calibrations shall also be performed when meters, gages, and dials have been repaired or replaced.

8.1.3 Reproducibility Tests for Qualified Machine Welding Settings

8.1.3.1 When to Test. The reproducibility test shall be performed to demonstrate that the welding equipment can repeatedly produce welds that meet the acceptance criteria in Clause 9. The reproducibility tests shall be performed when either of the following occurs:

- (1) A major component of the welding equipment, as determined by the Fabricator, is either repaired or replaced.
- (2) The welding equipment is moved from one location to another.

8.1.3.2 Test Requirements

(1) The reproducibility test shall be performed in accordance with a WPS. A minimum of three test welds shall be made in succession.

8.2 Friction Stir Welding Tool

8.2.1 Identification. Any friction stir welding tool employed for production shall be permanently identified prior to usage.

8.3 Preweld Joint Preparation and Fit-Up

8.3.1 Joint Preparation. The root face and adjoining surfaces shall be prepared in accordance with the WPS.

8.3.2 Preweld Cleaning. Clean all surfaces to be welded in accordance with the WPS. Surfaces (e.g., base metals, tools, and fixtures) that may affect the quality of the resulting weld shall be free from surface oxides, protective finishes, oils, grease, dirt, or any other contaminants or discontinuities. Chemical cleaning methods (e.g., alkaline cleaning, solvent wipe, or acid etching) or mechanical cleaning methods (e.g., wire brushing, scraping, abrasive blasting, or machining) shall be used before welding, as needed, to ensure compliance with the above-mentioned requirements.

8.3.3 Root Opening. The gap between joint members being welded shall be in accordance with the WPS.

8.4 Preheat Temperature Control. The requirements for preheating shall be in accordance with the WPS.

8.5 Tack Welds. If required, tack welding of detail parts shall be accomplished by FSW or fusion welding in accordance with the WPS. Subsequent welding shall consume tack welds along with their heat affected zones unless removed in other processing. The requirements of 8.3 through 8.4 shall apply.

8.6 Welding. All welding shall be performed in accordance with an approved WPS. Before starting a welding cycle, the settings on the welding equipment and control system shall be set to those listed in the WPS.

8.7 Postweld Surface Preparation. When required by the WPS, all flash, overlapping metal, or other protruding metal along the edges of the weld shall be removed after visual inspection, but before other nondestructive examinations. Removal shall be done by a method that shall not degrade the weld joint or base metal properties. Postweld surface preparation shall be performed, so the weld metal and base metal thickness remain within drawing tolerances.

8.8 Weld Identification Requirements

8.8.1 Interim Identification. Each welding operator shall identify his work by interim marking of the weldment or by marking the applicable shop planning paperwork. Alternate tracking methods may be used with approval from the

Engineering Authority. The interim identification shall remain next to or with the weld through final inspection. Marking methods and materials shall not be detrimental to the base metal or interfere with subsequent operations.

8.8.2 Final Identification. Each welded assembly, or the documentation accompanying each welded assembly, shall be marked as follows:

- (1) Date of welding,
- (2) Welder's signature or individually assigned stamp or code,
- (3) Date of weld inspection,
- (4) Weld inspector's signature or individually assigned stamp or code.

8.9 Acceptance Inspection. The completed weldment shall be submitted to the Fabricator's quality assurance organization or its designee for acceptance inspection.

9. Inspection

9.1 General. Three quality levels are given in order to permit application to a wide range of welded constructions. The quality levels are designated by the symbols A, B, and C. They correspond directly with Class A, B, and C in Subclause 4.1. For example, quality level A corresponds to the highest requirement on the finished weld. The quality levels refer to production quality and not to the fitness for purpose of the product manufactured.

The choice of quality level shall take into account the design requirements, subsequent processing (e.g., surfacing), type of stress (e.g., static, dynamic), service conditions (e.g., temperature, corrosion), and consequences of failure. Economic factors are also important and should include the cost not only of welding but also of inspection, test, and repair.

9.2 Inspection Personnel

9.2.1 Qualification of Nondestructive Examination (NDE) Personnel. Nondestructive examination (NDE) personnel shall be qualified to NAS 410.

9.2.2 Visual Weld Inspection Personnel. Personnel performing visual weld inspections shall be certified to the requirements of AWS QC1 or by experience, training, and testing requirements defined in AWS B5.1 and approved by the Engineering Authority.

