AWS D17.3/D17.3M:2021
An American National Standard

# Specification for Friction Stir Welding of Aluminum Alloys for Aerospace Applications


American Welding Society®

**AWS D17.3/D17.3M:2021**
**An American National Standard**

**Approved by the**
**American National Standards Institute**
**October 2, 2020**

# Specification for Friction Stir Welding of Aluminum Alloys for Aerospace Applications

**3rd Edition**

**Revises AWS D17.3/D17.3M:2016**

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

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.

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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 Industry. It must be reviewed every five years, and if not revised, it must be either reaffirmed or withdrawn.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 Industry 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 Industry 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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# Foreword

This foreword is not part of this standard 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 the United Kingdom, 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 the FSW process because, unlike friction welding, the 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, served as the model for this specification.

This is the third edition of AWS D17.3/D17.3M, *Specification for Friction Stir Welding of Aluminum Alloys for Aerospace Applications*. A vertical line in the margin or underlined text in clauses, tables, or figures indicates an editorial or technical change from the 2016 edition.

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, 8669 NW 36 St, #130, Miami, FL 33166.

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# Specification for Friction Stir Welding of Aluminum Alloys for Aerospace Applications

## 1. General Requirements

**1.1 Scope.** This specification contains the requirements for friction stir welding (FSW) of aluminum aerospace hardware. The requirements include design of welded joints, qualification of procedures and operators, fabrication and inspection. The FSW methods covered by this specification are conventional FSW, retractable probe FSW, stationary shoulder FSW, and self-reacting FSW.

**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.

## 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.

AWS documents:

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

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 B5.2, *Specification for the Qualification of Welding Inspector Specialists and Welding Inspector Assistants;*

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

AWS D17.1/D17.1M, *Specification for Fusion Welding for Aerospace Applications;*

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

AIA/NAS document:

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

ANSI document:

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

ASTM documents:

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

ASTM E164, *Standard Practice for Ultrasonic Contact Examination of Weldments;*

ASTM E1417, *Standard Practice for Liquid Penetrant Examination;*

ASTM E1742, *Standard Practice for Radiographic Examination.*

ASTM E2700, *Standard Practice for Contact Ultrasonic Testing of Welds Using Phased Arrays.*

## 3. Terms and Definitions

AWS A3.0M/A3.0, *Standard Welding Terms and Definitions, Including Terms for Adhesive Bonding, Brazing, Soldering, Thermal Cutting, and Thermal Spraying*, provides the basis for terms and definitions used herein. Terms and definitions from ASTM B881, *Standard Terminology Relating to Aluminum- and Magnesium-Alloy Products,* are also used. However, the following terms and definitions are included below to accommodate usage specific to this document.

**angular distortion.** Distortion between two welded pieces such that their surface planes are not parallel (see Figure 3.2).

**angular mismatch.** Mismatch between two unwelded pieces such that their surface planes are not parallel.

*NOTE: In this specification, angular mismatch is measured the same as angular distortion (see Figure 3.2).*

**anvil.** Structure supporting the root side of the joint.

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

**bobbin tool**. Nonstandard term for self-reacting tools.

**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, per the engineering drawing.

**conventional FSW.** Friction stir weld using a fixed length probe where the axial force is reacted by an anvil.

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

**dwell time.** The period of time the rotating shoulder(s) (once in full contact with the workpiece) remains stationary before travel begins.

**Engineering Authority.** Contracting agency or corporate organization that acts for and on behalf of the Customer on all matters within the scope of this specification. 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 probe (see Figure 3.1).

**FSW exit hole close-out.** Techniques used to fill the exit hole which may include friction plug welding (FPW), fusion welding or employing the use of metal consumable inserts.

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

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

**friction plug weld.** A solid-state weld method made in a circular hole, commonly used for FSW exit hole close-out.

**heel.** Part of the tool shoulder that is at the rear of the tool relative to its forward motion (see Figure 3.1).

**heel plunge depth.** Distance the heel extends into the workpiece (see Figure 3.1).

**hook.** Faying surface that curves upward or downward along the side of the weld metal in a friction stir welded lap joint and is considered a discontinuity (see Figure 3.5).

**inclusion**. Entrapped foreign solid material. These are generally more dense than the base metal and include examples such as tooling and fixturing materials as well as tungsten from GTAW tack welds.

**joint gap.** A nonstandard term for root opening of a square groove joint.

**linear mismatch.** Misalignment between two welded pieces such that while their surface planes are parallel, they are not in the required plane (see Figure 3.7).

**machine stiffness.** The ability of a machine to resist deflection when subjected to applied forces.

**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.

**penetration ligament.** The nominal distance between the anvil and the probe tip during welding (see Figure 3.1).

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

*NOTE: In this specification, 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 used to generally describe flat, non-round metal products other than pipe.*

**plunge depth.** Distance tool probe penetrates into the weld joint (see Figure 3.1).

**probe.** Part of the welding tool that extends into the workpiece to make the weld (see Figures 3.1 and 3.10).

**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.

**retractable probe FSW.** Friction stir welding method in which the probe is axially movable (retractable) inside the shoulder via a secondary linear axis which may also embody an independent rotation drive.

**self-reacting FSW.** Friction stir welding method in which the anvil is replaced by a root-side shoulder that reacts to the crown-side shoulder load, squeezing the material between the crown-side shoulder and the root-side shoulder (see Figure 3.8).

**self-reacting tool.** FSW tool with two shoulders, separated by a fixed length probe or an adjustable length probe, that is used for the self-reacting FSW method (see Figure 3.8).

**side tilt angle.** The angle, in degrees, that the tool's axis is tilted transverse to the longitudinal weld axis (line of travel) (see Figure 3.1).

**stationary shoulder friction stir welding (SSFSW)**. FSW tool with a rotating probe and a non-rotating shoulder (see Figure 3.11).

**tilt angle.** The angle in degrees that the tool rotational axis tilts relative to a line perpendicular to the workpiece surface in the plane of the weld joint (see Figure 3.1).

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

**tool rotation speed.** Angular rotation rate of the welding tool.

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

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

**welding tool.** The non-consumable component, a portion of which is in contact with the workpiece, effectively producing the friction stir weld (see Figures 3.1 and 3.10).

**working envelope.** The spatial volume within which the FSW system physically operates.

**work instruction.** Fabricator document that describes manufacturing details necessary for welding.

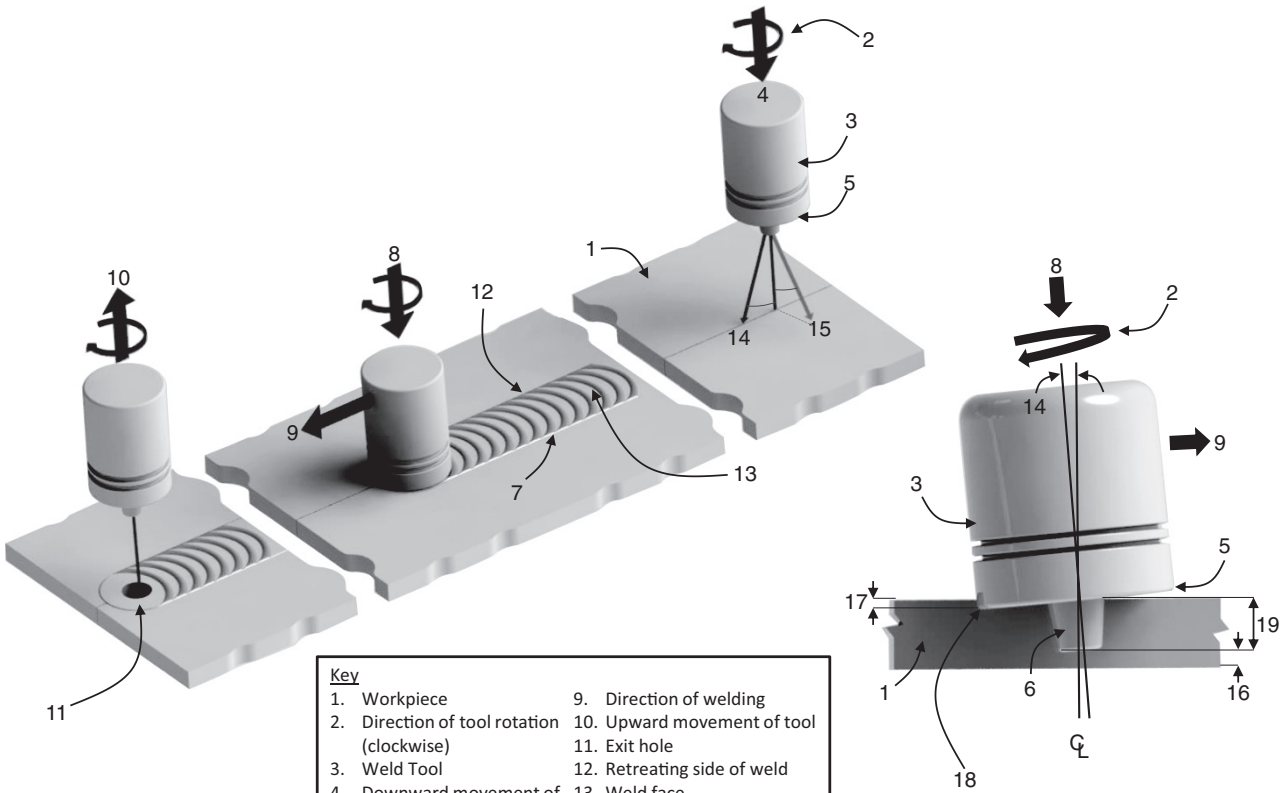
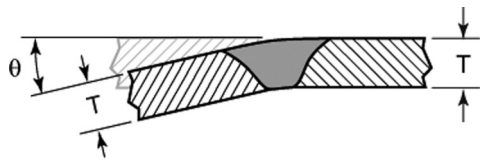
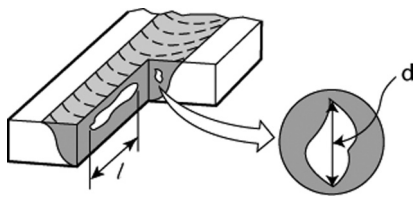



**Figure 3.1—Friction Stir Welding Nomenclature**




Key
T Thickness of base metal.
θ Angle between original surface and postweld surface.

