

Friction Stir Welding

Standards & specifications in today's U.S. manufacturing and fabrication

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Agenda

- Introduction
- Overview of current FSW standards in industry
 - Public
 - Proprietary
- Elements common to weld specifications
- FSW specification AWS D17.3
- Closing remarks and questions

AWS TSD 1.1:200X, *Specification for Preparation of AWS Standards*

standard. A document that provides rules or guidelines, is produced by consensus, and is approved by a recognized body. The term *standard* encompasses five AWS document formats:

- 1) **code.** A code is intended to be a mandatory document. It includes a set of conditions and requirements relating to a specific subject. A code describes industry-accepted procedures by which it can be determined that the requirements have been met. It is written to make it suitable for adoption by governmental entities, trade groups, insurance companies, and other authorities as a part of a law or regulation or cited as a normative reference in other standards. A typical code is AWS D1.1, *Structural Welding Code – Steel*.
- 2) **specification.** A specification details the essential technical requirements for a material, product, system, or service. It specifies the procedures, methods, qualifications, or equipment by which it can be determined that the requirements have been met. A specification is mandatory when cited as a normative reference by a mandatory document or agreed to be mandatory by the concerned individuals or agencies, such as when used for procurement purposes. A typical specification is AWS D17.1, *Specification for Fusion Welding for Aerospace Applications*.
- 3) **method.** A method details industry-accepted procedures for performing a test, sampling technique, analysis, or measurement. A typical method-type document is AWS B4.0, *Standard Methods for Mechanical Testing of Welds*.
- 4) **guide.** A guide provides general information regarding one or more methods to accomplish a specific task. A typical guide is AWS D3.5, *Guide for Steel Hull Welding*.
- 5) **recommended practice.** A recommended practice document details one or more industry-accepted techniques for performing a specific operation, procedure, or process. A typical recommended practice document is AWS D10.12, *Recommended Practices and Procedures for Welding Low-Carbon Steel Pipe*.

FSW licensees in the U.S.

General Dynamics Corporation
Eclipse Aviation Corporation
Montana Tech
Concurrent Technologies Corporation
General Tool Company
University of Montana
Vanderbilt University
North Carolina A&T State University
Los Alamos National Laboratory
MTS Systems Corporation
Friction Stir Lin, Inc.
General Electric Company
Old Dominion University

Square D
Spirit AeroSystems, Inc.
Advanced Joining Technologies, Inc.
Space Exploration Technologies
Transformation Technologies, Inc.
University of Wisconsin-Madison
NSWC Carderock Division
Nova-Tech Engineering, Inc.
Advanced Metal Products
United Launch Alliance
South Dakota School of Mines
Wichita State University
Remmele Engineering, Inc.

Brigham Young University
University of South Carolina
United Defense LP
Tower Automotive, Inc.
Rockwell International Corporation
NASA
Lockheed Martin Corporation
EWI
The Boeing Company
Alcoa
Southern Methodist University
Oak Ridge National Laboratory

FSW specifications in U.S. industry

Publicly available

- 1) JSC - NASA PRC-0014, Rev. B, *Process Specification for Friction Stir Welding*
- 2) AWS, *Specification for Friction Stir Welding of Aluminum Alloys for Aerospace Hardware*
(pending)
- 3) MSFC - NASA-STD(I)-5006A, *Welding Requirements for Aerospace Flight Hardware* (pending)

U.S. companies using FSW specifications

Proprietary

- 1) Lockheed-Martin (TP5511)
- 2) Tower Automotive
- 3) Advanced Joining Technologies (AJT)
- 4) General Dynamics Land Systems
- 5) Eclipse Aircraft
- 6) Boeing
- 7) United Space Alliance (USA)
- 8) Spirit Aviation
- 9) General Electric

FSW manufacturing specifications

Written to support customers' end use and contractual requirements

- 1) Ground support equipment (GSW)
- 2) FAA – Eclipse jet
- 3) NASA – Man-rated hardware

Common elements in FSW weld specs

- Supporting sub-tier documents
- General requirements
- Process development
 - Process Qualification Record (PQR)
 - Weld Process Specification (WPS)
 - Certified WPS
- Weld operator qualification
- Fabrication / process constraints
- Quality / inspection
- Acceptance criteria
- Equipment calibration

Sub-tier documents – Normative references

- ANSI Z49.1, *Safety in Welding and Cutting and Allied Processes*
- 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*
- AWS A1.1, *Metric Practice Guide for the Welding Industry*
AWS A2.4, *Standard Symbols for Welding, Brazing, and Nondestructive Evaluation*
AWS A3.0, *Standard Welding Terms and Definitions, Including Terms for Brazing, Soldering*
AWS QC1, *Standard for AWS Certification of Welding Inspectors*
AWS B2.1, *Standards for Welding Procedure and Performance Qualifications*
- ASNT SNT-TC-1A, *Recommended Practice*

Mandatory supporting documents

AWS A3.0, Standard Welding Terms and Definitions

AWS B2.1, Standard Welding Procedure and Performance Qualification

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

Specification for friction stir welding of aluminum alloys for aerospace hardware

- Prepared by AWS D17.3 sub-committee
- Under the direction of AWS Technical Activities Committee
- Approved by AWS Board of Directors
- Approved by ANSI

Normative references

AIA/NAS document:[1]

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

ANSI document:[2]

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

ASTM documents:[3]

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

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

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

General requirements

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.

