

Specification for Welding Procedure and Performance Qualification



Documents

Document Sharing Hub

AWS B2.1/B2.1M:2021
An American National Standard

Approved by the
American National Standards Institute
November 26, 2021

Specification for Welding Procedure and Performance Qualification

7th Edition

Revises AWS B2.1/B2.1M:2014

Prepared by the
American Welding Society (AWS) B2 Committee on Procedure and Performance Qualification

Under the Direction of the
AWS Technical Activities Committee

Approved by the
AWS Board of Directors

Abstract

This specification provides the requirements for qualification of welding procedure specifications, welders, and welding operators for manual, semiautomatic, mechanized, and automatic welding. The welding processes included are electrogas welding, electron beam welding, electroslag welding, flux cored arc welding, gas metal arc welding, gas tungsten arc welding, laser beam welding, oxyfuel gas welding, plasma arc welding, shielded metal arc welding, stud arc welding, and submerged arc welding. Base metals, filler metals, qualification variables, welding designs, and testing requirements are also included.



ISBN Print: 978-1-64322-215-8
ISBN PDF: 978-1-64322-216-8
© 2021 by American Welding Society
All rights reserved
Printed in the United States of America

Photocopy Rights. No portion of this standard may be reproduced, stored in a retrieval system, or transmitted in any form, including mechanical, photocopying, recording, or otherwise, without the prior written permission of the copyright owner.

Authorization to photocopy items for internal, personal, or educational classroom use only or the internal, personal, or educational classroom use only of specific clients is granted by the American Welding Society provided that the appropriate fee is paid to the Copyright Clearance Center, 222 Rosewood Drive, Danvers, MA 01923, tel: (978) 750-8400; Internet: <www.copyright.com>.

Statement on the Use of American Welding Society Standards

All standards (codes, specifications, recommended practices, methods, classifications, and guides) of the American Welding Society (AWS) are voluntary consensus standards that have been developed in accordance with the rules of the American National Standards Institute (ANSI). When AWS American National Standards are either incorporated in, or made part of, documents that are included in federal or state laws and regulations, or the regulations of other governmental bodies, their provisions carry the full legal authority of the statute. In such cases, any changes in those AWS standards must be approved by the governmental body having statutory jurisdiction before they can become a part of those laws and regulations. In all cases, these standards carry the full legal authority of the contract or other document that invokes the AWS standards. Where this contractual relationship exists, changes in or deviations from requirements of an AWS standard must be by agreement between the contracting parties.

AWS American National Standards are developed through a consensus standards development process that brings together volunteers representing varied viewpoints and interests to achieve consensus. While AWS administers the process and establishes rules to promote fairness in the development of consensus, it does not independently test, evaluate, or verify the accuracy of any information or the soundness of any judgments contained in its standards.

AWS disclaims liability for any injury to persons or to property, or other damages of any nature whatsoever, whether special, indirect, consequential, or compensatory, directly or indirectly resulting from the publication, use of, or reliance on this standard. AWS also makes no guarantee or warranty as to the accuracy or completeness of any information published herein.

In issuing and making this standard available, AWS is neither undertaking to render professional or other services for or on behalf of any person or entity, nor is AWS undertaking to perform any duty owed by any person or entity to someone else. Anyone using these documents should rely on his or her own independent judgment or, as appropriate, seek the advice of a competent professional in determining the exercise of reasonable care in any given circumstances. It is assumed that the use of this standard and its provisions is entrusted to appropriately qualified and competent personnel.

This standard may be revised, corrected through publication of amendments or errata, or supplemented by publication of addenda. Information on the latest editions of AWS standards including amendments, errata, and addenda is posted on the AWS web page (www.aws.org). Users should ensure that they have the appropriate edition, amendments, errata, and addenda.

Publication of this standard does not authorize infringement of any patent or trade name. Users of this standard accept any and all liabilities for infringement of any patent or trade name items. AWS disclaims liability for the infringement of any patent or product trade name resulting from the use of this standard.

AWS does not monitor, police, or enforce compliance with this standard, nor does it have the power to do so.

Official interpretations of any of the technical requirements of this standard may only be obtained by sending a request, in writing, to the appropriate technical committee. Such requests should be addressed to the American Welding Society, Attention: Managing Director, Standards Development (see Annex H). With regard to technical inquiries made concerning AWS standards, oral opinions on AWS standards may be rendered. These opinions are offered solely as a convenience to users of this standard, and they do not constitute professional advice. Such opinions represent only the personal opinions of the particular individuals giving them. These individuals do not speak on behalf of AWS, nor do these oral opinions constitute official or unofficial opinions or interpretations of AWS. In addition, oral opinions are informal and should not be used as a substitute for an official interpretation.

This standard is subject to revision at any time by the AWS B2 Committee on Procedure and Performance Qualification. 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 B2 Committee on Procedure and Performance Qualification 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 B2 Committee on Procedure and Performance Qualification 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.

Dedication

The AWS B2 Committee dedicates the 2021 edition of B2.1/B2.1M, *Specification on Welding Procedure and Performance Qualification*, to Edward G. Yevick for his significant contribution to Welding Qualifications and Welding. A life member of AWS and a recipient of the Samuel Wylie Miller Award for outstanding efforts and contributions to welding. Mr. Yevick worked in the welding industry for 53 years. Positions in AWS held throughout his career include: Chairman of the Pittsburgh Section 1980/81, Chairman of D11 Committee on Welding Cast Iron Castings. Chairman of D14.7 Committee on Recommended Practices for Surfacing and Reconditioning of Industrial Mill Rolls. Mr. Yevick also served three terms on the AWS Technical Activity Committee (TAC). Additionally, Mr Yevick was a member and contributed to the D14, D14.1, D14.3, D14.4, D14.5, D14.6, D14.8, D14.9, B2.1, and C5 committees. In addition to his contributions to welding he was also a member of the American Society for Non-Destructive Testing for over 50 years.

Personnel

AWS B2 Committee on Procedure and Performance Qualification

T. Anderson, Chair	<i>ITW Welding North America</i>
J. M. Rosario, Secretary	<i>American Welding Society</i>
J. Alston	<i>Jefferson Lab</i>
M. E. Barrett	<i>Westinghouse</i>
E. W. Beckman	<i>Consultant</i>
J. P. Bell	<i>Yates Construction</i>
K. L. Bingham	<i>Los Alamos National Laboratory</i>
D. T. Braun	<i>Southside Virginia Community College</i>
M. W. Bumgarner	<i>Bumgarner Consulting, LLC</i>
M. C. Cook	<i>Mid-America Carpenters Regional Council Apprentice & Training Programs</i>
J. L. Cooley	<i>YMC Mechanical</i>
T. A. Davenport	<i>Arcos Industries, LLC</i>
J. D. Farren	<i>Naval Surface Warfare Center</i>
J. J. Fluckiger	<i>Idaho National Laboratory</i>
M. F. Herrle	<i>Arise</i>
T. A. Mihalik	<i>International Training Institute</i>
S. D. Mobley	<i>Oak Ridge National Laboratory</i>
T. C. Mueller	<i>Motion Engineering Ltd.</i>
J. L. Pasqua	<i>Salco Products</i>
A. B. Rigato	<i>Pacific Northwest National Laboratory</i>
W. M. Ruof	<i>Bechtel Plant Machinery, Incorporated</i>
J. J. Sekely	<i>Welding Services, Incorporated</i>
M. L. Thomas	<i>Rocky Mountain Testing, LLC</i>
R. K. Wiswesser	<i>Welder Training & Testing Institute</i>

Advisors to the AWS B2 Committee on Procedure and Performance Qualification

M. Bernasek	<i>C-SPEC</i>
H. R. Castner	<i>Edison Welding Institute (retired)</i>
B. J. Hable	<i>Ford Motor Company</i>
K. Y. Lee	<i>DNV</i>
B. B. MacDonald	<i>Consultant</i>
C. D. Morell	<i>U.S. Nuclear Regulatory Commission (retired)</i>
J. F. Pike	<i>Acoustical Sheetmetal</i>
F. A. Schweighardt	<i>Airgas</i>
A. W. Sindel	<i>TRC Solutions</i>
C. E. Spaeder, Jr.	<i>Consultant</i>
W. J. Sperko	<i>Sperko Engineering Services, Incorporated</i>
R. F. Waite	<i>Robert F. Waite, PE PC</i>
G. M. Wisbrock, Jr.	<i>Consultant</i>

AWS B2B Subcommittee on Welding Qualification

T. A. Davenport, Chair	<i>Arcos Industries, LLC</i>
J. M. Rosario, Secretary	<i>American Welding Society</i>
J. Alston	<i>Jefferson Lab</i>
T. Anderson	<i>ITW Welding North America</i>

AWS B2B Subcommittee on Welding Qualification (Continued)

E. W. Beckman	<i>Consultant</i>
J. P. Bell	<i>Yates Construction</i>
K. L. Bingham	<i>Los Alamos National Laboratory</i>
D. T. Braun	<i>Southside Virginia Community College</i>
M. W. Bumgarner	<i>Bumgarner Consulting, LLC</i>
M. C. Cook	<i>Mid-America Carpenters Regional Council Apprentice & Training Programs</i>
J. L. Cooley	<i>YMC Mechanical</i>
J. D. Farren	<i>Naval Surface Warfare Center</i>
J. J. Fluckiger	<i>Idaho National Laboratory</i>
J. F. Hernandez	<i>SBC Global</i>
T. A. Mihalik	<i>International Training Institute</i>
S. D. Mobley	<i>Oak Ridge National Laboratory</i>
T. C. Mueller	<i>Motion Engineering Ltd.</i>
J. L. Pasqua	<i>Salco Products</i>
A. B. Rigato	<i>Pacific Northwest National Laboratory</i>
J. J. Sekely	<i>Welding Services, Incorporated</i>
M. L. Thomas	<i>Rocky Mountain Testing, LLC</i>
R. K. Wiswesser	<i>Welder Training & Testing Institute</i>

Advisors to the AWS B2B Subcommittee on Welding Qualification

M. Bernasek	<i>C-SPEC</i>
H. R. Castner	<i>Edison Welding Institute (retired)</i>
B. J. Hable	<i>Ford Motor Company</i>
K. Y. Lee	<i>DNV</i>
A. S. Luby	<i>Moraine Park Technical College</i>
C. D. Morell	<i>U.S. Nuclear Regulatory Commission (retired)</i>
J. F. Pike	<i>Acoustical Sheetmetal</i>
A. W. Sindel	<i>TRC Solutions</i>
W. J. Sperko	<i>Sperko Engineering Services, Incorporated</i>
G. Trepus	<i>Boeing Research and Technology</i>
G. M. Wisbrock, Jr.	<i>Consultant</i>

AWS B2C Subcommittee on Materials

W. M. Ruof, Chair	<i>Bechtel Plant Machinery, Incorporated</i>
J. M. Rosario, Secretary	<i>American Welding Society</i>
D. M. Allbritten	<i>Consultant</i>
T. Anderson	<i>ITW Welding North America</i>
M. Bernasek	<i>C-SPEC</i>
J. L. Cooley	<i>YMC Mechanical</i>
J. D. Farren	<i>Naval Surface Warfare Center</i>
J. J. Fluckiger	<i>Idaho National Laboratory</i>
M. F. Herrle	<i>Arise</i>
Kofford	<i>Idaho National Laboratory</i>
T. C. Mueller	<i>Motion Engineering Ltd.</i>
A. B. Rigato	<i>Pacific Northwest National Laboratory</i>

Advisors to the AWS B2C Subcommittee on Materials

C. E. Cross	<i>Los Alamos National Laboratory</i>
A. Donlevy	<i>International Titanium Association</i>
P. Pollak	<i>Pollak & Associates</i>
C. E. Spaeder, Jr.	<i>Consultant</i>
L. T. Vernam	<i>AlcoTec Wire Corporation</i>
G. M. Wisbrock, Jr.	<i>Consultant</i>

Foreword

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

The AWS B2 Committee on Procedure and Performance Qualification was formed in 1979. The first edition of B2.1, *Standard for Welding Procedure and Performance Qualification*, was published in 1984. This standard introduced the concept of Standard Welding Procedure Specifications (SWPSs) in addition to a set of rules for qualifying welding procedures, welders, and welding operators. The following edition, renamed B2.1:1998, *Specification for Welding Procedure and Performance Qualification*, was an extensive revision of B2.1-84. The Committee has published numerous Standard Welding Procedure Specifications; B2.2, *Standard for Brazing Procedure and Performance Qualification*; B2.3, *Specification for Soldering Procedure and Performance Qualification*; and B2.4, *Specification for Welding Procedure and Performance Qualification for Thermoplastics*.

AWS B2.1-84, *Standard for Welding Procedure and Performance Qualification*, was revised in 1998, 2000, 2005, 2009, and 2014.

This is the seventh edition of B2.1, *Specification for Welding Procedure and Performance Qualification*. This revision has undergone several modifications including the updating of definitions and materials.

A vertical line in the margin or underlined text in clauses, tables, or figures indicates an editorial or technical change from the 2014 edition.

Comments and suggestions for the improvement of this standard are welcome. They should be sent to the Secretary, AWS B2 Committee on Procedure and Performance Qualification, American Welding Society, 8669 NW 36 St, # 130, Miami, FL 33166.

This page is intentionally blank.