**Figure 3.2—Angular Distortion/Angular Mismatch**




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**

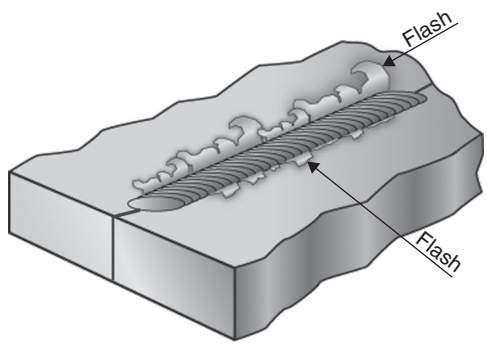
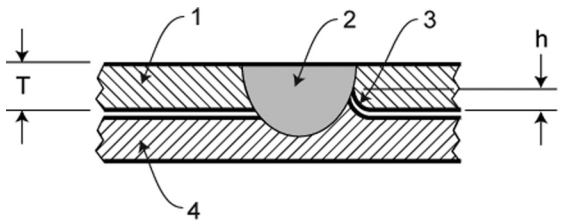
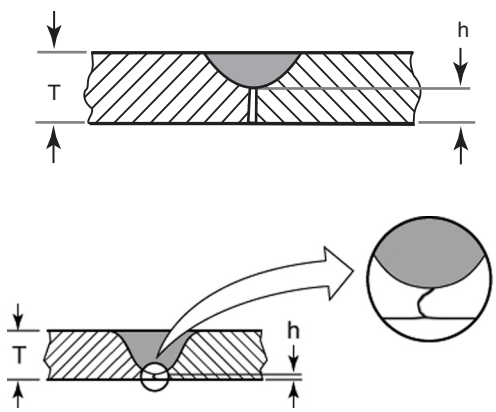



**Figure 3.4—Flash**




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

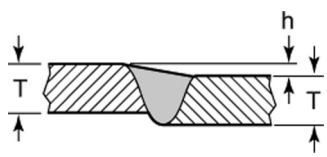
**Figure 3.5—Hook**




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

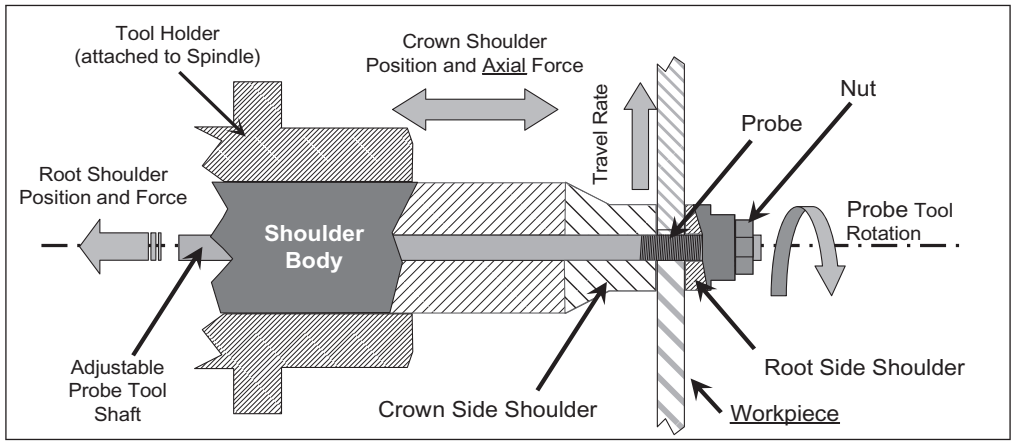
Note: There are varying degrees of incomplete joint penetration. They include the original joint line with: (a) no plastic deformation of the unfused edge of the joint; (b) plastic deformation of the unfused edge of the joint. Refer to Table 9.1 for acceptance criteria.

**Figure 3.6—Varying Degrees of Incomplete Joint Penetration**



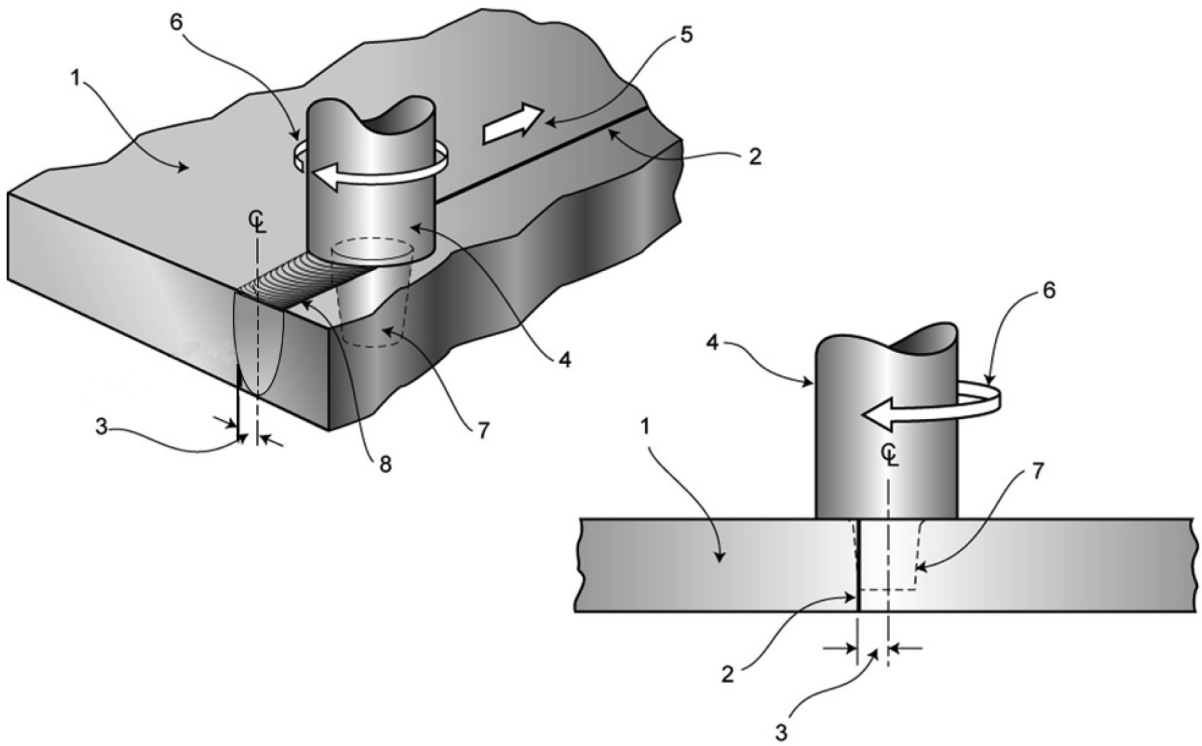

Key
T Nominal thickness of the base metal
h Height of mismatch

**Figure 3.7—Linear Mismatch**



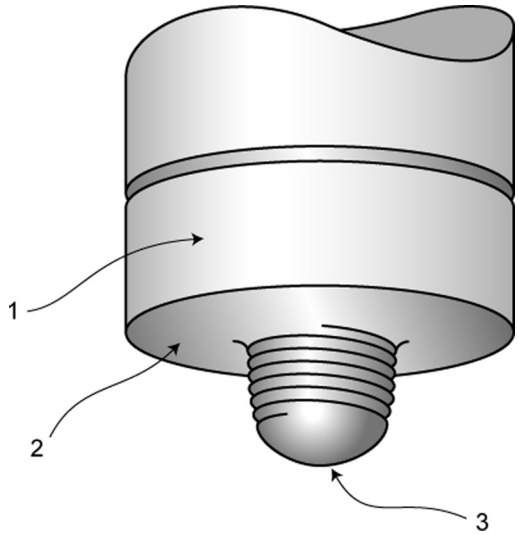

Note: Adjustable length probe is shown.

**Figure 3.8—Self-Reacting Tool**




Key
1 Workpiece
2 Joint
3 Tool offset
4 Welding Tool
5 Direction of welding
6 Direction of tool rotation (clockwise)
7 Probe
8 Weld face
9 Tool Centerline

**Figure 3.9—Tool Offset**




Key
1 Welding Tool
2 Shoulder
3 Probe

**Figure 3.10—Components of Tool**

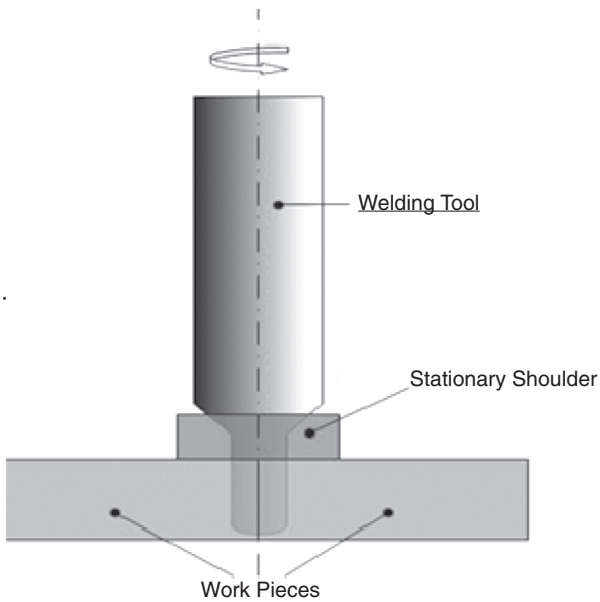



**Figure 3.11—Stationary Shoulder Friction Stir Welding (SSFSW)**

# 4. General Requirements for FSW

**4.1 Classification.** All welds produced in accordance with this specification shall be classified by the Engineering Authority as either 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 the material and process aspects that affect mission or systems requirements. A weld joint may be zoned with multiple classifications if specified by the Referencing Document.