9.3 Visual Weld Inspection. All welds shall undergo visual inspection for conformance to the requirements of Table 9.1.

9.4 Nondestructive Examination

9.4.1 Penetrant Testing (PT). Class A and Class B welds shall be dye penetrant tested in accordance with ASTM E 1417. Class C welds shall be dye penetrant tested when specified in the engineering drawing.

9.4.2 Radiographic Testing (RT). Class A groove welds shall be radiographically tested in accordance with ASTM E 1742. When radiographic testing of fillet welds or partial penetration groove welds is required, the acceptance criteria of the root shall be given in the engineering drawing. Class B and Class C welds shall be radiographically inspected in accordance with ASTM E 1742 when specified in the engineering drawing.

9.4.3 Ultrasonic Testing (UT). Ultrasonic testing may be used instead of radiographic testing when specified in the engineering drawing. Ultrasonic inspection shall be performed in accordance with ASTM E 164.

When immersion ultrasonic inspection is specified on the engineering drawing, an approved standard shall be specified by the engineering drawing.

9.4.4 Other Nondestructive Tests. Nondestructive tests, procedures, techniques, equipment, or materials (e.g., acoustic emission, electromagnetic or eddy current, leak, neutron radiographic, etc.) not specifically addressed in this document may be used when an approved standard is specified in the engineering drawing.

9.5 Acceptance Criteria

9.5.1 General. The dimension of any discontinuity shall be defined by its largest dimension. Two or more discontinuities shall be treated as one when the spacing between them is less than the largest dimension of the larger

Table 9.1
Acceptance Levels for Discontinuities^a

Discontinuity	Class A	Class B	Class C
Cracks	None	None	None
Incomplete joint penetration (only when complete joint penetration is required of a groove weld)	None	None	None
Inclusions			
a. Individual size (maximum)	0.33T or 0.06 in [1.5 mm], whichever is less	0.50T or 0.09 in [2.3 mm], whichever is less	Not applicable
b. Spacing (minimum)	Four times the size of the larger adjacent discontinuity	Two times the size of the larger adjacent discontinuity	Not applicable
c. Accumulated length in any 3 in [76 mm] of weld (maximum)	1.33T or 0.24 in [6.1 mm], whichever is less	1.33T or 0.24 in [6.1 mm], whichever is less	Not applicable
Internal cavity, or cavity open to surface	None	None	Reject only cavities open to the surface
Linear mismatch across joint (maximum) Groove welds only	1.05 times the base metal thickness tolerance	1.075 times the base metal thickness tolerance	Not applicable
Overlap (cold lap)	See 8.7	See 8.7	See 8.7
Angular distortion of the joint (degrees) (maximum) Groove welds only	3 degrees	3 degrees	Not applicable
Underfill (maximum) Applies only if the weld face will not be postweld machined.			
a. For the full length of the weld (maximum depth)	0.05T	0.075T	0.10T
b. Individual defect (maximum depth)	0.07T or 0.03 in [0.76 mm], whichever is less	0.10T or 0.03 in [0.76 mm], whichever is less	0.125T or 0.03 in [0.76 mm], whichever is less
c. Accumulated length in any 3 in of weld (maximum)	0.20 in [5.1 mm]	0.60 in [15 mm]	1.0 in [25 mm]
Weld flash (maximum height)	See 8.7	See 8.7	See 8.7

^a See 9.5.1 for general rules regarding the acceptance criteria.

Note: A hook has been identified as a discontinuity, but no acceptance criteria have been agreed upon. See *Terms and Definitions*.

discontinuity. Discontinuities that will be removed in subsequent machining shall not be a cause for rejection. Any weld with unacceptable discontinuities, which has gone through a subsequent manufacturing operation that affects the metallurgical characteristics (other than stress relief or postweld heat treatment) or that cannot be rewelded without affecting the final metallurgical or surface characteristics, shall be rejected. Removal of unacceptable weld metal is allowed provided the minimum weld size is met. Incidental removal of base metal during discontinuity removal is acceptable, provided the minimum thickness requirements and any other engineering requirement (e.g., surface roughness) are met. When determining the minimum thickness of the metal in an area where a discontinuity was removed, in a joint with varying cross section, use the thickness of the metal at the location of the removed discontinuity.

9.5.2 Acceptable Welds. Welds shall be acceptable if they meet the requirements of Table 9.1. Welds not meeting these requirements shall be rejected.