Table of Contents

	Page No.
<i>Dedication</i>	iv
<i>Personnel</i>	v
<i>Foreword</i>	vii
<i>List of Tables</i>	xi
<i>List of Figures</i>	xi
<i>List of Forms</i>	xii
1. General Requirements	1
1.1 Scope	1
1.2 Units of Measure	2
1.3 Safety	2
2. Normative References	2
3. Terms and Definitions	3
4. Procedure Qualification	5
4.1 General	5
4.2 Standard Welding Procedure Specifications	5
4.3 Welding Procedures Qualified by Employer	7
4.4 Evaluation of Test <u>Coupons</u>	9
4.5 Qualification Thickness Limitations	9
4.6 Special Test <u>Coupon</u> Acceptance Criteria	12
4.7 Pipe and Plate Groove Test <u>Coupons</u> and Acceptance Criteria	12
4.8 Fillet Test <u>Coupons</u> and Acceptance Criteria	14
4.9 Cladding Test <u>Coupons</u> and Acceptance Criteria	16
4.10 Hardfacing Test <u>Coupons</u> and Acceptance Criteria	18
4.11 Stud Welds and Acceptance Criteria	19
4.12 Test <u>Coupons</u> less than 1/16 in [1.5 mm] Acceptance Criteria	20
4.13 Welding Procedure Specification Data	23
4.14 Procedure Qualification Variables	25
5. Performance Qualification	35
5.1 General	35
5.2 Qualification by Standard Test	37
5.3 Qualification by Workmanship Test	38
5.4 Test <u>Coupons</u>	38
5.5 Examination Procedures and Acceptance Criteria	48
5.6 Performance Qualification Variables	50

<i>Annexes</i>	53
Annex A (Normative)—Illustrations—Weld Position, Test Specimens, and Text Fixtures.....	55
Annex B (Normative)—Filler Metal Grouping	75
Annex C (Normative)—Base Metal Grouping.....	79
Annex D (Normative)—Radiographic Examination Procedure.....	301
Annex E (Informative)—Basis for Establishing a Standard Welding Procedure Specification (SWPS).....	305
Annex F (Informative)—Sample Forms.....	307
Annex G (Informative)—Macroetch Procedure	313
Annex H (Informative)— <u>Requesting an Official Interpretation on an AWS Standard</u>	317
Annex I (Informative)—Guidelines for Requesting Adoption of New Materials Under the AWS B2.1 Standard ..	319
List of AWS Documents on Welding Procedure and Performance Qualification.....	323

List of Tables

Table	Page No.
4.1 Test Methods Required for Procedure Qualification	10
4.2 Thickness and Size Limitations for Fillet Welds for Procedure Qualification	10
4.3 Thickness Limitations of Plate and Pipe for Groove Welds for Procedure Qualification	11
4.4 Thickness Limitations for Cladding and Hardfacing for Procedure Qualification	11
4.5 Minimum Shear Strength for Aluminum Fillet Welds	17
4.6 Minimum Tensile Load Requirements for Aluminum Stud Welds	20
4.7 Minimum Torque Requirements for Steel Stud Welds	21
4.8 Minimum Torque Requirements for Aluminum Stud Welds	21
5.1 Examination Requirements for Performance Qualification	36
5.2 Number of Bend Tests for Performance Qualification	38
5.3 Allowable Base Metals for Performance Qualification	40
5.4 Allowable Filler Metals for Performance Qualification	40
5.5 Position Limitations for Performance Tests	41
5.6 Limitations for Performance Qualification on Groove Welds in Pipe and Tube	51
5.7 Limitations for Performance Qualification in Plate Groove Welds	51
5.8 Limitations for Performance Qualification in Pipe Fillet Welds	51
B.1 Grouping of Welding Electrodes and Rods for Qualification	76
B.2 Classification of Ferrous Weld Metal for Procedure Qualification	78
C.1 Listing of Base Metal Specifications—Ferrous Alloys	80
C.1 Listing of Base Metal Specifications—Nonferrous Alloys	129
C.2 M-Number Listing of Base Metals—Ferrous Alloys	156
C.2 M-Number Listing of Base Metals—Nonferrous Alloys	234
C.3 Listing of Base Metal Specifications—Iron Castings	285
C.4 <u>Listing of Base Metal Specifications for Standard Welding Procedure Specifications for Naval Applications—Ferrous Alloys</u>	287
D.1 Acceptable Linear Discontinuities for Radiographic Examination	302
D.2 Acceptable Rounded Discontinuities for Radiographic Examination	302

List of Figures

Figure	Page No.
4.1 Welding Procedure Selection Criteria	6
4.2 Location of Groove Weld Test Specimens—Pipe	12
4.3 Location of Test Specimens for Welded Box Tubing	13
4.4 Location of Tension, Longitudinal Bend, and Fracture Toughness <u>Test Specimens—Plate</u>	14
4.5 Location of Tension, Fracture Toughness, and Transverse Bend <u>Test Specimens—Plate</u>	15
4.6 Location of Fillet Weld Shear Test and Macroetch Specimens	16
4.7 Fillet Weld Break Test and Macroetch Specimens for Procedure Qualification	17
4.8 Location of Cladding Test Specimens	18
4.9 Location of Hardfacing Test Specimens	19
4.10 <u>Rotating Tool Design Characteristics (FSW)</u>	34
5.1 Selection of Performance Qualification Method—Workmanship Test or Standard Test	36

Figure	Page No.
5.2 Typical Workmanship Test <u>Coupons</u>	39
5.3 Location of 1G, 2G, 5G, and 6G Bend Specimens—Pipe Groove <u>Test Coupon</u>	42
5.4 Location of Bend Specimens—Combined Pipe Positions 2G and 5G	43
5.5 Location of Bend Specimens for Box Tube.....	44
5.6 Location of Transverse Bend Specimens—Plate Groove <u>Test Coupon</u>	44
5.7 Location of Longitudinal Bend Specimens—Plate Groove <u>Test Coupon</u>	45
5.8 Location of Fillet Test Specimens—Plate.....	45
5.9 Location of Fillet Test Specimens—Alternate <u>Test Coupon</u> —Plate	46
5.10 Location of Fillet Test Specimens—Pipe	46
5.11 Location of Fillet Test Specimens—Alternate Weld—Pipe	47
5.12 Location of Cladding Specimens—Plate.....	47
5.13 Location of Test Specimen—Hardfacing <u>Test Coupon</u> —Plate	48
A.1A Welding Test Positions—Groove, Cladding, and Hardfacing Welds.....	57
A.1B Limits of Welding Positions—Groove, Cladding, and Hardfacing Welds	58
A.1C Welding Test Positions—Fillet Welds	59
A.1D Limits of Welding Positions—Fillet Welds	60
A.1E Welding Positions—Stud Welds	61
A.2A Transverse Face and Root Bend Specimens	62
A.2B Longitudinal Face and Root Bend Specimens	63
A.2C Transverse Side Bend Specimens	63
A.3A Reduced Section Tension Specimen—Rectangular.....	64
A.3B Reduced Section Tension Specimen—Round	65
A.3C Alternate Tension Specimen for Pipe 3 in [76 mm] O.D. or Less	65
A.3D Alternate Tension Specimen for Pipe 2 in [51 mm] O.D. or Less	66
A.4A Weld Cladding Side Bend Specimens.....	67
A.4B Weld Cladding and Hardfacing Chemical Analysis Specimens	67
A.5A Guided Bend Fixture—Bottom Ejecting Type	68
A.5B Guided Bend Fixture—Bottom Type.....	69
A.5C Guided Bend Fixture—Wrap-Around	70
A.5D Stud Weld Bend Test Fixture	71
A.5E Stud Weld Torque Test Fixture	72
A.5F Stud Weld Tension Test Fixture	73
D.1 Rounded Indication Charts for Radiographic Examination.....	303

List of Forms

Form	Page No.
F.1 Example of a Performance Qualification Test Record.....	308
F.2 Example of a Welding Procedure Specification	309
F.3 Example of a Procedure Qualification Record	310

Specification for Welding Procedure and Performance Qualification

1. General Requirements

1.1 Scope. This specification provides requirements for welding procedure and welding performance qualification. It is the intent that this specification be referenced by other documents, such as codes, specifications, contracts, and quality control or quality assurance manuals. Such documents are recognized in this specification as Referencing Documents. Requirements imposed by the Referencing Document supersede the requirements of this specification.

The requirements for the qualification of welding procedures are provided in Clause 4, Procedure Qualification. The requirements for the performance qualification of welders and welding operators are provided in Clause 5, Performance Qualification.

This specification also defines and establishes qualification variables. Qualification requirements are based on the premise that the Referencing Document will specify fabrication, design, base metal, filler metal, preheat, interpass temperature, postweld heat treatment (PWHT), nondestructive examination, and test requirements applicable to the product. Welding procedure and performance qualifications which meet the requirements of other codes and specifications are acceptable, provided they also meet the requirements of this specification.

Base metals and filler metals have been grouped into categories that will minimize the number of qualification tests required. Substitution of one base metal or filler metal for another, even when within the allowable rules, should only be made after an evaluation of the material's suitability for its intended use. For some materials, additional tests may be appropriate to verify the material's suitability. Materials not listed require separate qualification.

This specification is intended for use with the following welding processes:

EBW	= Electron Beam Welding
EGW	= Electrogas Welding
ESW	= Electroslag Welding
FCAW	= Flux Cored Arc Welding
GMAW	= Gas Metal Arc Welding
GTAW	= Gas Tungsten Arc Welding
LBW	= Laser Beam Welding
OFW	= Oxyfuel Gas Welding
PAW	= Plasma Arc Welding
SAW	= Submerged Arc Welding
SMAW	= Shielded Metal Arc Welding
SW	= Arc Stud Welding

Employers shall be responsible for the welding performed by their organization, including the use of qualified welding procedures, qualified welders, and qualified welding operators. The welding procedure may be an AWS Standard Welding Procedure Specification (SWPS) published by the American Welding Society, or it shall be qualified by the Employer as required under the rules of Clause 4, Procedure Qualification. It is the Employer's responsibility to assure that welding procedure specifications (WPSs) meet all requirements of the Referencing Document.

When not otherwise specified by the Referencing Document, the edition of this specification to be used should be established in accordance with the following:

- (1) Editions may be used at any time after the effective date of issue.
- (2) Latest edition of this document should be used for new contracts.

(3) Editions established by contract date may be used during the entire term of the contract, or the provisions of later editions may be used when agreed upon by the contracting parties.

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 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; some safety and health information is provided, but such issues are not fully 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:

- (1) AWS A2.4, *Standard Symbols for Welding, Brazing, and Nondestructive Examination*;
- (2) AWS A3.0M/A3.0, *Standard Welding Terms and Definitions, Including Terms for Adhesive Bonding, Brazing, Soldering, Thermal Cutting, and Thermal Spraying*;
- (3) AWS B4.0, *Standard Methods for Mechanical Testing of Welds*;
- (4) AWS B4.0M, *Standard Methods for Mechanical Testing of Welds (Metric Customary Units)*;
- (5) AWS D1.4/D1.4M, *Structural Welding Code—Reinforcing Steel*; and
- (6) AWS D11.2, *Guide for Welding Iron Castings*.

Other Documents:

- (1) ANSI Z49.1, *Safety in Welding, Cutting, and Allied Processes*;

- (2) ASME *Boiler and Pressure Vessel Code*, Section V;
- (3) ASME *Boiler and Pressure Vessel Code*, Section IX; and
- (4) ASTM E165, *Standard Test Method for Liquid Penetrant Examination*.

3. Terms and Definitions

AWS A3.0M/A3.0 provides the basis for terms and definitions used herein. However, the following terms and definitions are included below to accommodate usage specific to this document.

A-Number. A designation used to classify ferrous weld metal for procedure qualification based upon chemical composition of a weld deposit (see Annex B).

backing gas. A nonstandard term for **root shielding gas**.

circumferential weld. A fillet or groove weld that is a complete circle (360°) between two faying surfaces and has a diameter of less than 24 in.

control method (FSW). The manner of monitoring and controlling the position of the rotating tool with respect to the weld joint during the friction stir welding process.

control method, force (FSW). A control method that uses a force set point, such as plunge force or travel force, to control the tool position. Under the force control method, the plunge depth or travel speed can vary, within a specified range, during welding.

control method, position (FSW). A control method that uses a set plunge position relative to the plate surface to control the tool position. Under the position control method, the plunge force can vary, within a specified range, during welding.

control method, travel (FSW). A control method that uses a set travel speed to control the tool position. Under the travel control method, the travel force can vary, within a specified range, during welding.

Employer. The contractor or manufacturer that adopts this specification for welding procedure and performance qualification. Closely related companies, including those with different names, for which effective control of welding is as one organization, shall be considered as one Employer.

F-Number. A designation used to group welding filler metal for procedure and performance qualifications based essentially on their usability characteristics (see Annex B).

fracture toughness. A mechanical property of materials exhibiting their ability to resist crack propagation as determined by any of the following tests, including but not limited to: Charpy V-notch, dynamic tear, plane-strain fracture toughness, and drop-weight nil-ductility transition temperature.

friction stir welding (FSW). A variation of friction welding producing a weld by the friction heating and plastic material displacement caused by a rapidly rotating tool traversing the weld joint.

M-Number. A designation used to group base metals for procedure and performance qualifications consistent with the P-Number designation established by the ASME *Boiler and Pressure Vessel Code*, Section IX, but which also incorporate materials not recognized or used under ASME rules (see Annex C).

performance qualification variable. One of a set of requirements that define the qualification limits of welders and welding operators.

pipe. Used generally to refer to pipe and tube.

plate. Used to refer to rolled, extruded, or forged products other than pipe and tube.

procedure qualification record (PQR). A record of the welding variables used to produce an acceptable test coupon and the results of tests conducted on that coupon to qualify a welding procedure specification.

procedure qualification variable. One of a set of elements that define the qualification limits of a welding procedure specification (WPS).

process separation, hybrid welding. The distance between each welding process as specified in the WPS.

process sequence, hybrid welding. The order of each welding process with respect to the direction of travel.

qualification variable. See **performance qualification variable and procedure qualification variable.**

qualified welding procedure. A welding procedure specification (WPS) meeting the qualification requirements of this specification based on qualification tests of coupons. Qualified welding procedures are of two types:

- (1) AWS Standard Welding Procedure Specifications (SWPSs) published by the American Welding Society, and
- (2) welding procedure specifications (WPSs) qualified by an Employer for the Employer's own use.

Qualifier. The Employer, organization, or individual responsible for conducting and supervising qualification testing.

radial weld. A fillet or groove weld that is not a complete circle between two faying surfaces having rounded portions with a radius of less than 12 in.

Referencing Document. The fabrication code, specification, contract document, or internal document such as quality control or quality assurance manuals that invokes this specification.

root shielding gas. A shielding gas used to provide a protective atmosphere to the root surface of the weld.

Standard Welding Procedure Specification (SWPS). A welding procedure specification qualified according to the requirements of AWS B2.1/B2.1M, approved by AWS, and made available for production welding by companies or individuals other than those performing the qualification test.

test coupon. A weldment used for procedure or performance qualification testing.

test specimen. A sample of a test coupon subjected to testing.

test specimen blank. The section removed from a test coupon from which the test specimen is prepared.

torch shielding gas. Protective gas emanating from the torch, used to prevent or reduce atmospheric contamination.

trailing gas. A gas used to produce a protective atmosphere that extends beyond the weld pool in the direction opposite of travel.

welding procedure specification (WPS). A document providing the required welding variables for a specific application to assure repeatability by properly trained welders and welding operators.

welding variable. Any controllable detail of a welding procedure which is required to be addressed on the welding procedure specification (WPS).