The choice of weld class 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.

**4.1.1 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.

**4.1.2 Class B—Semicritical Application.** A welded joint whose failure would reduce the overall performance of the hardware or system or preclude the intended functioning or use of equipment, but loss of the system or the endangerment of personnel would not occur.

**4.1.3 Class C—Noncritical Application.** A welded joint whose failure would not affect the efficiency of the system or endanger personnel.

**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 Square Groove.** A square-groove weld 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 of a complex weld joint. Welding terminology shall be in accordance with AWS A3.0M/A3.0. Welding symbols shall be in accordance with AWS A2.4. 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 not defined in the Welding Procedure Specification (WPS).

(3) Extent of welding, such as: weld location, joint penetration, and weld path as applicable.

(4) Final weld contour and weld finishing requirements (as-welded or subsequently finished).

(5) Weld classification in accordance with 4.1.

(6) When required, postweld heat treatment.

(7) When required, joint properties, such as: static strength, fatigue strength, toughness, stress corrosion cracking resistance, or general corrosion resistance requirements.

**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.** All welds shall be inspected in accordance with 9.2 and 9.3. 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.

# 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.

**6.1.1 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, except properly documented WPSs qualified under the provisions of this code by a company that later has a name change due to voluntary action or consolidation with a parent company may utilize the new name on its WPS documents while maintaining the supporting WPQR qualification records with the old company name.

**6.1.2 Identification of a WPS and a Welding Procedure Qualification Record (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 Specification Qualification Method**. The two methods for qualifying a welding procedure are shown in Table 6.2.

**Table 6.1**
**Sequence for Qualifying a Welding Procedure Specification**

| Activity | Result | Party Involved |
|---|---|---|
| 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 the supporting WPQR | Fabricator |
| Release for production | Copy of WPS or work instruction | Fabricator |

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

**Table 6.2**
**Methods for Qualifying a Welding Procedure Specification**

| Method Based On | Application |
|---|---|
| **Standard Welding Procedure Specification 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 Specification test** (see 6.2.2) | Can always be applied in general, but requires a test coupon under production conditions. Suitable for mass production. |

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

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

**6.3 Welding.** When welding the procedure qualification test coupons, the welding operator shall be under the supervision of the Fabricator.

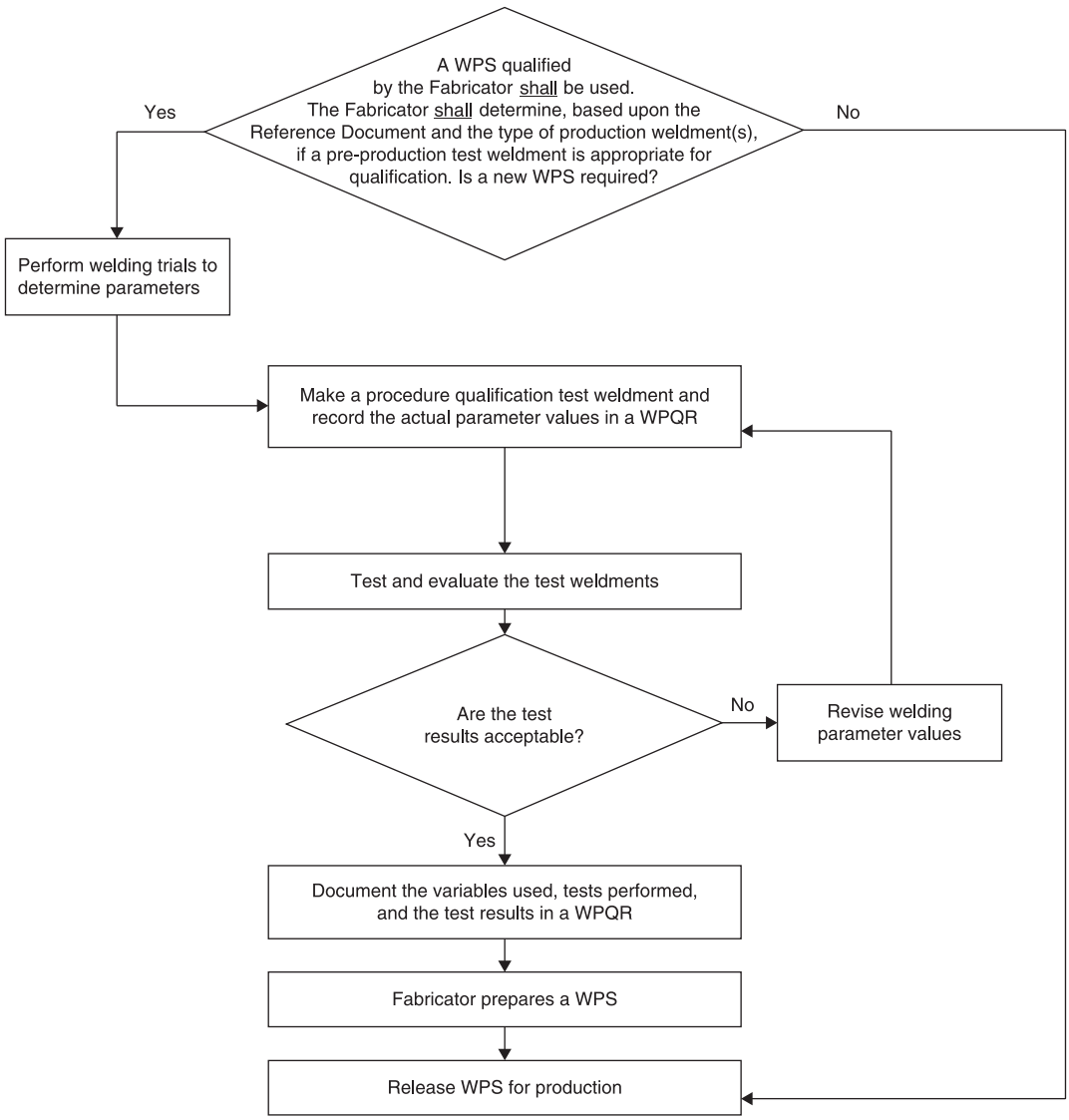


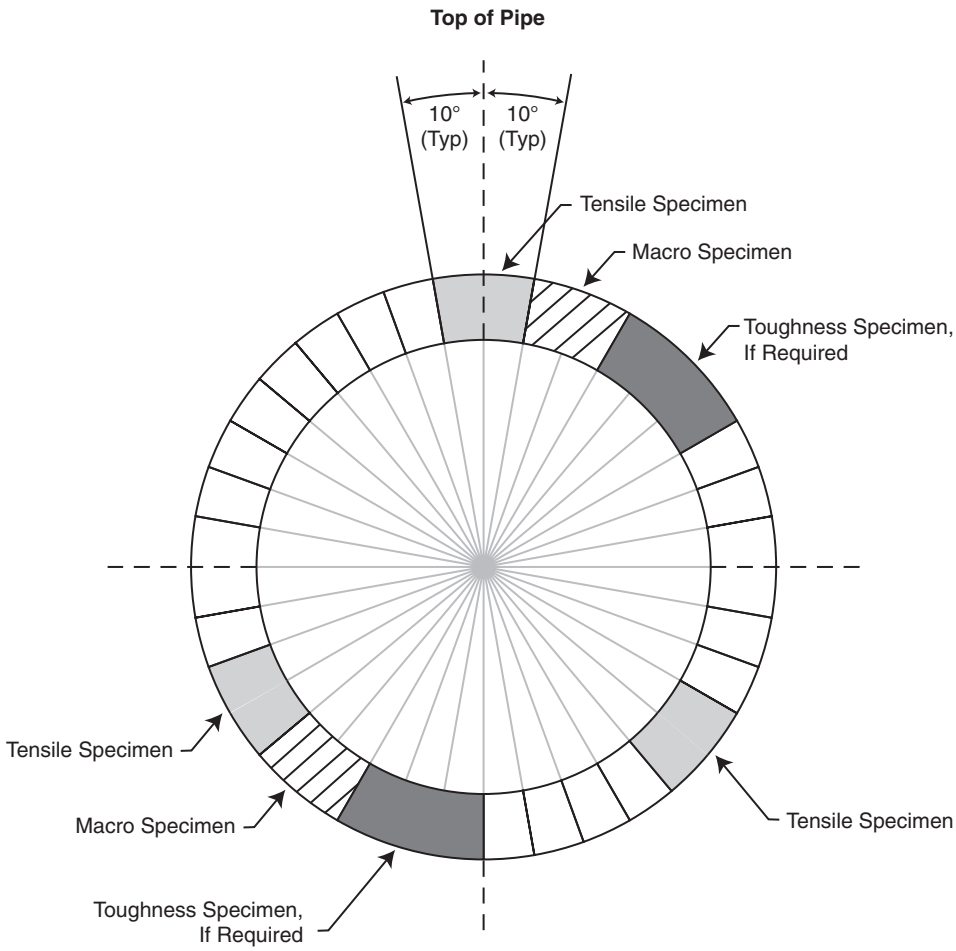

**Figure 6.1—Flow Diagram for the Development and Qualification of a Welding Procedure Specification**

### 6.4 Evaluation of Test Welds

**6.4.1 Visual Inspection.** Prior to removing test specimen from the completed test coupon, the weld shall be visually inspected in accordance with the acceptance criteria defined in Table 9.1.