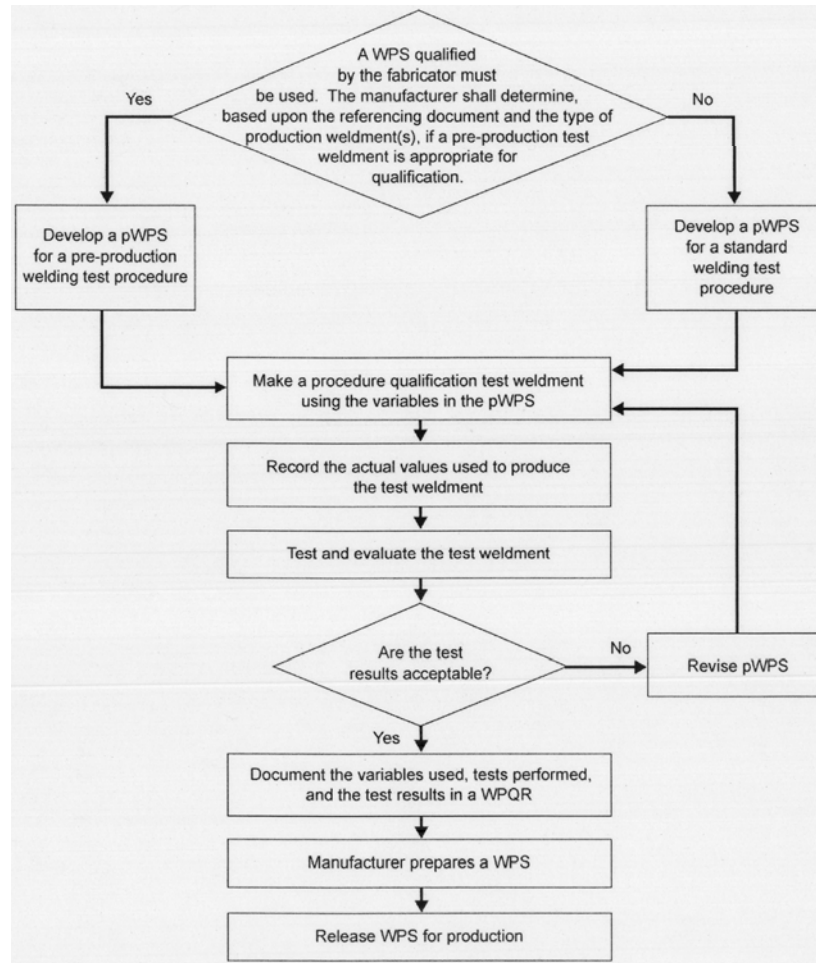
Class A – Critical application. A welded joint whose failure would cause significant danger to personnel, loss of the flight vehicle, loss of control, loss of a system, loss of a major component, unintentional release of critical stores, inability to release armament stores, abortion of the mission, 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 Engineering Authority.
- 4.3 **Drawing Precedence.** When requirements in this specification conflict with those on the engineering drawing, then 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.

Process development



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.

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].

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.

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 the groove and fillet weld coupons in place. 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 friction stir welding method qualifies only for that friction stir welding 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.

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.

7.3.3 Disqualification.

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 C, Figure C.1.

Fabrication / process constraints

- 8. Fabrication.**
- 8.1 Welding Equipment Requirements.**
 - 8.1.1 Equipment Capabilities and Performance.**
 - 8.1.2 Calibration.**
 - 8.1.3 Reproducibility Tests for Qualified Machine Welding Settings.**
 - 8.1.3.1 When to Test.**
 - 8.1.3.2 Test Requirements.**
- 8.2 Friction Stir Welding Tool.**
 - 8.2.1 Identification.**
- 8.3 Preweld Joint Preparation and Fit-up.**
 - 8.3.1 Joint Preparation.**
 - 8.3.2 Preweld Cleaning.**
 - 8.3.3 Root Opening.**
- 8.4 Preheat Temperature Control.**
- 8.5 Tack Welds.**
- 8.6 Welding.**
- 8.7 Postweld Surface Preparation.**
- 8.8 Weld Identification Requirements.**
 - 8.8.1 Interim Identification.**
 - 8.8.2 Final Identification.**
- 8.9 Acceptance Inspection.**

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 not only the cost of welding but also of inspection, test, and repair.

9.2 Inspection Personnel

9.2.1 Qualification of NDT Personnel. Nondestructive testing 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

Acceptance criteria

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 discontinuity. Discontinuities that will be removed in subsequent machining shall not be 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

Closing remarks

- Welding and technology advancements never before seen in industry are reflected in FSW specifications used in today's manufacturing sector.
- Lack of publicly available specifications is one of the reasons why the FSW process has not propagated through the manufacturing sectors.
- The FSW specification becomes an integral supporting document to the legal agreement written between two entities for deliverable items.
- Understanding the process and supporting specifications is essential for a successful FSW manufacturing operation.