4. Procedure Qualification

4.1 General

The purpose of a welding procedure qualification is to demonstrate the capabilities of a weld to meet required properties.

4.1.1 Each welding procedure shall be qualified.

4.1.2 This standard establishes two categories of qualified welding procedures:

(1) *Category 1.* Standard Welding Procedure Specifications (SWPSs) in accordance with 4.2 supported by PQRs reviewed and validated by the B2G Subcommittee on Procedure Qualification Records. The basis for establishment of an SWPS is described in Annex E.

(2) *Category 2.* Welding procedure specifications (WPSs) qualified by the Employer in accordance with 4.3.

To determine if SWPSs or WPSs qualified by the Employer are appropriate, the flow chart in Figure 4.1 may be utilized.

4.1.3 Tests previously conducted by an Employer to meet other codes, specifications, or earlier editions of this specification, may be used by the Employer to support a WPS in accordance with this specification. The procedure qualification record(s) (PQR) must address all qualification variables (see 4.14, Procedure Qualification Variables) applicable to the welding process(es) used and the test results must meet all requirements of this specification. If all the requirements are not met, another qualification test may be conducted following the qualification variables of the original PQR. A PQR supplement shall be prepared to document the additional tests results.

4.1.4 A matrix indicating data to be included in the WPS for a process or combination of processes is provided in 4.13, welding procedure specification Data. There are no required formats for WPSs or PQRs; however suggested forms are shown in Annex F. Any format may be used providing all applicable information is recorded, including a certifying statement acknowledging the validity of the data and certifying that the test coupons were made and tested in accordance with the requirements of AWS B2.1/B2.1M, *Specification for Welding Procedure and Performance Qualification*.

4.1.5 PQRs shall not be revised except to correct errors or add new or omitted information. All such changes shall be identified, authorized by the Employer, and dated on the PQR.

4.1.6 A WPS may require the support of more than one PQR, while one PQR may support a number of WPSs. Compatible PQRs using different qualification variables may be combined to support one WPS. Compatibility shall be determined based on either experience, or testing, or both.

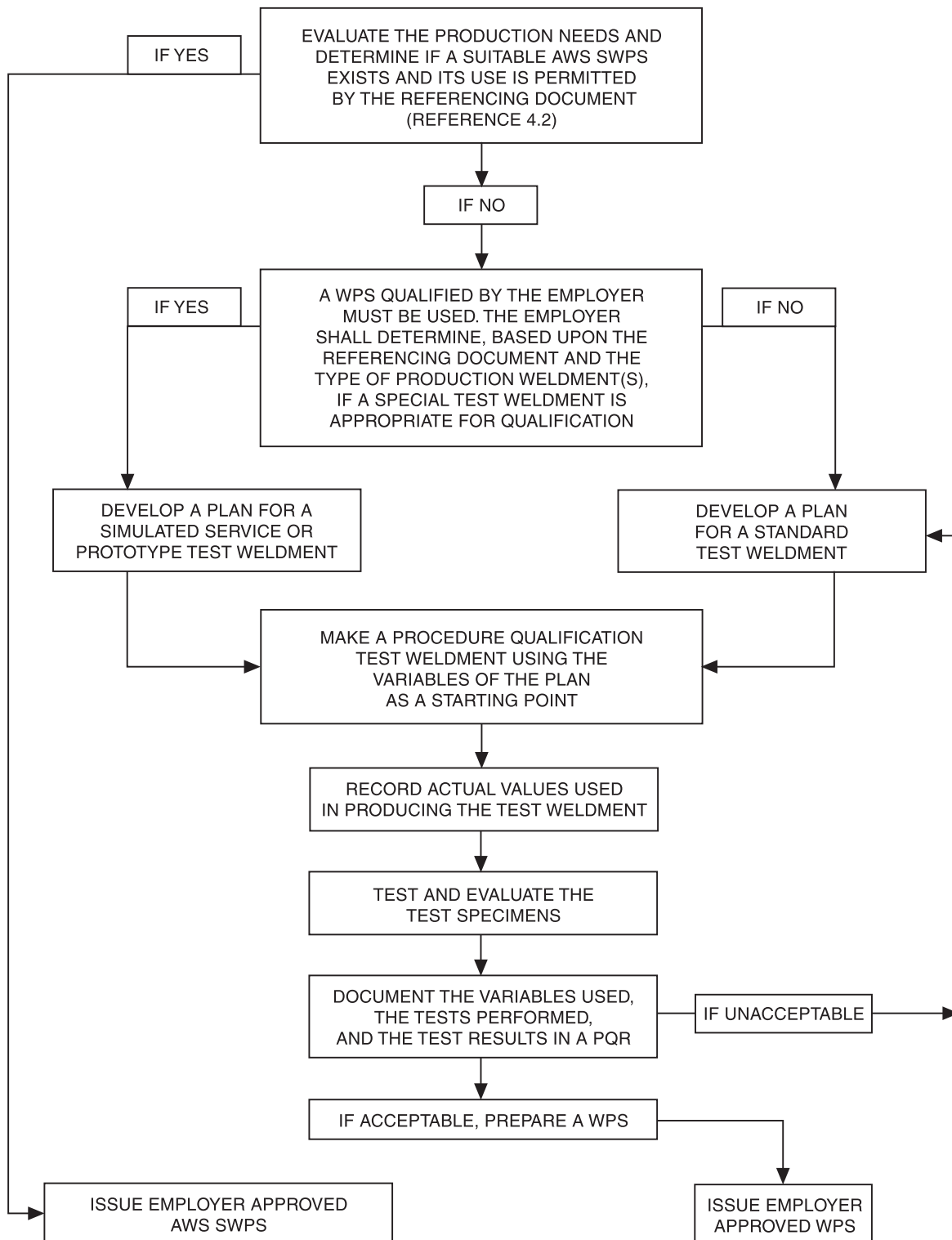
4.1.7 WPSs and PQRs shall be identified according to a system that allows permanent traceability from the WPS to its supporting PQRs.

4.1.8 A change in a WPS beyond that allowed in 4.14, Procedure Qualification Variables shall require requalification of the procedure and preparation of a new or revised WPS. Changes not addressed in 4.14 shall not require requalification, provided such changes are documented in a new or revised WPS.

4.1.9 WPSs qualified to earlier editions of B2.1 shall be qualified to this edition without revision or further testing.

4.2 Standard Welding Procedure Specifications

4.2.1 Procedures permitted for use without employer qualification tests shall be limited to AWS Standard Welding Procedure Specifications (SWPSs).



Note: Figure 4.1 is provided to aid the user of this standard in determining whether an AWS Standard Welding Procedure Specification (SWPS) may be used for their application. Figure 4.1 can be used to determine if a special test coupon or a standard test coupon is applicable, and the steps needed to develop a welding procedure which meets the requirements of this document.

Figure 4.1—Welding Procedure Selection Criteria (see 4.1.2)

4.2.2 Employers may use an SWPS without modification, if it provides sufficient direction for use in production. An Employer may supplement the SWPS with additional information or requirements, provided the welding variables remain within the ranges shown on the SWPS.

4.2.3 Prior to use of an SWPS, the Employer shall signify acceptance of responsibility for the production application of the procedure by signing and dating the SWPS. SWPSs published under previous editions of this standard are acceptable for use under this edition of AWS B2.1/B2.1M, *Specification for Welding Procedure and Performance Qualification*.

4.2.4 Welding variables shall not be changed beyond the ranges specified in the SWPS.

4.2.5 Multiple SWPSs may not be combined to perform a single production weld.

4.2.6 SWPSs shall not be combined with or used to supplement Employer qualified WPSs.

4.2.7 An Employer's procedure qualification record (PQR) shall not be used to modify an SWPS.

4.3 Welding Procedures Qualified by Employer

4.3.1 The qualification variables for the various processes used in making a procedure qualification test coupon are listed in 4.14, Procedure Qualification Variables.

4.3.2 Mechanical test specimens shown in Annex A shall be used for testing. The provisions of AWS B4.0, *Standard Methods for Mechanical Testing of Welds* or AWS B4.0M, *Standard Methods for Mechanical Testing of Welds (Metric Customary Units)*, may be used for mechanical testing of welds made for procedure qualification. However, in instances where the provisions of AWS B4.0, B4.0M and AWS B2.1/B2.1M are in conflict, the provisions of AWS B2.1/B2.1M shall take precedence. The test results shall be recorded on or appended to a PQR containing the actual qualification variables.

4.3.3 If the results meet the acceptance criteria specified, the Employer shall sign and date the PQR indicating that the PQR is an accurate record of the welding and testing of the procedure qualification test coupon. The Employer may then prepare and issue an approved WPS. The Employer shall sign and date the WPS to signify acceptance of responsibility for use of the WPS in production.

4.3.4 Each WPS shall be supported by one or more PQRs, and shall specify a range or a single value for each welding variable applicable to the welding process identified in 4.13, welding procedure specification data. Additionally, a WPS shall specify a range or a single value for each qualification variable for the welding process used as identified in 4.14, Procedure Qualification Variables.

4.3.5 Except as permitted in 1.1, a WPS qualified by one Employer is not transferable to another Employer.

4.3.6 Special test coupons may be used for procedure qualification, when permitted by the Referencing Document, and shall be governed by the limits on qualification variables given in 4.14, Procedure Qualification Variables.

4.3.7 This specification recognizes two types of special test coupons:

(1) *Simulated Service Test Coupons*. These are test coupons in which qualification requires tests simulating service conditions. Tests may include fracture toughness, flexural, and/or static, or cyclic loading to simulate the type of loading that the coupon will encounter in service. Proof tests such as hydrostatic or leak tests may also be appropriate.

(2) *Prototype Structure Test Coupons*. These are test coupons in which a prototype of the actual coupon is subjected to field tests in which it is loaded and demonstrated to perform the function for which it was designed.

4.3.8 Unless otherwise permitted by the Referencing Document, coated metals, such as galvanized or painted metals, require separate qualification unless the coating is removed from the weld area prior to welding.

4.3.9 Except as otherwise provided in 4.14, the type and dimensions of the groove are not procedure qualification variables.

4.3.10 Unless specifically required otherwise by the procedure qualification variables (4.14), a qualification in any position qualifies the procedure in all positions. The welding process and electrodes must be suitable for use in the positions permitted by the WPS. A welder or welding operator making and passing the procedure qualification test is qualified for the position tested (see 5.4.3).

4.3.11 The base metals may consist of either plate or pipe, or other product forms. Qualification in plate also qualifies for pipe welding and vice versa. The dimensions of the test coupon shall be sufficient to provide the required test specimens (see Annex A).

4.3.12 Base metals are grouped for qualification purposes on the basis of weldability, similar mechanical properties, chemical composition, and metallurgical compatibility. Such groups are assigned M-Numbers in Annex C of this specification.

4.3.13 For the welding of base metals with different M-Numbers, a procedure qualification test shall be made for each combination of M-Numbers to be joined. However, a procedure qualification test with one M-Number shall also qualify for that metal welded to itself and to each of the lower M-Number metals for:

- (1) Base metals M-1, M-3, M-4, and M-5A; and
- (2) Welding processes SMAW, GTAW, GMAW, FCAW, SAW, and PAW melt-in-technique.

(Example: M-5A to M-5A would qualify for M-5A to M-5A as well as M-5A to M-4, M-5A to M-3, and M-5A to M-1.)

4.3.14 If the Referencing Document requires fracture toughness testing, then procedure qualification shall be made for each combination M-Number and Group Number to be joined. A procedure qualification shall be made for each M- Number and Group Number combination of base metals, even though procedure qualification tests have been made for each of the two base metals welded to itself.

4.3.14.1 If the welding procedure specification (WPS) for welding the combination of base metals specifies the same qualification variables, including electrode or filler metal, as both WPSs for welding each base metal to itself, such as a change only in the base metal, then the WPS for welding the combination of base metals is also qualified.

4.3.14.2 When base metals of two different M-Numbers and Group Numbers are qualified using a single test coupon, that test coupon qualifies the welding of those two M-Numbers and Group Numbers to themselves, as well as to each other using the variables qualified.

4.3.15 Base metals listed in Annex C or listed in ASME Boiler and Pressure Vessel Code, Section IX, shall be considered as listed materials. If an unlisted base metal has the same UNS number designation as a base metal listed in Table C.1 and Table C.2, it shall be considered as assigned to that M-Number or M-Number plus Group Number; however, within this instance, only base metals listed in Tables C.1 and C.2 may be used for procedure qualification test coupons. PQRs for unlisted base metals shall not be used to support a WPS for welding listed base metals, other unlisted base metals, or vice versa.

4.3.16 Unassigned base metals shall be identified in the WPS and on the PQR by specification, type and grade, or by chemical analysis and mechanical properties. The minimum tensile strength shall be defined by the organization that specified the unassigned base metal if the tensile strength of that base metal is not defined by the material specification.

4.3.17 When fracture toughness is a requirement and a qualified procedure exists which satisfies all requirements except fracture toughness, it is necessary only to prepare an additional test coupon with sufficient material to provide the required fracture toughness test specimens. The test coupon shall be welded using that procedure, plus those variables applicable to fracture toughness. A new or revised PQR shall be prepared and the WPS shall then be revised or a new WPS issued to accommodate the qualification variables for fracture toughness applications listed in 4.14, Procedure Qualification Variables.

4.3.18 Cladding and hardfacing require separate qualification for each base metal M-Number, and filler metal combination. Welds made to join clad metals to other clad metals or to unclad metals shall be separately qualified or may be qualified by a combination of a PQR for joining an unclad metal and a PQR for applying the cladding.

4.3.19 For stud welding, the nominal chemical composition of the stud material shall be used to classify the stud as an M-Number material for purposes of procedure qualification.

4.3.20 During the welding of procedure qualification test coupons, welders and welding operators shall be under the full control and supervision of the Employer. Only activities (1), (5), (6), and (7) listed below may be subcontracted by the Employer.