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Annex A (Normative)

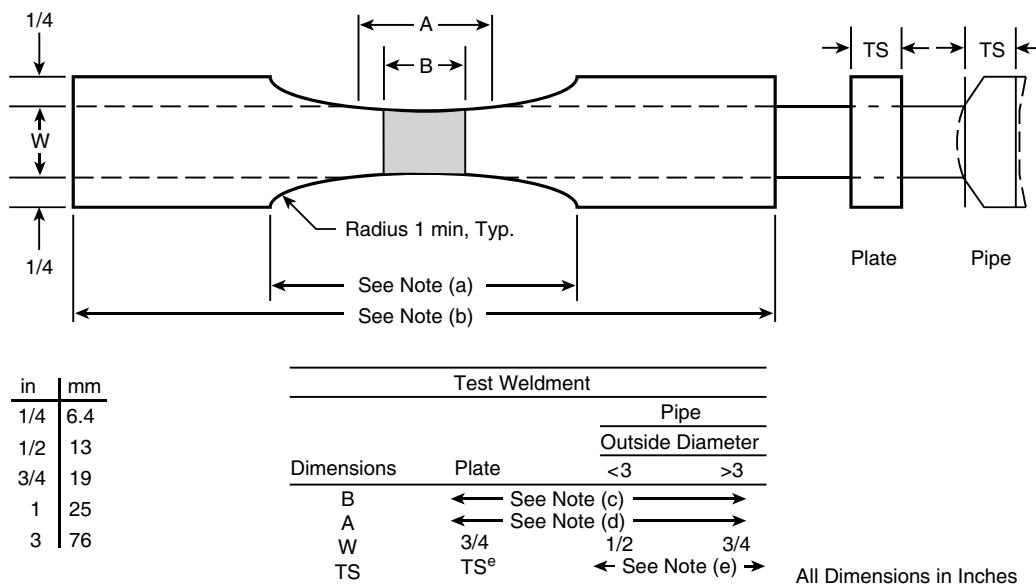
Illustrations of Test Specimens and Test Fixtures

This annex is part of AWS D17.3/D17.3M:2010, *Specification for Friction Stir Welding of Aluminum Alloys for Aerospace Applications*, and includes mandatory elements for use with this standard.

A1. Tension Specimens

Tension test specimens are illustrated in Figures A.1, A.2, A.3, and A.4. A single-test specimen may be used for a base metal thickness of 1 inch [25 mm] or less.

A1.1 For thicknesses over 1 inch [25 mm], single or multiple specimens may be used provided that: (1) collectively, multiple specimens representing the full thickness of the weld at one location, shall comprise a set, and (2) the entire thickness shall be mechanically cut into approximately equal thickness strips. For specimens that are not round (turned on a lathe), the test specimens' thickness shall be the maximum size that can be tested in the available equipment.



^a This section shall be cut by machining or grinding.

^b The specimen length shall be as required by the tension testing equipment.

^c B shall be equal to the greater dimension of the weld metal in the direction of the specimen's longitudinal axis.

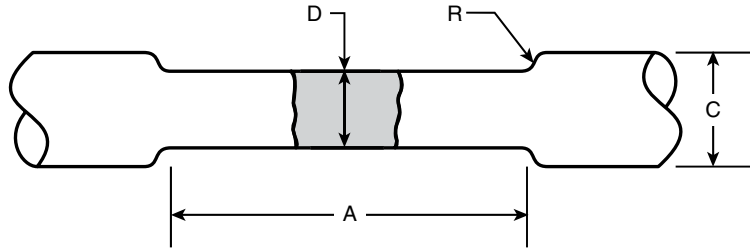
^d The length of the reduced section A shall be equal to B plus 1/2 in [13 mm] with a minimum of 2-1/4 in [57 mm]. The ends shall not differ in width from the ends to the center, but the width at either end shall not be more than 0.015 in [0.38 mm] greater than the width at the center. The weld shall be in the center of the reduced section.

^e The amount removed shall be the minimum needed to obtain plane parallel surfaces across the width of the reduced section.

Source: Adapted from AWS B2.1:2000, *Specification for Welding Procedure and Performance Qualification*, Figure II-3A.