**6.4.2 Destructive Tests**

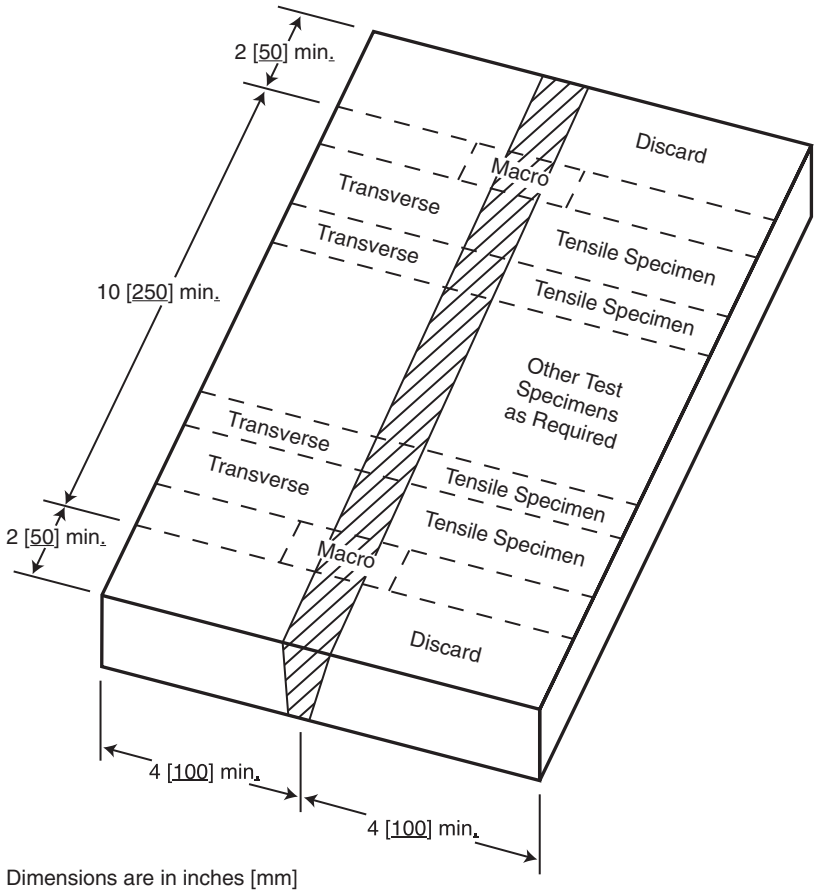
**6.4.2.1 Test Weld.** The test weld shall be evaluated using the tests required, as depicted in Figures 6.2 through 6.5, as a minimum. Test specimens shall be removed from the locations shown in Figure 6.2 for square groove welds in pipe, Figure 6.3 for square groove welds in plate, Figure 6.4 for fillet 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 coupon.




Notes:
1. The base metal thickness shall be determined in accordance with Table 6.5.
2. The dimensions for test specimens and details are given in Annex A.
3. In this specification, the term pipe will be used for pipe and tube.

*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**




Dimensions are in inches [mm]

Notes:
1. The base metal thickness shall be determined in accordance with Table 6.5.
2. The dimensions for test specimens 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**

**6.4.2.2 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.

**6.4.2.3 Acceptance Criteria**

(1) *Macroetch Test.* The macroetch test specimens shall meet the requirements of Table 9.1 at magnification no greater than 50X.

(2) *Tensile Test.* Each transverse-weld tensile test specimen shall meet the requirements of Table 6.4. For partial joint penetration welds, specimens shall be machined to remove unwelded thickness.

(3) *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 Table 6.4).

**Table 6.3**
**Destructive Tests Required for Qualifying a Welding Procedure**

| Type | Groove Weld | Fillet and Seam Welds |
|---|---|---|
| Tension test | Yes | See Note |
| Macro examination | Yes | Yes |
| Fracture toughness tests | See Note | See Note |
| Bend tests | See Note | See Note |
| Shear test | See Note | Yes |

Note: When specified in the Referencing Document.

**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[g] | T4 | Natural aging | 0.7 |
| Heat treatable alloys[g] | T4 | Artificial aging | 0.7[h] |
| Heat treatable alloys[g] | T5 and T6 | Natural aging | 0.6 |
| Heat treatable alloys[g] | T5 and T6 | Artificial aging | 0.7[h] |

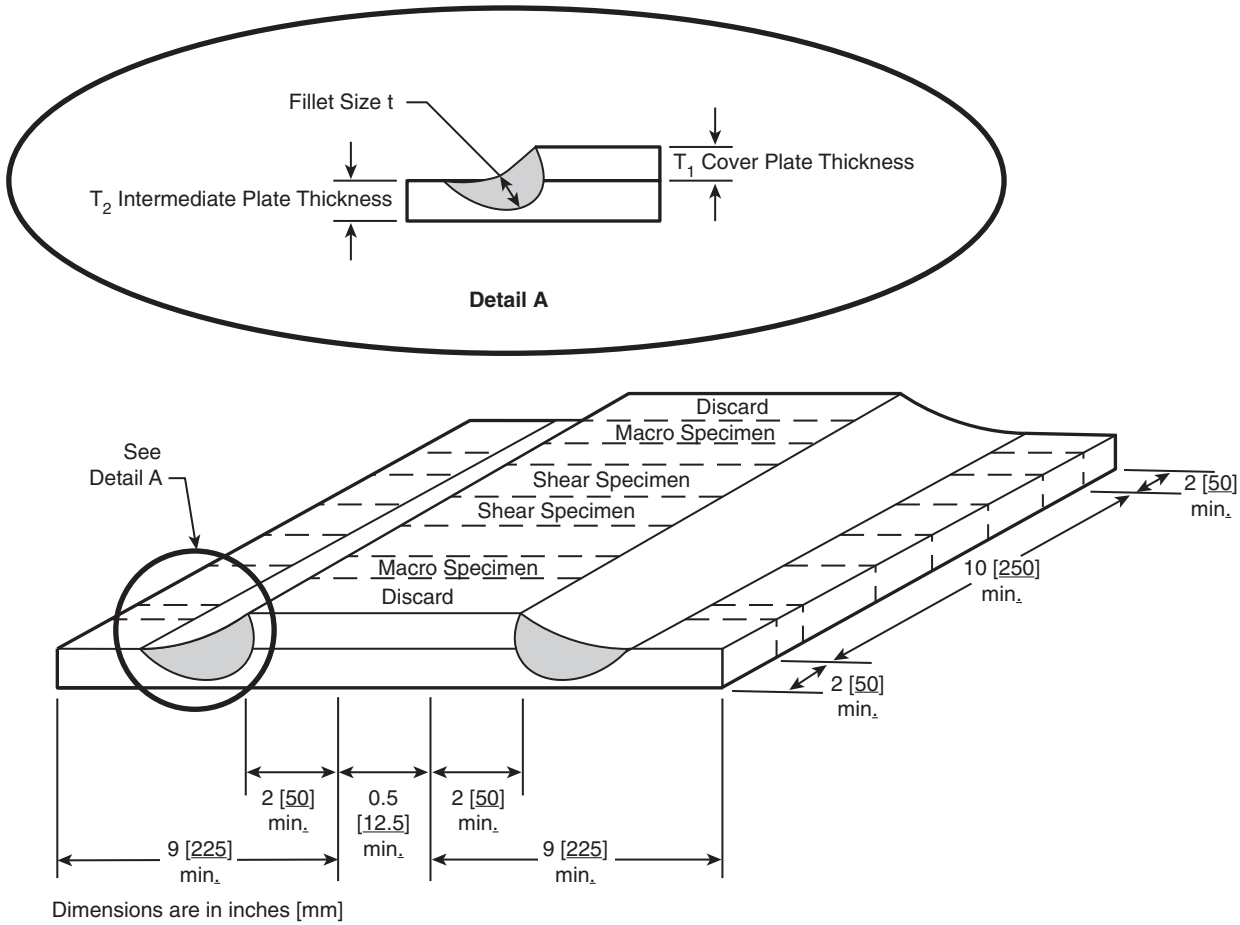
[a] The data in this table was taken from fusion welding specifications because there is no statistically derived friction stir welding data available.
[b] For base metal in other tempers not shown in this table, the ultimate tensile strength of the welded test specimen shall be in accordance with the 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 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] Only applies to 6000 series alloys. For 2000 series and 7000 series alloys, the temper base metal before welding and the postweld aging conditions shall be in accordance with the Referencing Document.
[h] 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.

**6.5 Preparation of a Welding Procedure Specification (WPS).** The Fabricator shall prepare a WPS. The WPS shall provide all of the information required to make a weld. The minimum information required in a WPS is given below in Points 1–13. An example of a WPS form is given in Annex B, Figure B.1. A WPS may be presented in either written or electronic format, provided all applicable information is recorded. The WPQR shall be used to qualify the essential variables to be entered into the WPS.

1. **Fabricator's Information**
   (1) Identification of the Fabricator
   (2) Identification of the WPQR.

2. **Base Metal**
   (1) Product form (e.g., plate, extrusion, forging)
   (2) Temper
   (3) Material specification (e.g., dimension and composition)
   (4) Surface coating condition.

3. **Base Metal Dimensions**
   (1) Nominal thickness of the members composing the welded joint
   (2) Outside diameter of pipe, where applicable.