- (1) Preparation of test materials for welding,
- (2) Instruction of the welder or welding operator on use of the welding procedure,
- (3) Performance of welding,
- (4) Recording of actual qualification variables used in the test (see 4.1.4),
- (5) Preparation of test specimens from the completed test coupon,
- (6) Performance of examinations and tests,
- (7) Documenting of test results, and
- (8) Certification of the final PQR.

4.3.21 Qualification requirements for cast iron materials are given in AWS D11.2, *Guide for Welding Iron Castings*.

4.3.22 Qualification requirements for reinforcing bar are given in AWS D1.4/D1.4M, *Structural Welding Code—Reinforcing Steel*.

4.4 Evaluation of Test Coupons

Test coupons shall be subjected to the applicable tests in Table 4.1. The type, number, location, and evaluation criteria for tests shall be as given in 4.6 through 4.12, except that for special test coupons the evaluation of the coupon shall be in accordance with the Referencing Document.

4.5 Qualification Thickness Limitations

4.5.1 Limitations on the thickness ranges qualified by procedure qualification tests are given in the following tables:

- (1) Table 4.2—Thickness and Size Limitations for Fillet Welds for Procedure Qualification
- (2) Table 4.3—Thickness Limitations of Plate and Pipe for Groove Welds for Procedure Qualification
- (3) Table 4.4—Thickness Limitations for Cladding and Hardfacing for Procedure Qualification

4.5.2 The limitations in the tables cited in 4.5.1 are based upon the following criteria:

- (1) The size and number of passes of a fillet weld,
- (2) The base metal and weld metal thicknesses for groove welds, or
- (3) The base metal thickness for weld cladding and hardfacing.

4.5.3 Complete joint penetration groove welds shall also qualify partial joint penetration groove welds and fillet welds within the qualification limits given in Table 4.3.

4.5.4 In addition to the welding data required to be included in the WPS by 4.13, welding procedure specification data, when multiple processes or multiple filler metal classifications are used in a single test coupon, the thickness ranges permitted for use in the WPS shall apply separately to each welding process and filler metal classification. The weld deposit thickness for each welding process and each filler metal classification used in the qualification test shall be recorded on the PQR.

4.5.5 In addition to the procedure qualification variables required to be recorded on the PQR by 4.14, Procedure Qualification Variables, the weld deposit thickness for each welding process and each filler metal classification used in the qualification test shall be recorded on the PQR for all applications.

Table 4.1
Test Methods Required for Procedure Qualification
(see 4.4, 4.6, 4.7.4, 4.12.2, and 4.12.4)

	Number of Test	Groove Weld	Fillet Welds		Stud Welds	Weld Cladding	Hardfacing
			Bend-Break Test	Alternate Shear Test			
Visual Examination	1	Yes	Yes	Yes	(Note b)	(Note b)	(Note b)
Guided Bend Tests	4	Yes ^a	—	—	—	Yes	—
Tension Tests	2 Groove, 5 Stud	Yes	—	—	Yes, or Torque	—	—
Macro-Examination	(Note d)	(Note a)	Yes	Yes	Yes ^c	—	(Note b)
Bend-Break	2	—	Yes	—	—	—	—
Bend Tests	5 Stud	—	—	—	Yes	—	—
Torque Tests	5	—	—	—	Yes, or Tension	—	—
Fracture Toughness Tests	1	(Note b)	—	—	—	—	—
Shear Tests	2	—	—	Yes	—	—	—
Penetrant Examination	1	—	—	—	—	Yes	(Note b)
Chemical Analysis	1	—	—	—	—	Yes	(Note b)
Hardness Test	1	—	—	—	—	—	Yes

^a The use of a macro examination in lieu of bend tests shall be permitted only for welds made in M-26, M-81, and M-83 base materials.

^b If specified in referencing document.

^c Except that unclad, unpainted M-1 materials are exempted.

^d 2 macro examinations for single pass fillets, 2 macro examination for multiple pass fillets, 5 macro examinations for stud welds.

Table 4.2
Thickness and Size Limitations for Fillet Welds for Procedure Qualification
(see 4.5.1 and 4.8)

Fillet Test Coupon	Thickness and Size Range Qualified	
	Base Metal Thickness ^{a, b, c, e}	Fillet Weld Size ^d
Single Pass	Unlimited	Maximum welded single pass fillet size and smaller
Multiple Pass	Unlimited	1/2 of that welded during qualification to unlimited

^a For OFW, the maximum base metal thickness qualified is the thickness of the test coupon.

^b For GMAW-S, the maximum base metal thickness qualified is 1.1 times the test coupon thickness.

^c For fracture toughness applications less than 5/8 in [16 mm] thick, the base metal thickness of the test coupon is the minimum base metal thickness qualified.

^d For M-11 steels, the fillet weld size qualified shall be equal to or less than the fillet size used in the test.

Table 4.3
Thickness Limitations of Plate and Pipe for Groove Welds for Procedure Qualification
 (see 4.5.1, 4.5.3, 4.7.1, Figure 4.2, Figure 4.3, Figure 4.4, and Figure 4.5)

Test Weldment Thickness (T), in [mm] ^{a, b, c, d, f, g}	Base Metal Thickness Qualified ^{d, e}		Deposited Weld Metals Thickness Qualified ^d
	Minimum, in [mm]	Maximum, in [mm]	Maximum, in [mm]
< 1/16 [1.5]	1/2T	2T	2t
1/16 to 3/8 [1.5 to 10]	1/16 [1.5]	2T	2t
> 3/8 [10], but < 3/4 [19]	3/16 [5]	2T	2t
3/4 [19] to < 1-1/2 [38]	3/16 [5]	2T	2t when t < 3/4 [19] 2T when t ≥ 3/4 [19]
1-1/2 [38] to < 6 [152]	3/16 [5]	8 [203]	2t when t < 3/4 [19] 8 [203] when t ≥ 3/4 [19]
≥ 6 [152]	1 [25]	1.33T	2t when t < 3/4 [19] 8 [203] when 3/4 [19] ≤ t < 6 [152] 1.33t when t ≥ 6 [152]

^a Provided that the weld penetration can be measured. EBW and LBW qualified thickness range shall be 1.2T for test weldments 1 in [25 mm] and under in thickness and 1.1T for weldments over 1 in [25 mm] thick. If weld penetration cannot be measured, the qualified thickness ranges are 1.1T and 1.05T, respectively.

^b When the groove is filled using a combination of welding processes:

- (1) The test weldment thickness "T" is applicable for the base metal and shall be determined from the Base Metal Thickness Qualified column.
- (2) The thickness "t" of the weld metal for each welding process shall be determined from the Deposited Weld Metal Thickness Qualified column.
- (3) Each welding process qualified in this combination manner may be used separately only within the same qualification variables and the thickness limits.

^c For OFW, the maximum base metal thickness qualified is the thickness of the test weldment and the maximum weld metal thickness qualified is the thickness of the weld metal deposited in the test weldment.

^d For GMAW-S, the maximum thickness of base metal qualified is 1.1 times the thickness of the test weldment until the test weldment thickness is 1/2 in [13 mm], beyond which Table 4.3 applies. The maximum weld metal thickness qualified is 1.1 times the GMAW-S weld metal thickness deposited in the weldment. In addition, for thickness 3/8 in [10 mm] thick and greater, side bend tests shall be used to qualify GMAW-S short circuit WPSs.

^e For fracture toughness applications less than 5/8 in [16 mm] thick, the base metal thickness of the test weldment is the minimum base metal thickness qualified.

^f If any single pass in the test weldment is greater in thickness than 1/2 in [13 mm], the qualified base metal thickness is 1.1 times the test weldment thickness.

^g For base metals equal to or less than 3/8 in [10 mm], fillet welds have the same base metal thickness qualifications as groove welds. For base metals thickness greater than 3/8 in [10 mm], fillet welds have unlimited base metal thickness qualified.

Notes:

T = The thickness of the Test Weldment Base Metal.

t = The thickness of the Weld Deposit, excluding reinforcement.

Table 4.4
Thickness Limitations for Cladding and Hardfacing for Procedure Qualification (see 4.5.1)

Test <u>Coupon</u> Thickness (T), in [mm]	Qualified Base Metal Thickness, in [mm]	
	Minimum	Maximum
< 1 [25]	T	Unlimited
≥ 1 [25] and over	1 [25]	Unlimited

Note: The minimum weld metal thickness qualified for cladding and hardfacing is one layer if the test weldment has only one layer, and is two layers if the test coupon has two or more layers. The number of layers applies individually to each filler metal classification.

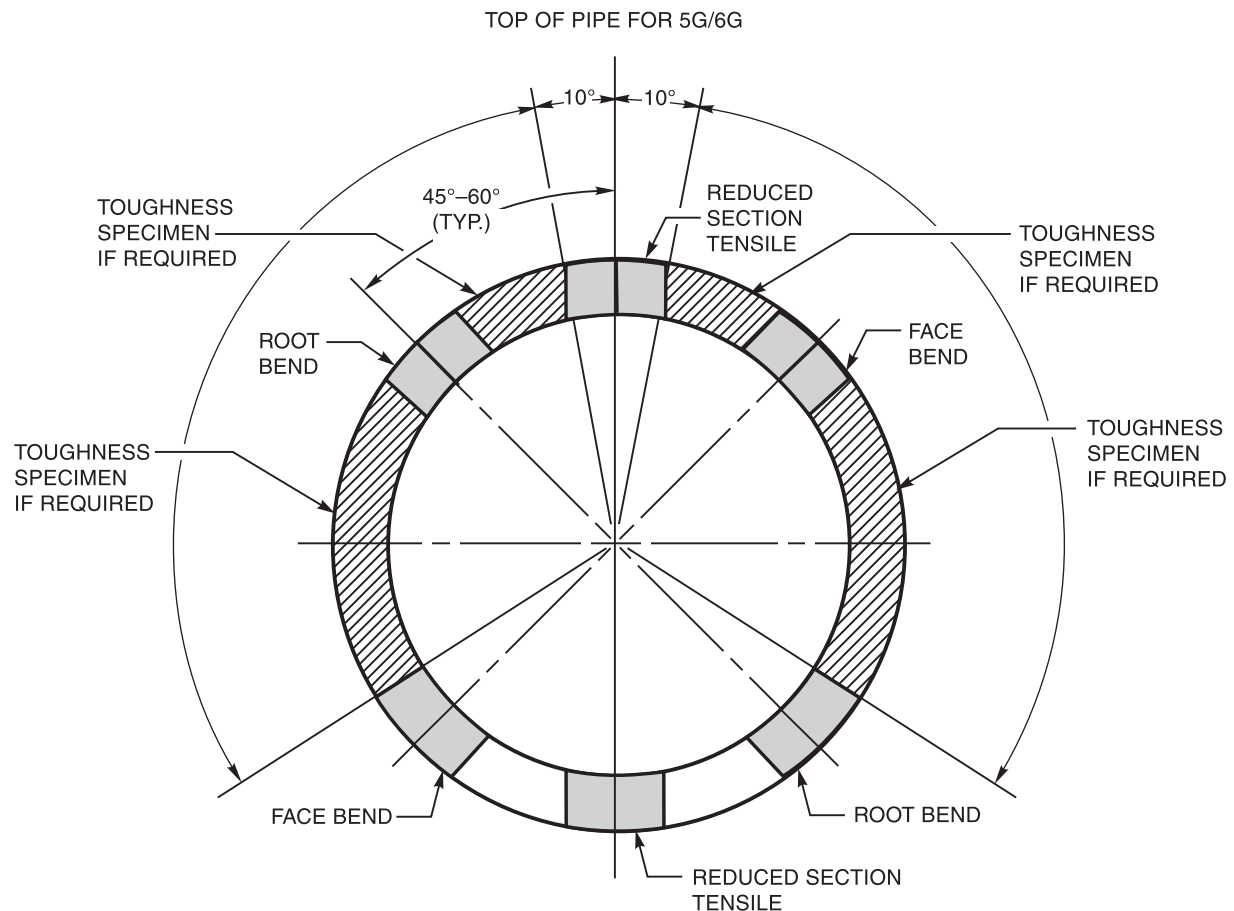
4.6 Special Test Coupon Acceptance Criteria

Special test coupons shall be examined and tested as specified by the Referencing Document. When a test in Table 4.1 is specified by the Referencing Document, the acceptance criteria shall be as required in this specification. The criteria for other tests shall be as specified in the Referencing Document.

4.7 Pipe and Plate Groove Test Coupons and Acceptance Criteria

4.7.1 Groove test coupons shall be large enough to provide the necessary test specimens. Multiple test coupons may be necessary to provide all the required test specimens. The test coupons are illustrated in Figures 4.2, 4.3, 4.4, and 4.5. The thickness of a test coupon (T) shall be determined as provided in Table 4.3.

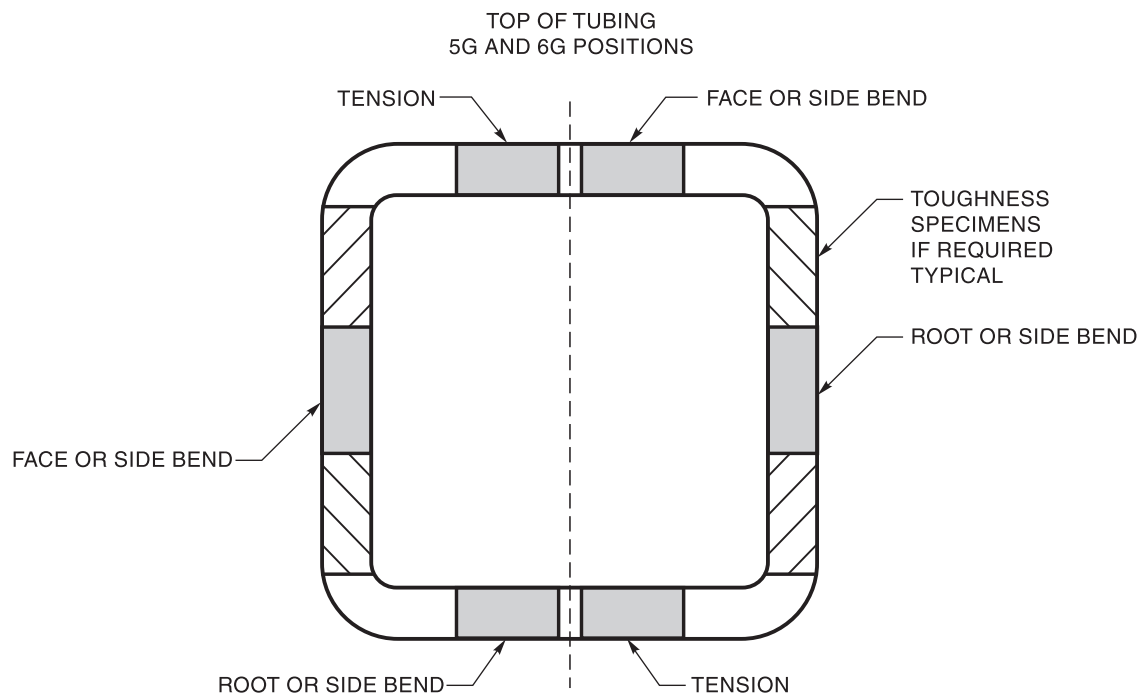
4.7.2 Test coupons for EBW and LBW shall have a joint geometry duplicating that to be used in production.