Figure A.1—Reduced Section Tension Specimen—Rectangular

in	mm
.188	4.77
.250	6.35
.350	8.89
.500	12.70
1/4	6.4
3/8	9.5
1/2	13
3/4	19



Standard Specimen Dimension, in. ^{a,c}				
Dimensions	0.505	0.353	0.252	0.188
A = Length of Reduced Section ^{b,d}	See Note (d)			
D = Diameter	0.500 ± 0.010	0.350 ± 0.007	0.250 ± 0.005	0.188 ± 0.003
R = Radius, Inches minimum	3/8 min.	1/4 min.	3/16 min.	1/8 min.
C = Diameter	3/4	1/2	3/8	1/4

^a The standard specimen that is selected shall be based upon the maximum diameter specimen that can be cut from the specimen blank.

^b The weld shall be in the center of the reduced section.

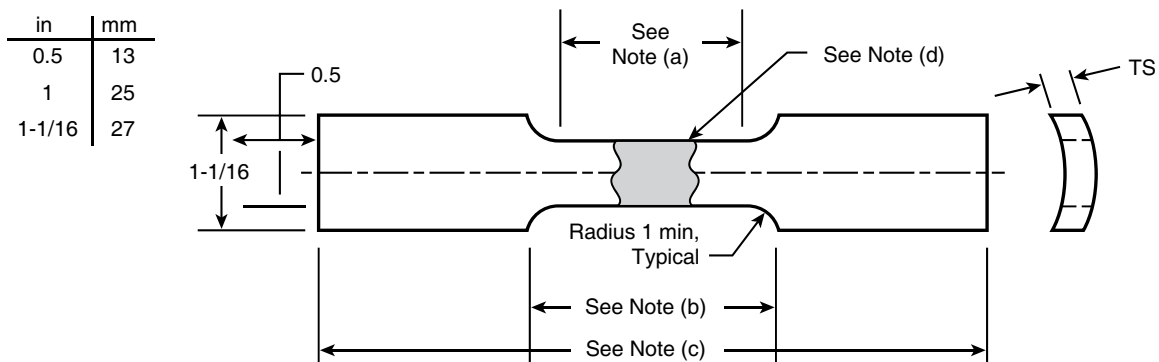
^c Where only a single specimen from a blank is required, the specimen's longitudinal axis shall be centered between the base metal surfaces.

^d The length of the reduced section shall be not less than the width of the weld metal plus 2D. It may have a gradual taper from the ends toward the center, with the ends not more than 1 percent greater in diameter than the center, which shall be the dimension D. The ends may be of any length and shape as required by the testing machine.

Note: For base metal thicknesses over 1 in [25 mm], multiple specimens are required and one complete set shall be made for each required test. The specimen blank shall be cut into strips of approximately equal thickness with their centerlines no more than 1 in [25 mm] apart. The centerline of the surface shall be within 5/8 in [16 mm] of that surface.

Source: Adapted from AWS B2.1:2000, *Specification for Welding Procedure and Performance Qualification*, Figure II-3B.

Figure A.2—Reduced Section Tension Specimen—Round



All Dimensions in Inches

^a The length of the reduced section shall be equal to the greater dimension of the weld metal in the direction of the specimen's longitudinal axis, plus 2T. The sides shall be approximately parallel. The weld shall be in the center of the reduced section.