Notes:
1. The base metal thickness shall be determined in accordance with Table 6.5.
2. The dimensions for test specimens and details are given in Annex A.
3. The test plate length shall be sufficient for the required number and type of specimens.

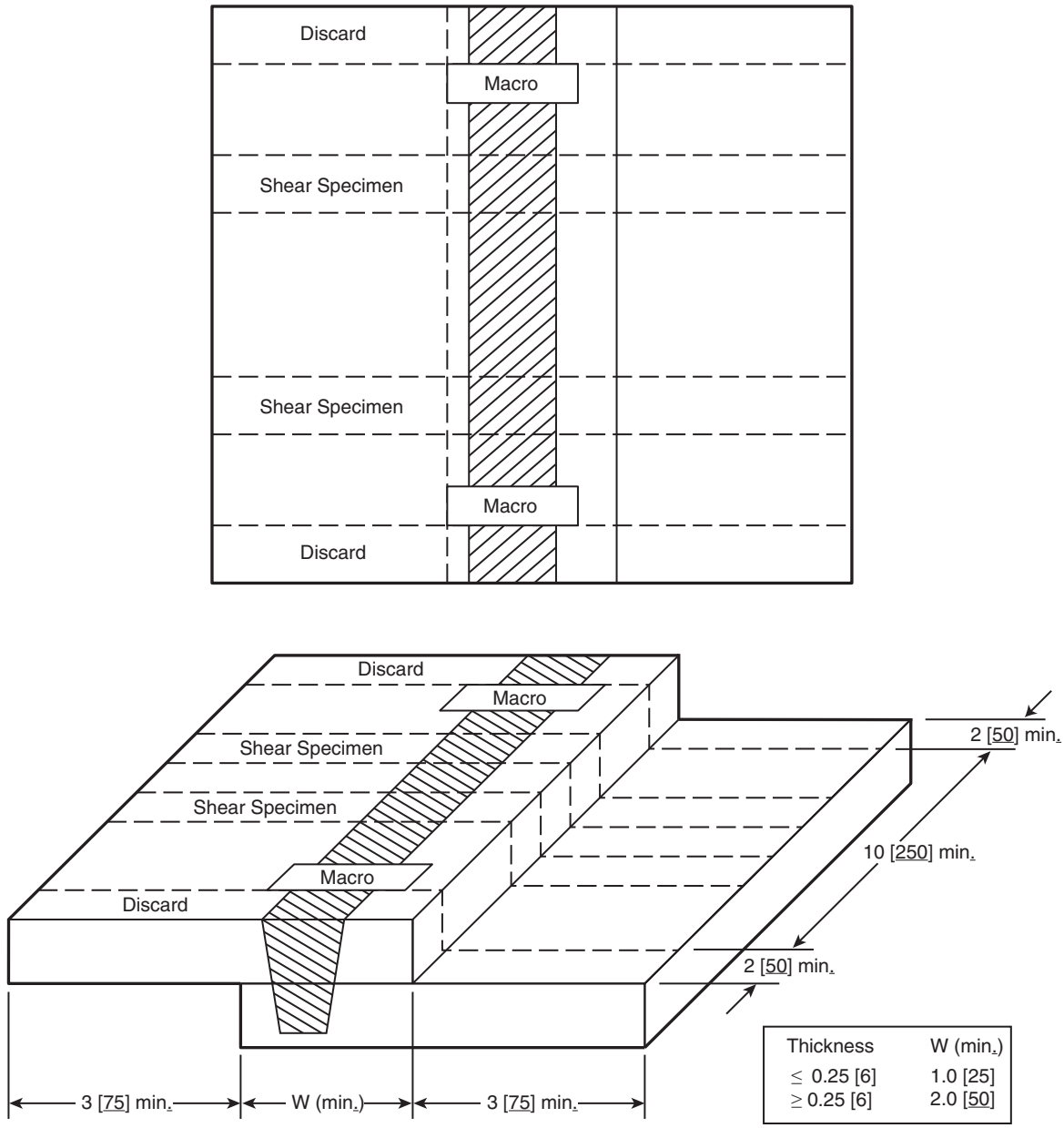
*Source:* Adapted from AWS B2.1:2000, Specification for Welding Procedure and Performance Qualification, Figure 2.6.

**Figure 6.4—Location of Fillet Weld Test Specimens—Plate**

**4. Equipment Identification**
(1) Model number
(2) Serial number
(3) Equipment manufacturer

**5. Tool Identification**
(1) Tool material, coatings, and surface treatment
(2) Engineering drawing, or part/drawing number
(3) Nominal probe length and tolerances

**6. Tack Welding**
(1) Process and its essential variables
(2) Location(s)
(3) Length and frequency as needed to meet fit-up requirements




Dimensions are in inches [mm]

Notes:
1. The base metal thickness shall be determined in accordance with Table 6.5.
2. The dimensions for test specimens 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**

**7. Joint Design**
(1) Weld joint type
(2) A sketch of the weld joint design and dimensional tolerances
(3) Joint gap tolerances
(4) Maximum allowable linear joint mismatch
(5) Maximum allowable angular mismatch
(6) Dimensions of starting and runoff weld tabs, method of attachment, and alloy type and material specification

*NOTE: Due to the resulting exit hole when using conventional friction stir weld or self-reacting friction stir weld methods, appropriate welding specification and/or drawing notes pertaining to the closure of the exit hole should be specified on the engineering drawing.*

**8. Preweld Cleaning**
(1) Preweld cleaning

**9. Welding Details**
(1) Tool rotation (e.g., rotation in either the clockwise or counter-clockwise direction, rotation speed including ramp-up/ramp-down rotation speeds)
(2) Plunge rate
(3) Weld run sequence and welding direction given on the sketch, if applicable
(4) Tilt angle
(5) Side tilt angle
(6) Dwell time
(7) Lap joint: Nominal overlap length
(8) Lap joint: advancing or retreating side near the edge of the sheet against which the tool is in contact
(9) Primary control method: force control, position control, or temperature control
(10) Nominal primary control parameter (force, depth, or temperature)
(11) Nominal allowable joint tool offset and direction
(12) Number of passes and direction of each pass, if applicable

**10. Travel Speed**
(1) Ramp-up/ramp-down speeds
(2) Travel speed.

**11. Thermal Management Method, as required**
(1) Specification or method(s) employed for active or auxiliary cooling or heating of the tool and/or workpiece.
(2) Preheat temperature, if applicable
(3) Fixture or anvil design and material

**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

**13. Welding Method**
(1) Conventional FSW
(2) Retractable probe FSW
(3) Self-reacting FSW
(4) Stationary shoulder friction stir welding (SSFSW)

**6.6 Welding Procedure Qualification Record (WPQR).** The WPQR is a record of welding variables used to produce an acceptable test coupon and the results of tests conducted on the weldment to qualify a WPS. The WPQR shall contain the actual welding procedure qualification test variables, the items listed in the WPS, 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 coupon results is qualified and shall be signed and dated by the examiner or the examining body. A WPQR shall include a statement acknowledging the validity of the data while also certifying that the weldments were made and tested in accordance with the requirements of this specification. See Figures C.1 and C.2, for two examples of WPQR forms.

**6.7 Qualification Limits.** A change in any of the essential variables listed in 6.5 shall require requalification; however, note that for the variables listed in Table 6.5, only changes to the parameters beyond the ranges listed shall require requalification.

**Table 6.5**
**Essential Variable Ranges[a, b]**

| Variable | Process Variant | | | |
|---|---|---|---|---|
| | Conventional | Retractable Probe | Stationary Shoulder | Self-reacting |
| Nominal thickness | ± 5% | ± 5% | ± 5% | ± 5% |
| Rotational speed | ± 5% | ± 5% | ± 5% | ± 5% |
| Plunge depth | ± 5% | ± 5% | ± 5% | ± 5% |
| Primary control parameter | ± 5% | ± 5% | ± 5% | ± 5% |
| Plunge rate | ± 5% | ± 5% | ± 5% | ± 5% |
| Travel speed | ± 5% | ± 5% | ± 5% | ± 5% |
| Tilt angle | ± 0.5° | ± 0.5° | ± 0.5° | ± 0.5° |
| Side tilt angle | ± 0.5° | ± 0.5° | ± 0.5° | ± 0.5° |
| Dwell time | ± 5% | ± 5% | ± 5% | ± 5% |

a. Percentages are applicable unless a range is specified in the WPS
b. A change in tack welding parameters does not require requalification.

**6.8 Welding Procedure Specification.** The Fabricator shall prepare the WPS for production welding based on the entries in the WPQR. Each WPS shall specify a range or a single value for each welding variable identified in 6.5 as applicable. An example of a WPS form is given in Annex B, Figure B.1.

**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. All revisions shall be authorized, identified, traceable, and dated on the WPQR and WPS.

*NOTE: 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.*

# 7. Welding Operator Qualification

**7.1 Qualification Requirements.** To become qualified, the welding operator shall demonstrate their 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 coupons in Figures 7.1 through 7.4 shall be used for the welding operator qualification test. The test coupon shall be welded in accordance with a WPS. The operator being qualified shall verify all aspects of the weld that would normally be required to make the weld in the production operation, in accordance with the WPS. Operators shall be qualified to Class A requirements, unless otherwise approved by the Engineering Authority.

When none of the test coupons 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 coupon 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-inches-long discard may be taken at the ends of groove, seam, 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 test weld shown in Figures 7.1 through 7.4 qualifies the welding operator to weld all base metal forms (plate or pipe) and joint types. A successful qualification of a special welding operator qualification test weld, as described in 7.1.2, qualifies the welding operator to weld that particular production weld joint.