Notes:

1. Fracture toughness test specimens, when required, shall be removed from the hatched sections.
2. Side bend test specimens may be substituted for face and root bends for metal thickness from 3/8 in to 3/4 in [10 mm to 19 mm] inclusive. For metal thickness over 3/4 in [19 mm], side bends shall be used.
3. Dimensions for the test specimen blanks and details of bend tests are shown in Annex A.
4. Material thickness shall be determined from the requirements provided in Table 4.3.

Figure 4.2—Location of Groove Weld Test Specimens—Pipe (see 4.7.1, 4.7.4, and 4.7.7)



Note: Material thickness shall be determined in accordance with Table 4.3.

Figure 4.3—Location of Test Specimens for Welded Box Tubing (see 4.7.1, 4.7.4, and 4.7.7)

4.7.3 Prior to removing test specimen blanks from the completed test coupon, the weld shall be visually examined on all accessible surfaces and shall meet the following criteria:

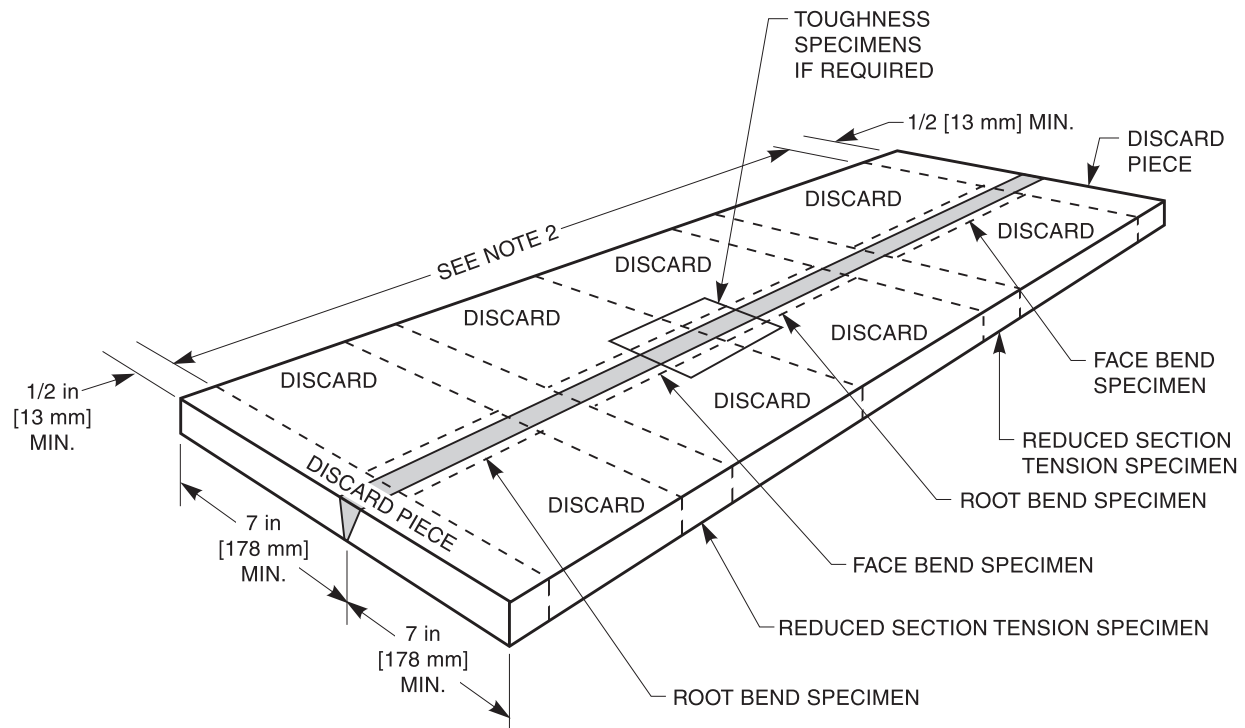
- (1) There shall be no evidence of cracks, incomplete fusion, or incomplete joint penetration.
- (2) The depth of undercut shall not exceed the lesser of 10% of the base metal thickness or 1/32 in [1 mm].
- (3) Porosity shall not exceed the limitations of the Referencing Document.

4.7.4 After visual examination, the test coupon shall be evaluated using the tests required in Table 4.1. Test specimen blanks shall be removed from the locations shown in Figures 4.2 and 4.3 for pipe and box tube, respectively, and Figure 4.4 or 4.5 for plate. The preparation and dimensions of test specimen blanks shall be as provided in Annex A of this specification.

4.7.5 Each tensile test specimen shall have a tensile strength not less than the following:

- (1) The specified minimum tensile strength of the base metal per Table C.2, or of the weaker of the two base metals if metals of different minimum tensile strength are used; or
- (2) The specified minimum tensile strength of the weld metal when the Referencing Document provides for the use of weld metal having a lower tensile strength than the base metal; or
- (3) If the test specimen breaks in the base metal outside of the weld or weld interface, the test shall be accepted, provided the strength is not more than 5% below the specified minimum tensile strength of the base metal per Table C.2; or
- (4) If the base metal has no specified minimum tensile strength then failure in the base metal shall be acceptable.

4.7.6 Bend test specimens shall be bent in one of the guided bend test fixtures shown in Annex A. For transverse test specimens, the weld metal and heat-affected zone (HAZ) shall be completely within the bent portion of the test specimen



Notes:

1. Material thickness shall be determined in accordance with Table 4.3.
2. Dimensions for the test specimen blanks and details of bend tests are shown in Annex A.
3. A longer test coupon will be required if fracture toughness test specimens are necessary. Fracture toughness specimens should be located near the midlength of the plate.
4. Make allowances for cutting.

Figure 4.4—Location of Tension, Longitudinal Bend, and Fracture Toughness Test Specimens—Plate (see 4.7.1, 4.7.4, and 4.7.7)

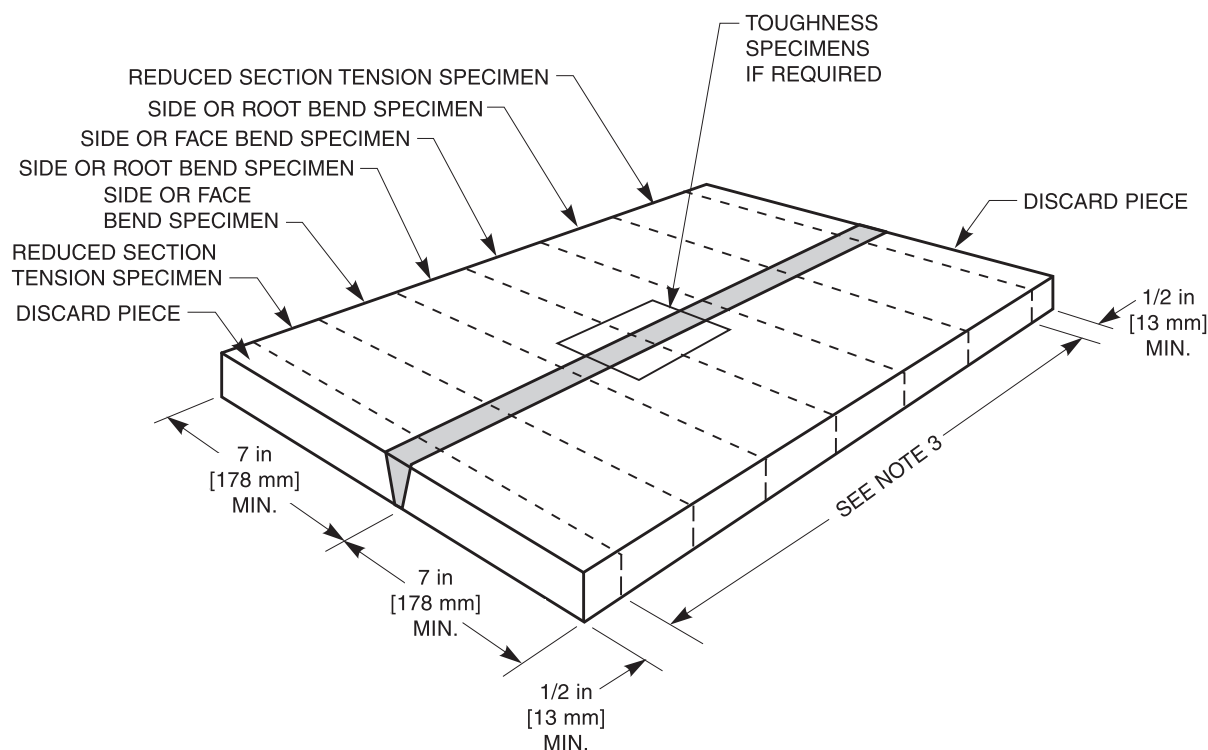
after bending. There shall be no open discontinuity exceeding 1/8 in [3 mm], measured in any direction on the convex surface of the test specimen after bending. Cracks occurring on the corners of the test specimen during bending shall not be considered, unless there is definite evidence that they result from weld discontinuities.

4.7.7 For fracture toughness testing, the type of test, number of test specimens, and acceptance criteria shall be in accordance with the Referencing Document. The procedures and apparatus shall conform to the requirements of AWS B4.0 or AWS B4.0M, *Standard Methods for Mechanical Testing of Welds*. Test specimen blanks shall be removed from test coupons in accordance with Figures 4.2, 4.3, 4.4, and 4.5, as applicable.

4.7.8 Macroetch Test Specimen. There shall be no cracks, incomplete joint penetration, or incomplete fusion in the macro cross section.

4.8 Fillet Test Coupons and Acceptance Criteria

Unless otherwise stated in the Referencing Document or this document, test coupons shall be tested in accordance with AWS B4.0, *Standard Methods for Mechanical Testing of Welds* or AWS B4.0M, *Standard Methods for Mechanical Testing of Welds (Metric Customary Units)*. Fillet welds may be qualified by fillet weld bend-break tests (see 4.8.5) or fillet weld shear tests (see 4.8.6). See Table 4.2 for thickness and size limitations.



Notes:

1. Material thickness shall be determined in accordance with Table 4.3.
2. Side bend test specimens may be substituted for face and root bend test specimens for metal thicknesses from 3/8 to 3/4 in [10 mm to 19 mm] inclusive. For metal over 3/4 in [19 mm] thick, side bend test specimens shall be used. For GMAW-S short-circuiting transfer of base metals 3/8 in [10 mm] thick and greater, side bend tests shall be used to qualify the WPS.
3. Dimensions for the specimen blanks and details of permitted bend tests are given in Annex A.
4. A longer test coupon will be required if fracture toughness test specimens are necessary. Fracture toughness specimens should be located near the midlength of the test coupon.

Figure 4.5—Location of Tension, Fracture Toughness, and Transverse Bend Test Specimens—Plate (see 4.7.1, 4.7.4, and 4.7.7)

4.8.1 Qualification of groove welds qualifies for fillet welds but not vice versa.

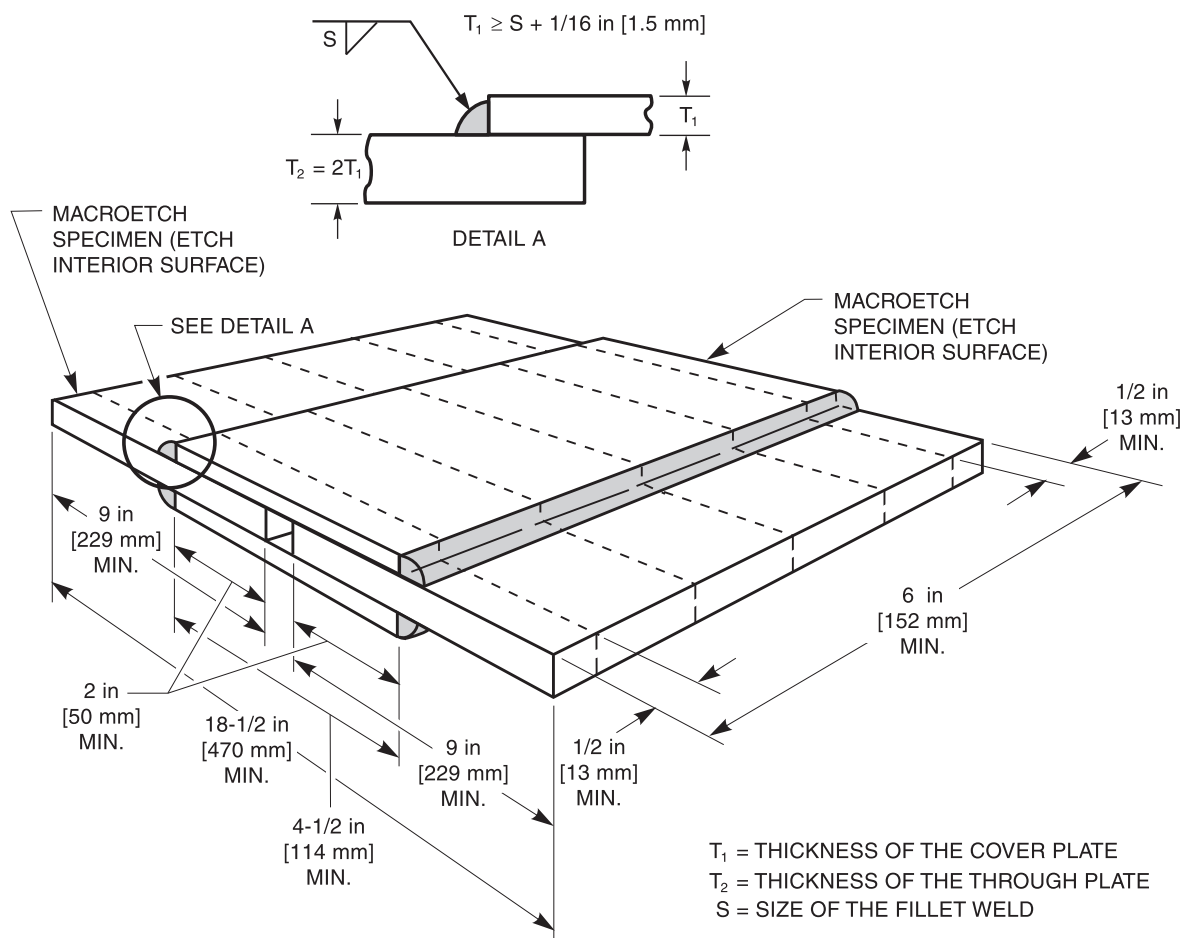
4.8.2 Fillet test coupon dimensions and test specimens are detailed in Figure 4.6 or 4.7, as appropriate.