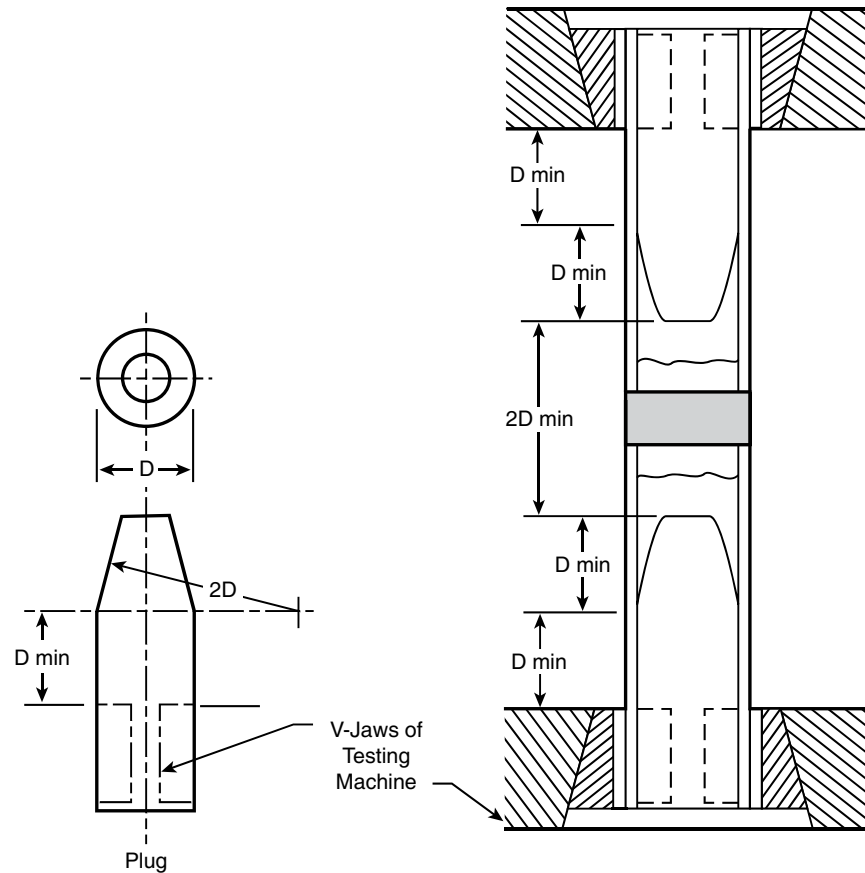
^b The reduced section shall be cut by machining or grinding.

^c The specimen length shall be as required by the tension testing equipment.

^d The weld metal thickness shall equal the base metal thickness.

Source: Adapted from AWS B2.1:2000, *Specification for Welding Procedure and Performance Qualification*, Figure II-3C.

Figure A.3—Alternate Tension Specimen for Pipe 3 in [76 mm] O.D. or Less



Notes:

1. The sides shall be approximately parallel. The weld shall be in the center of the “ $2D \text{ min}$ ” test section.
2. The specimen length shall be as required by the tension testing equipment.

Source: Adapted from AWS B2.1:2000, *Specification for Welding Procedure and Performance Qualification*, Figure II-3D.

Figure A.4—Alternate Tension Specimen for Pipe 2 in [51 mm] O.D. or Less

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Annex B (Informative)

Example of a Welding Operator Qualification Test Record Form

This annex is not part of AWS D17.3/D17.3M:2010, *Specification for Friction Stir Welding of Aluminum Alloys for Aerospace Applications*, but is included for informational purposes only.

Welding Operator Qualification Test Record for All Aluminum Alloys			
Name: _____		Identification: _____	
Welding Procedure Specification No: _____			
A. TEST WELD			
1. Aluminum Alloys: _____			
2. Dimension:			
Plate ☐ T = _____			
Pipe ☐ T = _____ Outer Diameter = _____			
3. Friction Stir Welding Method:			
Single Spindle ☐ Multiple Spindle ☐ Robotic ☐			
Simultaneous Two-Sided ☐ Other ☐			
B. TEST RESULTS			
1. Visual:		Pass ☐	Fail ☐
2. Radiographic:	N/A ☐	Pass ☐	Fail ☐
3. Metallographic:		Pass ☐	Fail ☐
4. Mechanical:		Pass ☐	Fail ☐
5. Ultrasonic:	N/A ☐	Pass ☐	Fail ☐
6. Other:	N/A ☐	Pass ☐	Fail ☐
C. VISUAL ACUITY TEST		Pass ☐	Fail ☐
D. QUALIFIED			
1. Plate and Pipe, Groove and Fillet Welds ☐			
2. Pre-Production Weld ¹ ☐			

¹In addition, pre-production qualifies plate and pipe, and groove and fillet welds.			
The above named individual is qualified in accordance with AWS D17.3 within the above limits for the friction stir welding method (see A3 above) used for this test weld.			
Date of Test Weld: _____		Signed by : _____	
		Qualifying Authority	

Figure B.1—Example of a Welding Operator Qualification Test Record Form

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Annex C (Informative)

Examples of Welding Procedure Specification Forms

This annex is not part of AWS D17.3/D17.3M:2010, *Specification for Friction Stir Welding of Aluminum Alloys for Aerospace Applications*, but is included for informational purposes only.