**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 and adheres to the two-year vision test requirement in 7.1.1.

**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.

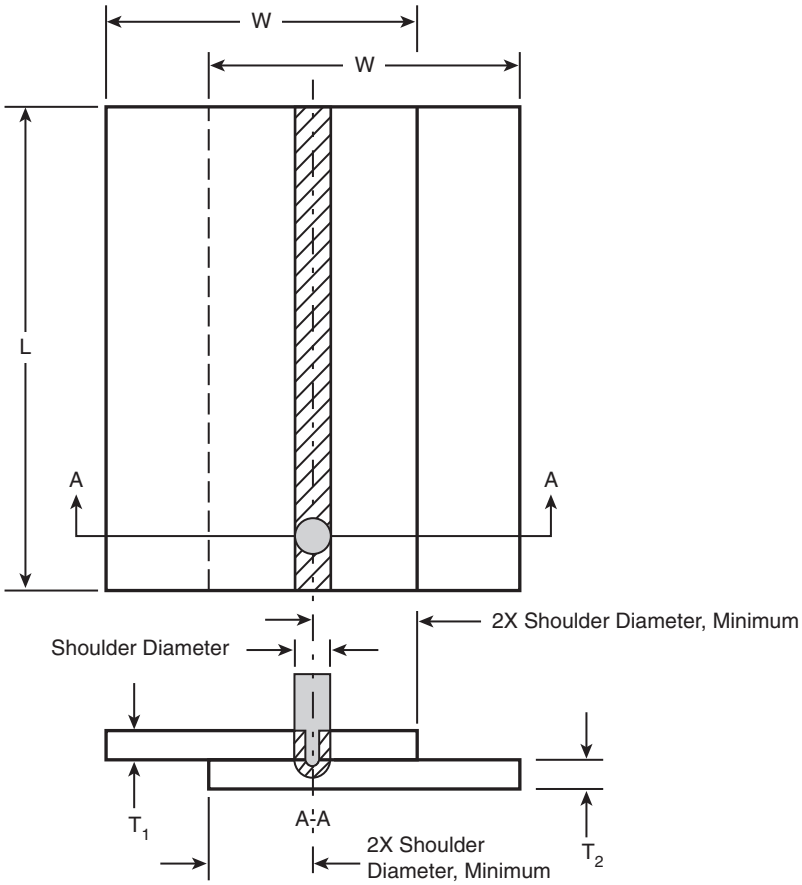
(2) The welding operator qualification tests were not performed successfully within the previous two years, as required in 7.3.1, and an auditable record of the welding operator's performance was not maintained by the Fabricator, as required in 7.3.2.

(3) 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 violated requirement(s) of 7.1.

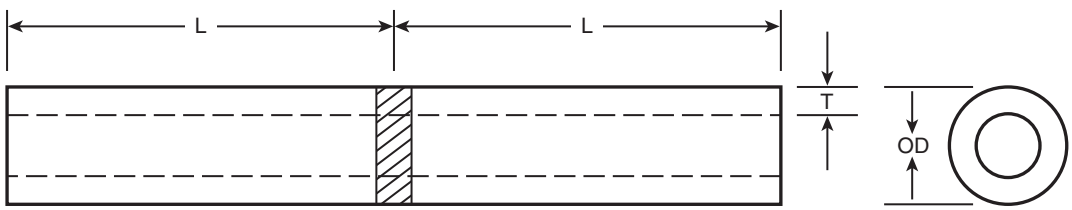
**7.3.5 Identification.** The Fabricator shall assign a unique number or other identification to each welding operator upon certification.

**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,* is given in Annex D, Figure D.1.



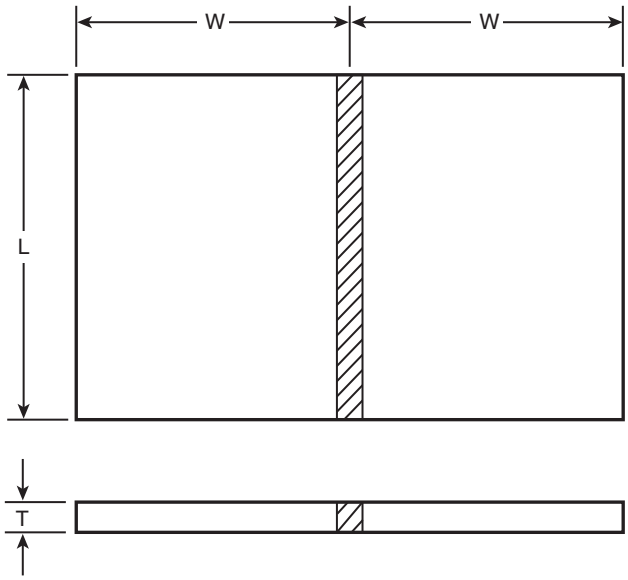

| Base Metal Thickness | Minimum Dimension in [mm] | |
|---|---|---|
| T | W | L |
| All | 4 [100] | 12 [300] |

**Figure 7.1—Seam Weld Test in Plate**



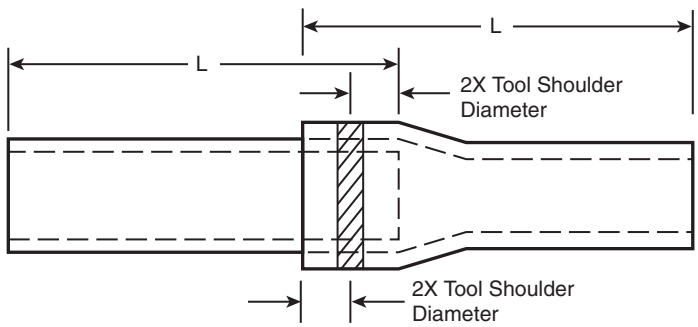

| Base Metal Thickness | Suggested Minimum Dimension in [mm] |
|---|---|
| T | L |
| All | 3 [75] |

**Figure 7.2—Square-Groove Weld Test in Pipe**




| Base Metal Thickness | Minimum Dimension in [mm] | |
|---|---|---|
| T | W | L |
| All | 4 [100] | 12 [300] |

**Figure 7.3—Square-Groove Weld Test in Plate**




| Base Metal Thickness | Minimum Dimension in [mm] |
|---|---|
| T | L |
| All | 3 [75] |

**Figure 7.4—Seam Weld Test in Pipe**

# 8. Fabrication

**8.1 Welding.** All welding shall be performed in accordance with an approved WPS. Before starting a welding cycle, the settings shall meet those listed on the WPS within the limits of variation allowed by Table 6.5.

**8.1.1 Additional in-process control parameter.** In applications that utilize more advanced control techniques (including, but not limited to, temperature, torque, power, joint tracking, non-destructive feedback), direct control over some of the welding parameters listed in Table 6.5 may be tied to the new in-process control variable. When this occurs, the substitute in-process control parameter shall be called out on the WPS with the associated limits of variation.

**8.1.2 Joint Tracking.** Joint tracking can be used to adjust the lateral position of the FSW tool when it is known that the joint position may vary over time or along the length of the weld. The welding equipment shall have the ability to adjust the position of the FSW tool in the lateral direction (i.e. cross-path) to the joint. Sample parameters include:

(1) Methodology (automatic, manual, or combination)

(2) Equipment (e.g., sensors, cameras, alarms, and tooling)

**8.1.3 Work Instruction.** Information beyond the WPS, such as fixturing and machine numerical control (NC) program details, shall be included in the work instruction document.

**8.2 Welding Equipment Requirements**

**8.2.1 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 concerns about the capability of the equipment to operate satisfactorily. The welding equipment shall be capable of maintaining weld quality and consistency.

**8.2.2 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.

**8.2.3 Reproducibility Test for Qualified Machine Welding Settings**

**8.2.3.1 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 test shall be performed when any 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;

(3) Welding in an area within the working envelope of the machine where the Fabricator determines a difference in machine stiffness from the location of the original qualification results in unacceptable welds;

(4) If calibration indicates equipment is operating outside of specified parameter tolerance;

(5) The equipment fails to produce acceptable weld quality in accordance with the settings of a qualified WPS.

**8.2.3.2 Test Requirements.** The reproducibility test shall be performed in accordance with a qualified WPS. The written procedure shall establish welding parameters, test requirements, test coupon configuration, and meet the acceptance criteria per Clause 9 of this Specification.

**8.3 Friction Stir Welding Tool**

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

**8.3.2** Tool life, tool cleaning, and tool inspection frequency shall be documented.

**8.4 Preweld Joint Preparation and Fit-Up**

**8.4.1 Preweld Cleaning.** Welding shall start within 48 hours of cleaning or as otherwise specified by 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.

**8.5 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. Fusion welders shall be qualified in accordance with AWS D17.1 or equivalent.

**8.5.1** Tack welding shall be allowed, provided that the tack welds are completely consumed by the final weldment.

**8.5.2** Tack welding parameters shall be included in the WPS.

**8.5.3** Tack welding, if used during production, shall be employed during the procedure qualification process.

**8.5.4** Fusion tack welds shall be autogenous unless filler metal use is specified by the Engineering Authority.

**8.6 Postweld Finishing.** When required, 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 finishing shall be performed so the weld metal and base metal thickness remain within drawing tolerances.

**8.7 Weld Identification Requirements**

**8.7.1 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.

**8.7.2 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, and

(4) Weld inspector's signature or individually assigned stamp or code.

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

**8.9 Rework.** A procedure applied to a nonconforming item that completely eliminates the nonconformance and results in a characteristic that conforms completely to the drawings, specifications, or contract requirements.

**8.9.1 Allowed Number of Rework Attempts.** The allowed number of rework attempts shall be as established in a rework WPS and supporting PQR.