4.8.3 Prior to removing test specimen blanks for testing, the completed test weld shall be visually examined and meet the following criteria:

- (1) There shall be no cracks or incomplete fusion.
- (2) Undercut depth shall not exceed the lesser of 10% of the base metal thickness or 1/32 in [1 mm].
- (3) Profile and porosity limitations shall be in accordance with the Referencing Document.

4.8.4 Macroetch Test Specimen. There shall be no cracks, incomplete joint penetration, or incomplete fusion in the macro cross section (see Figures 4.6 and 4.7).

4.8.5 Fillet Weld Bend-Break Test. If both single and multiple pass welds are to be qualified, one procedure qualification test coupon shall be welded with the maximum size single pass to be used, and a second shall be welded with the minimum size multiple pass to be used. The test specimens are shown in Figure 4.7. Test specimens shall be bent with the weld root in tension until the test specimen either fractures or until it is bent flat upon itself. The specimen shall be



Note: Length should be sufficient for the required number of specimens, which may be of any convenient width not less than 1 in [25 mm].

Figure 4.6—Location of Fillet Weld Shear Test and Macroetch Specimens (see 4.8.2 and 4.8.4)

accepted if it does not fracture or if the fillet fractures, the fractured surface shall exhibit no cracks or incomplete root fusion and no inclusion or porosity in the fracture surface exceeding 3/32 in [2 mm] in its greatest dimension. The sum of the greatest dimension of all inclusions and porosity shall not exceed 3/8 in [10 mm] in the specimen length.

4.8.6 Fillet Shear Test. Unless otherwise stated in the Referencing Document, the fillet shear strength shall be not less than 60% of the lower of the minimum specified tensile strength of the base metal or weld metal. If neither value is available, two specimen blanks of the base material shall be tension tested. The lowest value determined from these tests shall be the specified minimum tensile strength for qualification purposes. The minimum shear strength of aluminum fillet welds is listed in Table 4.5.

4.9 Cladding Test Coupons and Acceptance Criteria

4.9.1 The test coupon shall be welded as shown in Figure 4.8. The surface of the weld shall be prepared for liquid penetrant examination. Liquid penetrant examination shall be performed in accordance with ASTM E165, *Standard Test Method for Liquid Penetrant Examination*. The surface shall be evaluated based on the following acceptance criteria:

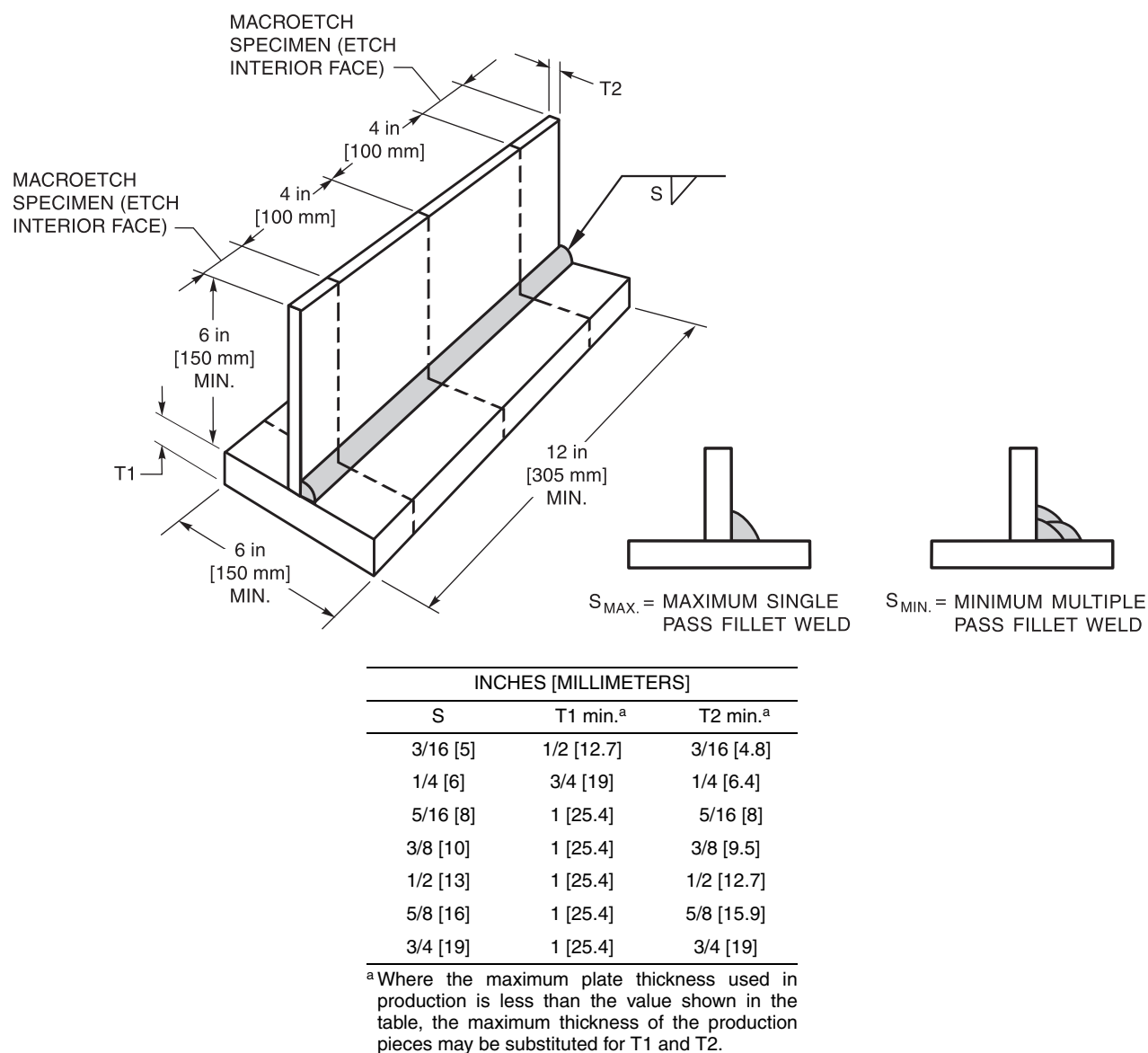


Figure 4.7—Fillet Weld Break Test and Macroetch Specimens for Procedure Qualification (see 4.8.2, 4.8.4, and 4.8.5)

**Table 4.5
Minimum Shear Strength for Aluminum Fillet Welds (see 4.12.4)**

Filler Alloy	Shear Strength	
	ksi	MPa
1100	7.5	52
2319	16.0	110
4043	15.0	103
5183	28.0	193
5356	26.0	179
5554	23.0	159
5556	30.0	207
5654	18.0	124

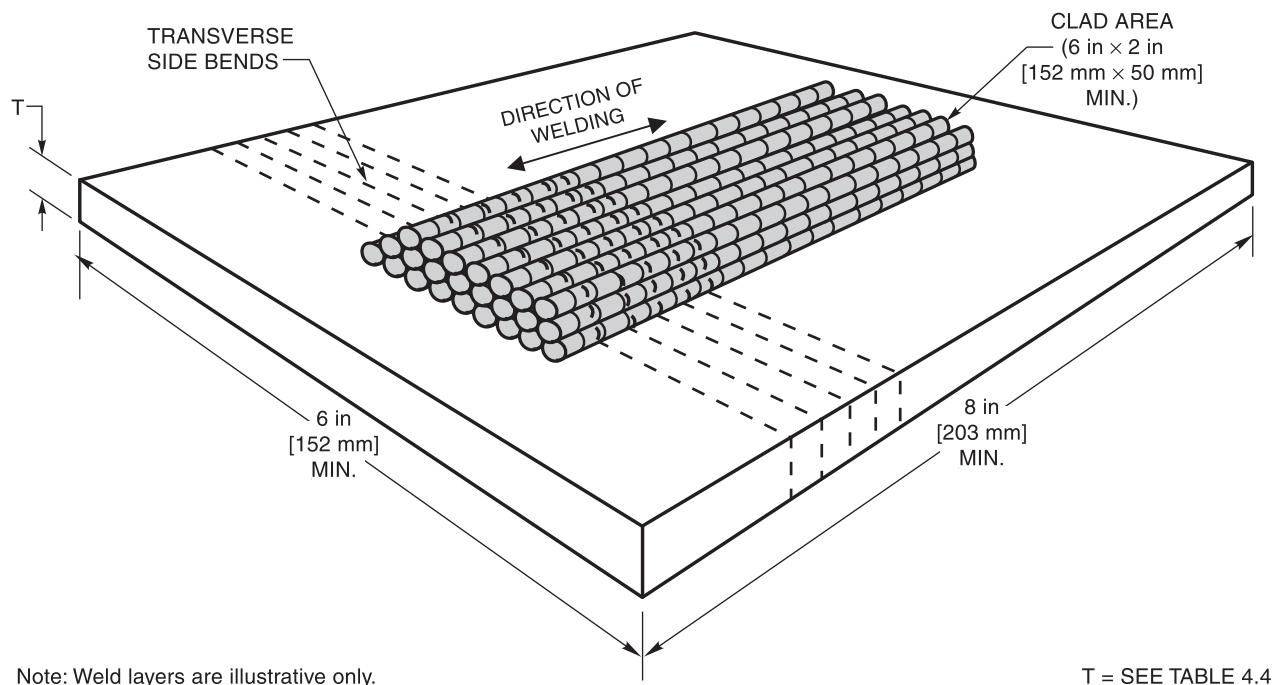


Figure 4.8—Location of Cladding Test Specimens (see 4.9.1 and 4.9.2)

- (1) There shall be no linear indications longer than 1/16 in [1.5 mm].
- (2) There shall be no more than four rounded indications in a line with dimensions greater than 1/16 in [1.5 mm] and separated from each other by less than 1/16 in [1.5 mm].

4.9.2 If the test coupon passes the liquid penetrant examination, four bend specimens shall be removed as shown in Figure 4.8.

4.9.3 Bend specimens from cladding test coupons shall be prepared in accordance with Annex A, Figure A.4A of this specification, and bent in one of the guided-bend test fixtures shown in Figures A.5A through A.5C.

4.9.4 Weld cladding bend specimens shall have no open discontinuity exceeding 1/16 in [1.5 mm] in the cladding, measured in any direction on the convex surface, and no open defects exceeding 1/8 in [3 mm] in length at the weld interface after bending.

4.9.5 A chemical analysis sample shall be removed as shown in Figure A.4B, and the results from the chemical analysis specimen shall meet the requirements of the Referencing Document.

4.10 Hardfacing Test Coupons and Acceptance Criteria

4.10.1 The test coupon shall be welded as shown in Figure 4.9. The hardfaced surface shall be prepared for hardness testing at the minimum weld metal thickness to be qualified. Hardness testing shall be performed at three locations, and the result of each test shall not be less than the minimum hardness specified in the Referencing Document.

4.10.2 If macroetch is required by the Referencing Document, the test coupon shall then be sectioned as shown in Figure 4.9. Both exposed faces shall then be polished and etched to provide a clear definition of the weld metal and the HAZ in accordance with Annex G of this specification. Examination results from both faces shall meet the acceptance criteria of the Referencing Document.

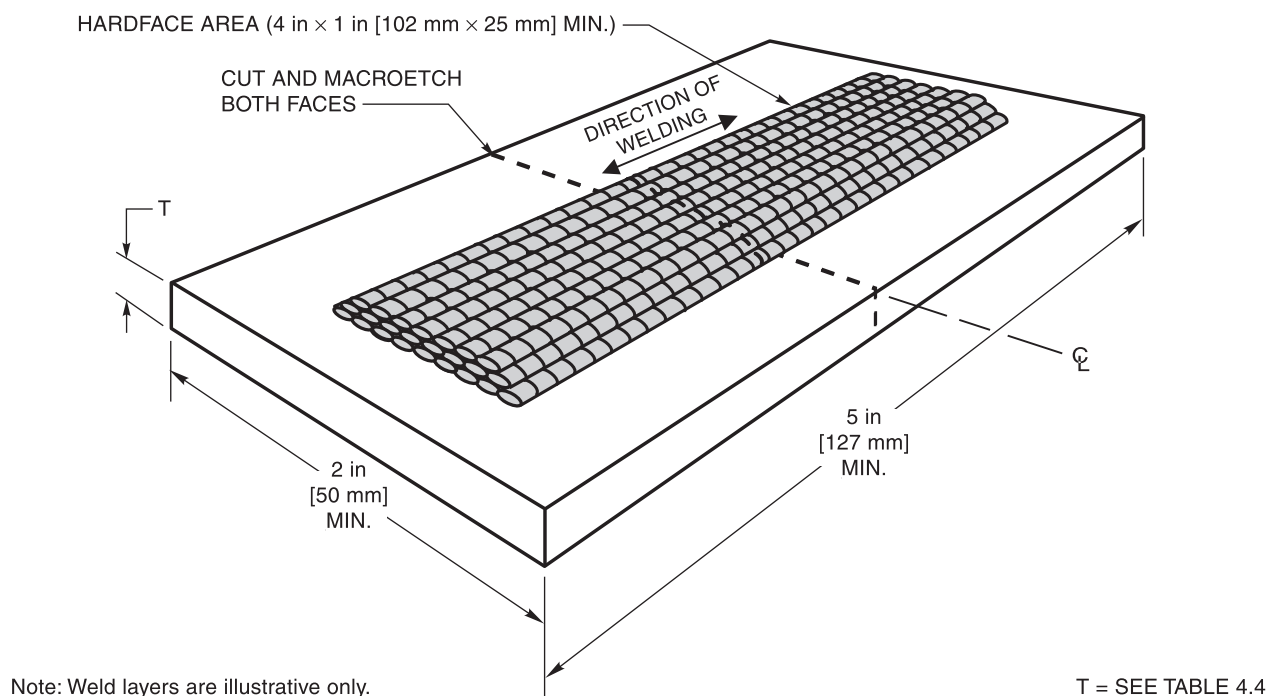


Figure 4.9—Location of Hardfacing Test Specimens (see 4.10.1 and 4.10.2)

4.10.3 If specified by the Referencing Document, a sample for chemical analysis shall be obtained from one macroetch specimen as shown in Annex A, Figure A.4B.