Preliminary Welding Procedure Specification (pWPS) for Friction Stir Welding

Fabricator's pWPS No.: _____
 Fabricator's WPQR No.: _____
 Friction stir welding operator's name: _____
 Base metal type and reference standard(s): _____
 Base metal thickness (T) (in [mm]): _____
 Outside diameter of pipe (in [mm]): _____
 Equipment identification: _____
 Tool identification (Sketch)*: _____
 Clamping arrangement (Sketch)*: _____
 Tack welding: _____
 Joint preparation and cleaning methods: _____
 Weld class: _____

Joint design

(Sketch)*

Welding details

Run	Rotation speed (r/min)	Plunge depth (in [mm]) and/or axial force (lbs [kN])	Tilt angle (°)	Side tilt angle (°)	Dwell time (s)	Welding speed (in [mm] / min), others

Preheating temperature (°F [°C]): _____ Preheat maintenance temperature (°F [°C]): _____
 Working temperature (°F [°C]): _____
 Post-weld processing: _____
 Post-weld heat treatment: _____
 Other information* _____

Fabricator _____

Name, date and signature _____

* If required

Figure C.1—Example of a Preliminary Welding Procedure Specification Form

Welding Procedure Specification for Friction Stir Welding	
Qualified Supporting WPQR(S):	WPS No.:
Governing Code: AWS D17.3	Date:
Friction Stir Welding Method:	Engineer:
Background	Sketch of Joint Design
Part:	
Weld Class:	
Aluminum Alloys	
Alloy 1 Temper: Thickness Range:	
Alloy 2 Temper: Thickness Range:	
Grain Direction	
Preweld Cleaning Root face: Plate or Tube Surface:	
Root Face or Surface Coating:	
Set-up	
Machine Model:	Probe Standoff from Root Surface:
Serial Number:	Axial Force (lbs [kN]):
Weld Tool Drawing Number:	Spindle Speed (R/MIN):
Weld Joint Type:	Direction of Tool Rotation:
Root opening (in [mm]):	Tilt Angle (degrees): Side Tilt Angle (degrees):
Tool Offset (in [mm]):	Plunge Speed (in [mm] / min):
Weld Fixture Drawing Number:	Dwell Time (s):
Anvil Material:	Clamp Pressure (psi [kPa]) ^a :
Note	Travel Speed (in [mm]/min):
^a 1,000 psi = 6.894757 MPa	
^a A 10 psi = 68.94757 kPa	
Welding Engineer _____ Date _____	
Manager _____ Date _____	

Figure C.2—Example of a Welding Procedure Specification Form

Annex D (Informative)

Examples of Welding Procedure Qualification Record Forms

This annex is not part of AWS D17.3/D17.3M:2010, *Specification for Friction Stir Welding of Aluminum Alloys for Aerospace Applications*, but is included for informational purposes only.

Welding Procedure Qualification Record for Friction Stir Welding

page 1 of 2

WPQR Number:	Date:
Governing Code: AWS D17.3	Engineer:
Friction Stir Welding Method:	
Fabricator:	
Background	Sketch of Joint Design
Part:	
Weld Class:	
Aluminum Alloys	
Alloy 1: Temper: Thickness Range:	Alloy 2: Temper: Thickness Range:
Grain Direction	Preweld Cleaning Root Face: Plate or Tube Surface:
Root Face or Surface Coating:	
Set-up	Welding Variables
Machine Model and Serial Number:	Probe Standoff from Root Surface (in [mm]):
Weld Tool Drawing Number:	Axial Force (lbs [kN]):
Weld Joint Type:	Spindle Speed (r/min):
Root Opening (in [mm]):	Direction of Tool Rotation:
Tool Offset (in [mm]):	Travel Speed (in [mm]/min):
Weld Fixture Drawing Number:	Tilt Angle (degrees): Side Tilt Angle (degrees):
Anvil Material:	Plunge Speed (in [mm]/min):
	Dwell Time (s):
	Clamp Pressure (psi [kPa]):
Welding Engineer _____ Date _____ Manager _____ Date _____	

Figure D.1—Example Number One of a Welding Procedure Qualification Record Form

Test Results

page 2 of 2

Specimen Identification Number	Yield Load (lbs [kN])	0.2 % Offset Tensile Yield Strength (ksi [MPa])	Ultimate Tensile Load (lbs [kN])	Ultimate Tensile Strength (ksi [MPa])	Elongation in 2 inch or 1 inch (%)