**8.9.2 Documentation of Rework.** All operations involved in rework shall be documented as required by the applicable quality assurance provisions using a method approved by the Engineering Authority.

**8.9.3 Inspection of the Rework.** The reworked weldment shall be submitted for an acceptance inspection in accordance with Clause 9.

**8.10 Repair.** A procedure that makes a nonconforming item acceptable for use. The purpose of the repair is to reduce the effect of the nonconformance. Repair is distinguished from rework in that the characteristics after repair still do not completely conform to the applicable drawings, specifications, or contract requirements. Repair procedures are authorized by MRB action. All repairs require MRB approval before implementation.

**8.10.1 Repair Instructions.** The Engineering Authority or its designee, such as the MRB, shall provide detailed instructions for the repair that include but are not limited to:

(1) allowed number of weld corrections during the repair

(2) required documentation

(3) details for each operation (including acceptance inspection) involved in the repair

# 9. Inspection

## 9.1 Inspection Personnel

**9.1.1 Qualification of Nondestructive Examination (NDE) Personnel.** NDE personnel shall be qualified in accordance with NAS 410 or another NDE standard that is satisfactory to the Engineering Authority. When the contract, purchase order, or engineering drawing specifies the use of an examination method not presently incorporated in NAS 410, the fabricator shall be responsible for developing and submitting to the Engineering Authority the training program, written practice, examination, and practical demonstrations equivalent to the requirements of NAS 410 or other standards. These shall establish the capability of the personnel performing the required examination.

**9.1.2 Visual Weld Inspection Personnel.**

All personnel performing visual weld inspections shall be certified by one of the following:

(1) AWS QC1

(2) a certification program approved by the Engineering Authority

(3) a certification program approved by the fabricator's quality organization management, that is based on the experience, training, and testing criteria cited in AWS B5.2.

**9.2 Visual Weld Inspection.** All welds shall undergo visual inspection for conformance to the requirements of Table 9.1. Welds that will not have material removed during subsequent machining shall be inspected in the as welded condition. Welds that have material removed during subsequent machining shall be visually inspected after machining. The fabricator may conduct an intermediate visual inspection prior to machining.

## 9.3 Nondestructive Examination

**9.3.1 Penetrant Testing (PT).** Class A and Class B welds shall be dye penetrant tested in accordance with ASTM E1417. Class C welds shall be dye penetrant tested when specified in the engineering drawing.

**9.3.2 Radiographic Testing (RT).** Class A groove welds shall be radiographically tested in accordance with ASTM E1742. 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 E1742 when specified in the engineering drawing.

**9.3.3 Ultrasonic Testing (UT).** Ultrasonic testing may be used in lieu of radiographic testing when specified in the engineering drawing, in the contract, or by the Engineering Authority. Ultrasonic testing shall be in accordance with ASTM E164, or equivalent. Phased array ultrasonic testing (PAUT) may be done in accordance with ASTM E2700, or equivalent. When immersion or PAUT is indicated, a reference standard shall be approved by the Engineering Authority.

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

## 9.4 Acceptance Criteria

**9.4.1 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 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.

**9.4.2 Acceptable Welds.** Welds shall be acceptable if they meet the requirements of Table 9.1. Welds not meeting these requirements shall be rejected. Alternate acceptance criteria for PAUT may be established by the Engineering Authority.

**Table 9.1**
**Acceptance Criteria[a]**

| Discontinuity | Class A | Class B | Class C |
|---|---|---|---|
| **Cracks** | None | None | None |
| **Incomplete joint penetration[b]** | None | None | None |
| **Subsurface inclusions and/or cavities** | | | |
| 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 |
| **Cavity open to surface** | None | None | None |
| **Linear mismatch across joint** (maximum)<br>Groove welds only | 0.05T | 0.075T | Not applicable |
| **Angular distortion (degrees)** (maximum)<br>Groove welds only | 3 degrees | 3 degrees | Not applicable |
| **Underfill** (maximum)<br>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 |

[a] See 9.4 for general rules regarding the acceptance criteria.
[b] Acceptance criteria of incomplete joint penetration does not apply to partial joint penetration welds (see Figure 3.6).

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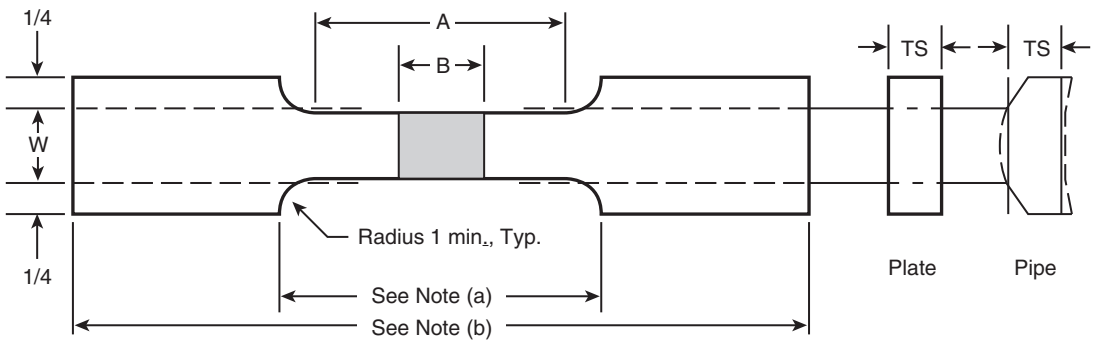
# Annex A (Normative)
# Illustrations of Test Specimens and Test Fixtures

This annex is part of this standard and includes mandatory elements for use with this specification.

## A1. Tension Specimens (TS)

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.




| in | mm |
|---|---|
| 1/4 | 6.4 |
| 1/2 | 13 |
| 3/4 | 19 |
| 1 | 25 |
| 3 | 76 |

| Test Specimen | | | |
|---|---|---|---|
| | | Pipe | |
| | | Outside Diameter | |
| Dimensions | Plate | ≦3 | >3 |
| B | ← See Note (c) → | | |
| A | ← See Note (d) → | | |
| W | 3/4 | 1/2 | 3/4 |
| TS | TS[e] | ← See Note (e) → | |

Plate and Pipe Dimensions in inches

Notes:

[a] This section shall be cut by machining or grinding.

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

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

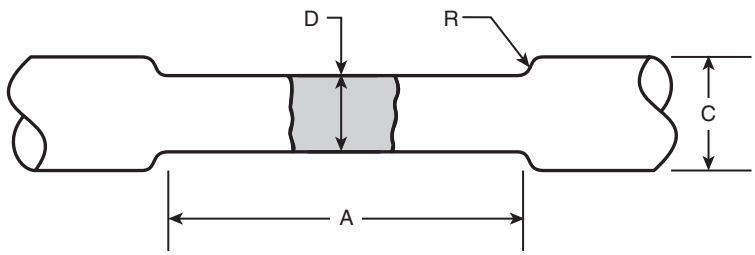
[d] The length of the reduced section A shall be equal to B plus 1/2 in [13 mm] with a minimum of 2-1/4 in [57 mm]. The ends shall not differ in width from the ends to the center, but the width at either end shall not be more than 0.015 in [0.38 mm] greater than the width at the center. The weld shall 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,b] | | | |
|---|---|---|---|---|
| Dimensions | 0.505 | 0.353 | 0.252 | 0.188 |
| A = Length of Reduced Section[c,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 = Reduced Section Diameter | 3/4 | 1/2 | 3/8 | 1/4 |

Notes:

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

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

[c] The weld shall be in the center of the reduced section.

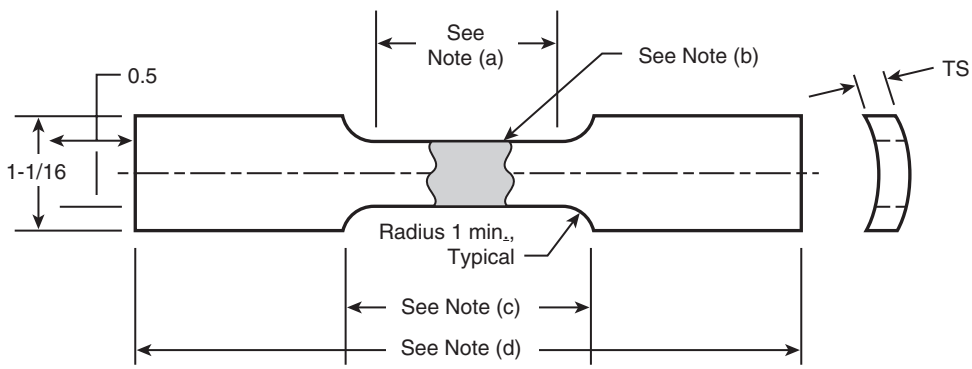
[d] The length of the reduced section shall be not less than the width of the weld metal plus 2D. It may have a gradual taper from the ends toward the center, with the ends not more than one percent greater in diameter than the center, which shall be the dimension D. The ends may be of any length and 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**

| in | mm |
|---|---|
| 0.5 | 13 |
| 1 | 25 |
| 1-1/16 | 27 |




All dimensions in inches

Notes:

[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.