4.11 Stud Welds and Acceptance Criteria

4.11.1 For studs welded to M-1 materials, ten welds are required to qualify each procedure. The following tests shall be applied to these welds:

- (1) Five bend specimens, and
- (2) Five tensile load specimens (or torque specimens).

4.11.2 For studs welded to other than M-1 materials, fifteen welds are required to qualify each procedure. The required tests are the same as provided in 4.11.1 for M-1 materials, except that five macroetch specimens are required in addition to the bend and tension specimens. Macroetch specimens shall consist of a cross section through the weld on the stud centerline. Specimens shall be polished and etched to provide a clear definition of the weld metal and HAZ in accordance with Annex G. There shall be no visible cracks on any of the five specimens.

4.11.3 Bend Tests. Studs shall be bent a minimum of 15° using a fixture similar to that shown in Annex A, Figure A.5D. Alternatively the studs shall be bent a minimum of 15° by hammer blows. Each of five welded studs shall be free of visible separation or fracture after bending.

4.11.4 Tensile Load Tests. Five stud welds shall be tested in a fixture similar to that shown in Annex A, Figure A.5F. Failure load shall be based on the minor diameter of the threaded section of externally threaded studs, except where the shank diameter is less than the minor diameter, or on the original cross-sectional area where failure occurs in a non-threaded, internally threaded, or reduced diameter stud. Each stud weld shall meet the strength requirements shown below, except a stud weld that breaks in the base metal outside of the weld or weld interface shall be acceptable.

Table 4.6
Minimum Tensile Load Requirements for Aluminum Stud Welds (see 4.11.4)

Stud Size	Stud Alloy	M-Number	Load	
			lb	N
6-32	1100	21	175	800
	5356	25	335	1500
8-32	1100	21	265	1200
	5356	25	550	2400
10-24	1100	21	340	1500
	5356	25	700	3100
10-32	1100	21	390	1700
	2319	24	1050	4700
1/4-20	1100	21	600	2700
	2319	24	1550	6900
	5356	25	1300	5800
	6061	23	1475	6600
5/16-18	1100	21	1075	4800
	5356	25	2200	9800
3/8-16	1100	21	1540	6900
	2319	24	3350	14 900
	5356	25	3175	14 100
7/16-14	5356	25	4300	19 100
1/2-13	5356	25	5800	25 800

(1) *Ferrous metals*. The failure strength shall be 35 000 psi [241 MPa], minimum.

(2) *Aluminum*. The failure load shall not be less than the values in Table 4.6.

(3) *Nonferrous metals*. Other than aluminum, the failure strength shall not be less than 1/2 of the minimum specified tensile strength of the stud.

4.11.5 Alternate Torque Test. Each of the five stud welds, in the unlubricated condition, shall resist the applicable torque shown in Table 4.7 for steel and Table 4.8 for aluminum before failure occurs. A test fixture similar to that shown in Annex A, Figure A.5E shall be used.

4.12 Test Coupons Less than 1/16 in [1.5 mm] Acceptance Criteria

4.12.1 The test coupon(s) shall be selected, depending upon the application, from those detailed in Figure 4.4 or 4.5. The required tests shall be in accordance with Table 4.1.

4.12.2 Completed groove test coupon(s) shall be visually examined and shall meet the following acceptance criteria:

(1) No incomplete joint penetration or incomplete fusion.

(2) Not more than one visible pore or inclusion exceeding 0.25 of the base metal thickness, shall be permitted in any 1 in [25 mm] of weld.

Table 4.7
Minimum Torque Requirements for Steel Stud Welds (see 4.11.5)

Nominal Diameter		Thread	Torque	
in	mm		lb·ft	N·m
1/4	6	28 UNF	5	7
1/4	6	20 UNC	4	5
5/16	8	24 UNF	9	12
5/16	8	18 UNC	8	11
3/8	10	24 UNF	17	23
3/8	10	16 UNC	15	20
7/16	11	20 UNF	27	37
7/16	11	14 UNC	24	33
1/2	12	20 UNF	42	57
1/2	12	13 UNC	37	50
9/16	14	18 UNF	60	81
9/16	14	12 UNC	54	73
5/8	16	18 UNF	84	114
5/8	16	11 UNC	74	100
3/4	20	16 UNF	147	199
3/4	20	10 UNC	132	179
7/8	22	14 UNF	234	317
7/8	22	9 UNC	212	287
1	24	12 UNF	348	472
1	24	8 UNC	318	431

Table 4.8
Minimum Torque Requirements for Aluminum Stud Welds (see 4.11.5)

Stud Size	Stud Alloy	M-No.	Torque	
			lb·in	N·m
6-32	1100	21	2.5	0.3
	5356	25	3.5	0.4
8-32	1100	21	5.0	0.6
	5356	25	7.5	0.8
10-24	1100	21	6.5	0.7
	5356	25	10.0	1.1
1/4-20	1100	21	21.5	2.4
	2319	24	60.0	6.8
	5356	25	32.5	3.7
	6061	23	55.0	6.2
5/16-18	1100	21	36.0	4.1
	5356	25	54.5	6.2
3/8-16	1100	21	53.0	6.0
	2319	24	135.0	15.3
	5356	25	81.0	9.2
7/16-14	5356	25	140.0	15.8

(3) Visible pores shall not extend through the weld thickness.

(4) The weld reinforcement shall not exceed 1/8 in [3 mm].

(5) Undercut shall not exceed 0.15 times the thickness of the test coupon base metal. After visual examination, the test coupon(s) shall be subjected to the same tests required for groove welds in Table 4.1 and shall meet the following requirements for acceptance:

4.12.2.1 Tension test(s) shall demonstrate that the welded joint meets the minimum specified tensile strength of the base metal.

4.12.2.2 Bend tests may be conducted in a test fixture similar to Annex A, Figure(s) A.5A, A.5B, or A.5C, and shall be acceptable if there are no cracks evident in the base metal or weld metal exceeding 1/16 in [1.5 mm] after bending. Alternatively, bend test(s) may consist of bending the specimen blank back upon itself, with the axis of the bend being parallel to the axis of the weld. Fractures or cracks resulting from bending shall show no evidence of weld related defects.

4.12.3 Completed fillet test coupon(s) shall be visually examined, and except for the first and last 1/2 in [13 mm] of weld shall meet the following acceptance criteria:

(1) The macro section specimens shall show complete fusion at the root and be free of cracks.

(2) Undercut shall not exceed 0.15 times the thickness of test coupon(s).

(3) Not more than one visible pore or inclusion exceeding 0.25 of the base metal thickness, shall be permitted in any 1 in [25 mm] of weld.

(4) The weld shall be free of overlap or cracks.

4.12.4 After visual examination, the fillet test coupon shall be subjected to the tests required for fillet welds in Table 4.1 and shall meet the following requirements:

(1) The macro section specimens shall show complete fusion at the root and be free of cracks.

(2) If not stated in the Referencing Document, the shear test shall demonstrate a shear strength not less than 60% of the lower of the minimum specified base metal tensile strength or of the minimum specified weld metal tensile strength. The shear strength of aluminum welds is listed in Table 4.5.

4.13 Welding Procedure Specification Data

The following matrix indicates the welding data to be included in a WPS for each welding process. A WPS may be presented in any format, written or tabular, provided the data required in this matrix are included (see 4.1.4). The WPS may list variables recorded on the PQR within the full range permitted for a qualification variable and practical limits determined by the Employer for other than qualification variables.

	E B W	E G W	E S W	F C A W	F S W	G M A W	G T A W	L B W	O F W	P A W	S A W	S M A W	S W
4.13.1 Joint Design													
(1) Joint type and dimensions.	X	X	X	X	X	X	X	X	X	X	X	X	
(2) Treatment of backside, method of gouging/preparation.	X	X	X	X		X	X	X	X	X	X	X	
(3) Backing material, if used.	X	X	X	X	X	X	X	X	X	X	X	X	
(4) Size, shape, ferrule/flux type.													X
4.13.2 Base Metal													
(1) M-Number and Group Number.	X	X	X	X	X	X	X	X	X	X	X	X	X
(2) Thickness range qualified.	X	X	X	X	X	X	X	X	X	X	X	X	X
(3) Diameter (tubular only).	X	X	X	X		X	X	X	X	X	X	X	X
(4) The coating description or type, if present.	X	X	X	X		X	X	X	X	X	X	X	X
4.13.3 Filler Metal													
(1) Specification, classification, F- and A-Number, or if not classified the nominal composition.	X	X	X	X	X	X	X	X	X	X	X	X	
(2) Weld metal thickness by process and filler metal classification.				X		X	X		X	X	X	X	
(3) Filler metal size or diameter.	X	X	X	X	X	X	X	X	X	X	X	X	
(4) Flux-electrode classification.			X								X		
(5) Penetration enhancing flux.							X						
(6) Supplemental filler metal.	X	X	X	X		X	X	X	X	X	X		
(7) Consumable insert and type.							X			X			
(8) Consumable guide.		X	X										
(9) Supplemental deoxidant.	X							X					
(10) Energized filler metal "hot."							X			X			
(11) <u>Preplaced filler metal.</u>					X								
4.13.4 Position													
(1) Welding position(s).	X	X	X	X		X	X	X	X	X	X	X	X
(2) Progression for vertical welding.	X			X		X	X	X	X	X	X	X	
4.13.5 Preheat and Interpass													
(1) Preheat minimum.	X			X		X	X	X		X	X	X	X
(2) Interpass temperature maximum (if applicable).	X			X		X	X	X		X	X	X	
(3) Preheat maintenance.	X			X		X	X	X		X	X	X	

4.13.6 Heat Treatment

- (1) PWHT temperature and time.

4.13.7 Shielding Gas

- (1) Torch shielding gas and flow rate range.

- (2) Root shielding gas and flow rate range.

- (3) Environmental shielding and vacuum pressure.

- (4)
- Trailing shielding gas and flow rate range.

- (5)
- Tool shielding gas and flow rate range.

4.13.8 Electrical

- (1) Current (or wire feed speed), current type, and polarity.

- (2) Voltage range (except for manual welding).

- (3) Beam focus current pulse frequency range, and filament type, shape and size.

- (4) Specification, classification, and diameter of tungsten electrode.

- (5) Transfer mode.

- (6) A change to or from pulsed current.

4.13.9 Variables (see 4.14.9)

- (1) Welding process and whether manual, semiautomatic, mechanized, or automatic.

- (2) For mechanized or automatic, single or multiple electrode and spacing.

- (3) Single or multipass.

- (4) Contact tube to work distance.

- (5) Cleaning.

- (6) Peening.

- (7) Conventional or keyhole technique.

- (8) Stud gun model and lift.

- (9) Standoff distance for mechanized and automatic welding.

- (10) Backing shoe type.

- (11) Stringer or weave bead.

- (12) Travel-speed range for mechanized or automatic welding and manual applications requiring heat input calculations.

- (13) Fuel gas and flame type (oxidizing, neutral, or reducing).

- (14)
- Joint restraint fixture.

	E B W	E G W	E S W	F C A W	F S W	G M A W	G T A W	L B W	O F W	P A W	S A W	S M A W	S W
(1) PWHT temperature and time.	X	X	X	X	<u>X</u>	X	X	X	X	X	X	X	X
(1) Torch shielding gas and flow rate range.		X		X		X	X	X		X			X
(2) Root shielding gas and flow rate range.							X			X			
(3) Environmental shielding and vacuum pressure.	X							X					
(4) <u>Trailing shielding gas and flow rate range.</u>					<u>X</u>								
(5) <u>Tool shielding gas and flow rate range.</u>					<u>X</u>								
(1) Current (or wire feed speed), current type, and polarity.	X	X	X	X		X	X			X	X	X	X
(2) Voltage range (except for manual welding).	X	X	X	X		X	X			X	X		
(3) Beam focus current pulse frequency range, and filament type, shape and size.	X												
(4) Specification, classification, and diameter of tungsten electrode.							X			X			
(5) Transfer mode.				X		X							
(6) A change to or from pulsed current.				X		X	X			X		X	
(1) Welding process and whether manual, semiautomatic, mechanized, or automatic.	X	X	X	X	<u>X</u>	X	X	X	X	X	X	X	X
(2) For mechanized or automatic, single or multiple electrode and spacing.	X	X	X	X		X	X			X	X		
(3) Single or multipass.	X	X	X	X		X	X	X	X	X	X	X	
(4) Contact tube to work distance.		X	X	X		X					X		
(5) Cleaning.	X	X	X	X		X	X	X		X	X	X	X
(6) Peening.		X	X	X		X	X			X	X	X	
(7) Conventional or keyhole technique.	X							X		X			
(8) Stud gun model and lift.													X
(9) Standoff distance for mechanized and automatic welding.	X							X		X			
(10) Backing shoe type.	<u>X</u>	X	X										
(11) Stringer or weave bead.				X		X	X			X	X	X	
(12) Travel-speed range for mechanized or automatic welding and manual applications requiring heat input calculations.	X	X	X	X		X	X	X		X	X		
(13) Fuel gas and flame type (oxidizing, neutral, or reducing).	<u>X</u>							<u>X</u>	X				
(14) <u>Joint restraint fixture.</u>					<u>X</u>								