Test Results

1. Visual:		Pass []	Fail []
2. Radiographic:	N/A []	Pass []	Fail []
3. Dye Penetrant:	N/A []	Pass []	Fail []
4. Metallographic:		Pass []	Fail []
4. Mechanical:			
5. Ultrasonic:	N/A []	Pass []	Fail []
6. Other	N/A []	Pass []	Fail []

Figure D.1 (Continued)—Example Number One of a Welding Procedure Qualification Record Form

Welding Procedure Qualification – Test Certificate**(page 1 of 3)**

Fabricator: _____

Address: _____

Fabricator's pWPS No.: _____

Fabricator's WPQR No.: _____

Examiner or examining body: _____

Code/testing standard: _____

Date of welding: _____

Friction stir welding operator's name: _____

Weld Class: _____

Base metal type and reference standard(s): _____

Base metal thickness (in [mm]): _____

Outside diameter of pipe (in [mm]): _____

Joint design (Sketch): _____

Postweld heat treatment: _____

Other information: _____

The signature below certifies that the test welds were prepared, welded, and tested satisfactorily in accordance with the requirements of the code/testing standard indicated above.

Location_____
Date of issue_____
Examiner or examining body
Name, date, and signature_____
Examiner or examining body
Print name and date**Figure D.2—Example Number Two of a Welding Procedure Qualification Record Form**

Record of Weld Test

(page 2 of 3)

Fabricator: _____

Address: _____

Fabricator's pWPS No.: _____

Fabricator's WPQR No.: _____

Examiner or examining body: _____

Friction stir welding operator's name: _____

Base metal type and reference standard (s): _____

Base metal thickness (in [mm]): _____ Outside diameter of pipe (in [mm]): _____

Welding equipment identification: _____

Welding tool identification (Sketch)* _____

Clamping arrangement (Sketch)* _____

Tack welding: _____

Joint preparation and cleaning methods: _____

Joint design
(Sketch)

Welding Details

Attach a copy of pWPS

Preheating temperature (°F [°C]): _____

Preheat maintenance temperature (°F [°C]): _____

Working temperature (°F [°C]): _____

Postweld processing: _____

Postweld heat treatment (time, temperature, method, heating, and cooling rates): _____

Other information*: _____

 Fabricator
 Name, date, and signature

 Examiner or examining body
 Name, date, and signature

 Examiner or examining body
 Print name and date

* If required

**Figure D.2 (Continued)—Example Number Two of a Welding Procedure Qualification
Record Form**

Test Results**(page 3 of 3)**

Fabricator: _____

Address: _____

Fabricator's pWPS No.: _____

Fabricator's WPQR No.: _____

Test laboratory's reference no.: _____

Examiner or examining body: _____

Visual testing

Acceptable	Unacceptable	Report No.

Macroscopic examination

Acceptable	Unacceptable	Report No.

Destructive testsTensile tests Required: Yes ☐ No ☐

Type ^a /No.	Test Specimen Ultimate Tensile Strength (F _{tuW}) (ksi [MPa])	Base Metal Ultimate Tensile Strength (F _{tuB}) (ksi [MPa])	Joint Efficiency F _{tuW} / F _{tuB}	Fracture Location	Remarks
Insert the required values					
1					
2					
^a Rectangular, round, or pipe					

Other tests*: _____

Remarks: _____

Tests carried out in accordance with the requirements of: _____

Laboratory report reference no.: _____

Test results were acceptable/not acceptable (delete as appropriate) _____

Test carried out in the presence of: _____

 Examiner or examining body
 Name, date, and signature

 Examiner or examining body
 Print name and date

* If required

Figure D.2 (Continued)—Example Number Two of a Welding Procedure Qualification Record Form

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Annex E (Informative)

Guidelines for the Preparation of Technical Inquiries

This Annex is not part of AWS D17.3/D17.3M:2010, *Specification for Friction Stir Welding of Aluminum Alloys for Aerospace Applications*, but is included for informational purposes only.

E1. 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.

E2. 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.

E2.1 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.

E2.2 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.

E2.3 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 annexes) 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.

E2.4 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.

E3. 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.

E4. Publication of Interpretations

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

E5. 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.

E6. 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.

List of AWS Documents on Welding in the Aircraft and Aerospace Industries

Designation	Title
D17.1	<i>Specification for Fusion Welding for Aerospace Applications</i>
D17.2/D17.2M	<i>Specification for Resistance Welding for Aerospace Applications</i>

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