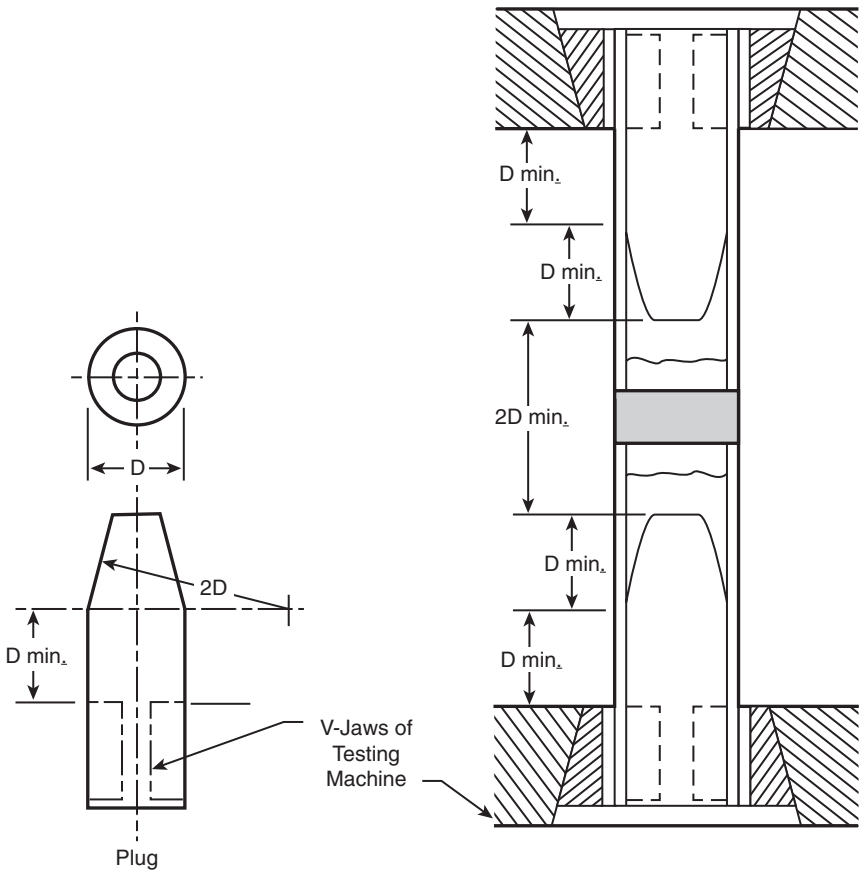
[b] The weld metal thickness shall equal the base metal thickness.

[c] The reduced section shall be cut by machining or grinding.

[d] 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-3G.

**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 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 Welding Procedure Specification Form

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

| **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<br>Temper/Specification:<br>Thickness Range: | |
| Alloy 2<br>Temper/Specification:<br>Thickness Range: | |
| Grain Direction | |
| Preweld Cleaning | |
| Root Face or Surface Coating: | |
| **Set-up** | **Welding Variables** |
| Machine Model: | Axial Force (lbs [kN]): |
| Serial Number: | Spindle Speed (R/MIN): |
| Weld Tool Drawing Number: | Direction of Tool Rotation: |
| Weld Joint Type: | Tilt Angle (degrees): |
| Joint Gap (in [mm]): | Plunge Speed (in [mm] / min): |
| Tool Offset (in [mm]): | Dwell Time (s): |
| Weld Fixture Drawing Number: | Clamp Pressure (psi [kPa]): |
| Anvil Material: | Travel Speed (in [mm]/min): |
| | |
| **Welding Engineer** | **Date** |
| **Manager** | **Date** |

**Figure B.1—Example of a Welding Procedure Specification Form**

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# Annex C (Informative)
# Examples of Welding Procedure Qualification Record Forms

This annex is not part of this standard 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:<br>Temper/Specification:<br>Thickness Range: | Alloy 2:<br>Temper/Specification:<br>Thickness Range: |
| Grain Direction | Preweld Cleaning |
| Root Face or Surface Coating: | Root Face: |
| | Plate or Tube Surface: |
| **Set-up** | **Welding Variables** |
| Machine Model and Serial Number: | Axial Force (lbs [kN]): |
| Weld Tool Drawing Number: | Spindle Speed (r/min): |
| Weld Joint Type: | Direction of Tool Rotation: |
| Joint Gap (in [mm]): | Travel Speed (in [mm]/min): |
| Tool Offset (in [mm]): | Tilt Angle (degrees): |
| Weld Fixture Drawing Number: | Plunge Speed (in [mm]/min): |
| Anvil Material: | Dwell Time (s): |
| | Clamp Pressure (psi [kPa]): |
| | |
| **Welding Engineer** | **Date** |
| **Manager** | **Date** |

**Figure C.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: | N/A[ ] | Pass[ ] | Fail[ ] |
| 5. | Mechanical: | N/A[ ] | Pass[ ] | Fail[ ] |
| 6. | Ultrasonic: | N/A[ ] | Pass[ ] | Fail[ ] |
| 7. | Other: | N/A[ ] | Pass[ ] | Fail[ ] |

**Figure C.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 WPQR No.: _____

Examiner or examining body: _____

Code/testing standard: _____

Date of welding: _____

Friction stir welding operator's name: _____

Weld Class: _____

Base metal type and material specification(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<br>Name, date, and signature |
| | | _____ |
| | | Examiner or examining body<br>Print name and date |

**Figure C.2—Example Number Two of a Welding Procedure Qualification Record Form**

**Record of Weld Test** **(page 2 of 3)**

Fabricator: _____
Address: _____
Fabricator's WPQR No.: _____
Examiner or examining body: _____

Friction stir welding operator's name: _____
Base metal alloy type and material specification(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**
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
Print name and date

_____
Examiner or examining body
Print name and date

* If required.

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

**Qualification Record Form**
**Test Results** **(page 3 of 3)**

Fabricator: _____
Address: _____
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 tests**
Tensile tests Required: Yes [ ] No [ ]

| Type[a]/No. | Test Specimen Ultimate Tensile Strength (FtuW) (ksi [MPa]) | Base Metal Ultimate Tensile Strength (FtuB) (ksi [MPa]) | Joint Efficiency FtuW / FtuB | 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 C.2 (Continued)—Example Number Two of a Welding Procedure Qualification Record Form**

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# Annex D (Informative)
# Example of a Welding Operator Qualification Test Record Form

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

**Welding Operator Qualification Test Record**

Name: _____ Identification: _____

Welding Procedure Specification No: _____

**A. TEST WELD**

1. Alloy(s): _____
2. Dimension: _____
   Plate [ ] T = _____
   Pipe [ ] T = _____
   Outer Diameter = _____
3. Essential Variables:
   Rotation speed [ ] Plunge depth [ ] Axial force [ ] Travel speed [ ] Tilt angle [ ]
   Side tilt angle [ ] Dwell time [ ]

**B. TEST RESULTS**

| | | | |
|---|---|---|---|
| 1. Visual: | | Pass [ ] | Fail [ ] |
| 2. Radiographic: | N/A [ ] | Pass [ ] | Fail [ ] |
| 3. Metallographic: | N/A [ ] | Pass [ ] | Fail [ ] |
| 4. Mechanical: | N/A [ ] | 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, Seam, and Fillet Welds [ ]
2. Special Welding Operator Qualification Weld [ ]

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 D.1—Example of a Welding Operator Qualification Test Record Form**

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# Annex E (Informative)
# Requesting an Official Interpretation on an AWS Standard

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

## E1. Introduction

The following procedures are here to assist standard users in submitting successful requests for official interpretations to AWS standards. Requests from the general public submitted to AWS staff or committee members that do not follow these rules may be returned to the sender unanswered. AWS reserves the right to decline answering specific requests; if AWS declines a request, AWS will provide the reason to the individual why the request was declined.

## E2. Limitations

The activities of AWS technical committees regarding interpretations are limited strictly to the interpretation of provisions of standards prepared by the committees. 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.

## E3. General Procedure for all Requests

**E3.1 Submission.** All requests shall be sent to the Managing Director, AWS Standards Development. For efficient handling, it is preferred that all requests should be submitted electronically through standards@aws.org. Alternatively, requests may be mailed to:

Managing Director
Standards Development
American Welding Society
8669 NW 36 St, # 130
Miami, FL 33166

**E3.2 Contact Information.** All inquiries shall contain the name, address, email, phone number, and employer of the inquirer.

**E3.3 Scope.** Each inquiry shall address one single provision of the standard unless the issue in question involves two or more interrelated provisions. The provision(s) shall be identified in the scope of the request along with the edition of the standard (e.g., D1.1:2006) that contains the provision(s) the inquirer is addressing.

**E3.4 Question(s).** All requests shall be stated in the form of a question that can be answered 'yes' or 'no'. The request shall be concise, yet complete enough to enable the committee to understand the point of the issue in question. When the point is not clearly defined, the request will be returned for clarification. Sketches should be used whenever appropriate, and all paragraphs, figures, and tables (or annexes) that bear on the issue in question shall be cited.

**E3.5 Proposed Answer(s).** The inquirer shall provide proposed answer(s) to their own question(s).

**E3.6 Background.** Additional information on the topic may be provided but is not necessary. The question(s) and proposed answer(s) above shall stand on their own without the need for additional background information.

## E4. AWS Policy on Interpretations

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 official interpretations are approved by the technical committee that is responsible for the standard. Communication concerning an official interpretation is directed through the AWS staff member who works with that technical committee. The policy requires that all requests for an official interpretation be submitted in writing. Such requests will be handled as expeditiously as possible, but due to the procedures that must be followed, some requests for an official interpretation may take considerable time to complete.

## E5. AWS Response to Requests

Upon approval by the committee, the interpretation is an official interpretation of the Society, and AWS shall transmit the response to the inquirer, publish it in the *Welding Journal*, and post it on the AWS website.

## E6. 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.

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

| Designation | Title |
|---|---|
| D17.1/D17.1M | *Specification for Fusion Welding for Aerospace Applications* |
| D17.2/D17.2M | *Specification for Resistance Welding for Aerospace Applications* |
| D17.3/D17.3M | *Specification for Friction Stir Welding of Aluminum Alloys for Aerospace Applications* |

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