	E B W	E G W	E S W	F C A W	F S W	G M A W	G T A W	L B W	O F W	P A W	S A W	S M A W	S W
4.13.9 Variables (Cont'd)													
(15) <u>Control method for plunge and travel direction.</u>					X								
(16) <u>Rotating tool type and design, configuration and dimension limits.</u>					X								
(17) <u>Pin material specification, chemical composition and minimum hardness.</u>					X								
(18) <u>Rotating tool operation limits.</u>					X								

4.14 Procedure Qualification Variables

This matrix lists the procedure qualification variables to be recorded on the PQR for each welding process. A change in a procedure qualification variable beyond the limits shown in 4.14 shall require a new or revised WPS and a new PQR (see 4.1.8). The PQR shall list the actual values of the variables used. The key to the entries in the body of the table is as follows:

Q— Qualification variable for all applications

T— Qualification variable for all fracture toughness applications

C— Qualification variable for weld cladding applications

H— Qualification variable for hardfacing applications

	E B W	E G W	E S W	F C A W	F S W	G M A W	G T A W	L B W	O F W	P A W	S A W	S M A W	S W
4.14.1 Joint Design													
(1) A change in groove type (V-groove, U-groove, single bevel, etc.).	Q							Q					
(2) A change from a fillet to a groove weld.	Q	Q	Q	Q		Q	Q	Q	Q	Q	Q	Q	
(3) A change in the M-Number of backing.	Q	Q	Q	Q		Q	Q	Q	Q	Q	Q	Q	
(4) The addition of thermal backgouging on M-11, M-23, M-24, M-26, or M-27 heat-treatable base metal.	Q	Q	Q	Q		Q	Q	Q	Q	Q	Q	Q	
(5) The addition or deletion of nonmetallic retainers or nonfusing metal retainers.		Q	Q										
(6) The addition or deletion of backing or backing shoes.		Q	Q										
(7) An increase in fitup gap beyond that used in the qualification test.	Q							Q					
(8) <u>A change in material of fixed backing anvils (when used). A change in backing anvil design that affects the weld cooling rate (e.g., a change from air-cooled to water-cooled, and vice versa). This variable is not applicable to tube-to-tube sheet or double-sided welds with overlapping fusion zones, or welds completed using self-reacting pins.</u>					Q								

	E B W	E G W	E S W	F C A W	F S W	G M A W	G T A W	L B W	O F W	P A W	S A W	S M A W	S W
4.14.1 Joint Design (Cont'd)													
(9) A change in joint design, including edge preparation geometry (e.g., a change from square butt edge to beveled edge), reductions in the smallest joint path radius to less than the shoulder radius, or joint paths crossing themselves or another HAZ.					Q								
(10) A change in joint spacing greater than $\pm 10\%$ of the qualification test coupon thickness. For WPSs qualified using intimate edge contact, the maximum allowable joint spacing is 1/16 in [1.5 mm].					Q								
4.14.2 Base Metal													
(1) A change in base metal thickness beyond the range permitted in 4.5.	Q	Q	Q	Q		Q	Q	Q	Q	Q	Q	Q	
(2) A change from one M-Number base metal to another M-Number base metal or to a combination of M-Number base metals, except as permitted in 4.3.13.	Q	Q	Q	Q		Q	Q	Q	Q	Q	Q	Q	Q
(3) A change from one unlisted base metal to a different unlisted base metal or to a listed base metal or vice versa.	Q	Q	Q	Q		Q	Q	Q	Q	Q	Q	Q	Q
(4) A change from one M-Number Group Number to any other M-Number Group Number, except as permitted in 4.3.14.	Q	T	T	T		T	T	Q		T	T	T	
(5) A change from one M-5 group (A, B, etc.) to any other. A change from M-9A to M-9B, but not vice versa. A change from one M-10 or M-11 group (A, B, etc.) to any other group.	Q	Q	Q	Q		Q	Q	Q	Q	Q	Q	Q	
(6) A change from an uncoated metal to a coated (such as painted or galvanized) metal unless the coating is removed from the weld area prior to welding, but not vice versa, except as permitted in 4.3.8.	Q	Q	Q	Q		Q	Q	Q	Q	Q	Q	Q	Q
(7) A change to another base metal type or grade (type or grade are materials of the same nominal chemical analysis and mechanical property range, even though of different product form), or to any other base metal type or grade. When joints are made between two different types or grades of base metal, a procedure qualification must be made for the applicable combinations of materials, even though procedure qualification tests have been made for each of the two base metals welded to itself.					Q								

	E B W	E G W	E S W	F C A W	F S W	G M A W	G T A W	L B W	O F W	P A W	S A W	S M A W	S W
4.14.2 Base Metal (Cont'd)													
(8) <u>A change in base metal thickness greater than 20%</u>					Q								
(a) <u>of the test coupon thickness for fixed-pin and retracting-pin rotating tools</u>													
(b) <u>beyond the minimum and maximum thickness or thickness transition slopes of the test coupon for self-retracting rotating tools.</u>													
4.14.3 Filler Metals													
(1) A change from one F-Number to any other F-Number or to any filler metal not listed in Annex B.	Q	Q	Q	Q		Q	Q	Q	Q	Q	Q	Q	
(2) For ferrous materials, a change from one A-Number to any other A-Number or to a filler metal analysis not listed in Annex B (the PQR and WPS shall state the nominal chemical composition, the AWS specification and classification, or the manufacturer's designation for filler metals which do not fall in an A-Number group). Qualification with A-1 shall qualify for A-2 and vice versa.	Q	Q	Q	Q		Q	Q	Q	Q	Q	Q	Q	
(3) For surfacing, a change in the chemical composition of the weld metal (A-Number or alloy type). Each layer shall be considered independent of other layers.			C, H	C, H		C, H	C, H		C, H	C, H	C, H	C, H	
(4) A change in AWS filler metal specification and classification.	T	T	T	T		T	T	Q	Q	T	T	T	
(5) A change in filler metal tensile strength exceeding 10 000 psi [69 MPa], or a change in filler metal classified to a strength lower than the specified minimum tensile strength designator of the base metal.	Q	Q	Q	Q		Q	Q		Q	Q	Q	Q	
(6) If the weld metal alloy content is largely dependent upon the composition of the flux, any change in the welding procedure which would result in the important weld metal alloying elements being outside the specified chemical composition range of the WPS.			Q								Q		
(7) A change in the cross-sectional area of filler metal added (excluding buttering) of $\pm 10\%$.	Q							Q					
(8) The addition or deletion of filler material.	Q				Q		Q	Q		Q			
(9) A decrease in thickness or a change in the nominal chemical composition of surfacing or buttering beyond that qualified.	C, H		C, H	C, H		C, H	C, H	C, H	C, H	C, H	C, H	C, H	

	E B W	E G W	E S W	F C A W	F S W	G M A W	G T A W	L B W	O F W	P A W	S A W	S M A W	S W
4.14.3 Filler Metals (Cont'd)													
(10) A change of filler metal/electrode nominal size/shape in the first layer.				C, H		C, H					C, H	C, H	
(11) Addition or deletion of supplementary filler metal (powder or wire), or a change of 10% in the amount.	T	T	T	T		Q	T	Q	Q	Q	Q	T	
(12) A change from single to multiple supplementary filler metal or vice versa.				C, H		C, H	C, H		C, H	C, H	C, H		
(13) A change from consumable guide to nonconsumable guide, and vice versa.			Q										
(14) Addition or deletion, or a change in the nominal amount or composition of supplementary metal (in addition to filler metal) beyond that qualified.		Q				Q					Q		
(15) A change from wire to strip electrodes and vice versa.			Q								Q		
(16) A change from one AWS flux-electrode classification listed to any other electrode-flux-electrode classification, or to an unlisted electrode-flux classification. A variation of 0.5% of the molybdenum content of the weld metal does not require requalification.			Q								Q		
(17) A change in the weld metal thickness beyond that permitted in 4.5.	Q	Q	Q	Q		Q	Q	Q	Q	Q	Q	Q	
(18) The addition or deletion, or a change in the nominal amount or composition of supplementary deoxidation material beyond that qualified.	Q							Q					
(19) <u>An increase in the thickness or width of preplaced filler metal.</u>					Q								
(20) <u>A change to another type or grade of preplaced filler metal (type or grade are materials of the same nominal chemical analysis and mechanical property range, even though of different product form).</u>					Q								
4.14.4 Position													
(1) The addition of a welding position, except that positions other than flat also qualify for flat.				C, H		C, H	C, H		C, H	C, H	C, H	C, H	Q
4.14.5 Preheat and Interpass Temperature													
(1) A decrease in preheat of more than 100°F [56°C] from that qualified.	Q			Q		Q	Q	Q		Q	Q	Q	Q
(2) An increase of more than 100°F [56°C] in the maximum interpass temperature from that recorded on the PQR.				T		T	T			T	T	T	

	E B W	E G W	E S W	F C A W	F S W	G M A W	G T A W	L B W	O F W	P A W	S A W	S M A W	S W
4.14.5 Preheat and Interpass Temperature (Cont'd)													
(3) For M-23, M-24, M-26, and M-27 heat-treatable materials an increase in the preheat or interpass temperature of more than 100°F [56°C] from that qualified.						Q	Q			Q		Q	
4.14.6 Postweld Heat Treatment													
(1) For the following M-Numbers 1, 3, 4, 5, 6, 7, 9, 10, 11, and 12, a change from any one condition to any other requires requalification:	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q
(a) No PWHT.													
(b) PWHT below the lower transformation temperature.													
(c) PWHT within the transformation temperature range.													
(d) PWHT above the upper transformation temperature.													
(e) PWHT above the upper transformation temperature, followed by treatment below the lower transformation temperature.													
(2) For all materials not covered above, a separate PQR is required for no PWHT and PWHT.	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q
(3) The qualification test <u>coupon</u> shall be subjected to heat treatment essentially equivalent to that of the production <u>coupon</u> , including at least 80% of the aggregate time at temperature.	T	T	T	T		T	T		T	T	T	T	
4.14.7 Shielding Gas													
(1) Addition or deletion of torch shielding gas.		Q		Q		Q	Q	Q		Q			Q
(2) A change in the specified nominal composition of shielding gas.		Q		Q		Q	Q	Q		Q			Q
(3) A change of shielding environment from vacuum to an inert gas or vice versa.	Q							Q					
(4) An increase in vacuum pressure.	Q												
(5) A change in shielding, as a result of a change in ferrule or flux type.													Q
(6) For M-51, M-52, M-61, and M-10I base metal, a change in the nominal composition or a decrease of 15% in the root shielding flow rate.						Q	Q			Q			
(7) For M-21 through M-27, an increase of 50% or more, or a decrease of 20% or more in the shielding gas flow rate used for qualification.						Q	Q			Q			

	E B W	E G W	E S W	F C A W	F S W	G M A W	G T A W	L B W	O F W	P A W	S A W	S M A W	S W
4.14.7 Shielding Gas (Cont'd)													
(8) The addition, deletion, or a change in composition, or a decrease exceeding 15% in the flow rate of root shielding gas on single-sided M-4X groove joints and for all welds in M-51 through M-54, M-61 and M-62, M-10I, M-10J, and M-10K.						Q	Q			Q			
(9) For M-10I, M-51 through M-54, and M-61 and M-62, the deletion of, or a change in composition of, or a decrease exceeding 10% in the trailing gas flow rate.						Q	Q	Q		Q			
(10) The addition, deletion, a 5% flow rate change for any gas used in the process, or a change in the orientation of the plasma-removing gas jet relative to the workpiece (e.g., coaxial transverse to beam).								Q					
(11) <u>For friction stir welding of M-6, M-7, M-8, M-10H, M-10I, M-41 through M-47, M-51 through M-53, and M-61 through M-62, the addition or deletion of trailing or tool shielding gas, or a change in gas composition or flow rate.</u>					Q								
4.14.8 Electrical Characteristics													
(1) An increase in heat input, or an increase in volume of weld metal deposited per unit length of weld, over that qualified. The increase shall be determined by (a), (b), or (c) for nonwaveform controlled welding, or by (b) or (c) for waveform controlled welding.	T	T	T	T		T	T	T		T	T	T	
(a) Heat input (J/in [J/mm])													
$= \frac{\text{Voltage} \times \text{Amperage} \times 60}{\text{Travel Speed (in/min [mm/min])}}$													
(b) Volume of weld metal measured by													
(i) an increase in bead size (width × thickness), or													
(ii) a decrease in length of weld bead per unit length of electrode.													
(c) Heat input determined using instantaneous energy or power by													
(i) for instantaneous energy measurements in joules (J)													
Heat input (J/in [J/mm])													
$= \frac{\text{Energy (J)}}{\text{Weld Bead Length (in [mm])}}$													
(ii) for instantaneous power measurements in joules per second (J/s) or Watts (W)													

4.14.8 Electrical Characteristics (Cont'd)

Heat input (J/in [J/mm])

$$= \frac{\text{Power (J/s or W)} \times \text{arc time (s)}}{\text{Weld Bead Length (in [mm])}}$$

The requirement for measuring the heat input or volume of deposited weld metal does not apply when the WPS is qualified with a PWHT above the upper transformation temperature or when an austenitic or M-No. 10H material is solution annealed after welding.

	E B W	E G W	E S W	F C A W	F S W	G M A W	G T A W	L B W	O F W	P A W	S A W	S M A W	S W
(2) A change exceeding $\pm 2\%$ in the voltage from that qualified.	Q												
(3) A change exceeding $\pm 5\%$ in the beam or beam focus current from that qualified.	Q												
(4) A change in the beam pulsing frequency or duration from that qualified.	Q												
(5) A change in filament type, size, or shape.	Q												
(6) A change in the type of power source, or a change in the arc timing exceeding 1/10 second, or a change in amperage exceeding $\pm 10\%$ from that qualified.													Q
(7) A change in the mode of metal transfer from short circuiting to globular, spray, or pulsed and vice versa.						Q							

4.14.9 Other Variables

(1) A change in welding process.	Q	Q	Q	Q		Q	Q	Q	Q	Q	Q	Q	Q
(2) A change in the number of electrodes in the same weld pool.		Q	Q	T		T	T			T	T		
(3) A change from multipass per side to single pass per side.	Q			T		T	T	Q		T	T	T	
(4) A change from the conventional welding to keyhole welding, or vice versa, or, the inclusion of both techniques unless each has been individually qualified.										T			
(5) A change in the stud gun model, or a change exceeding 1/32 in [1 mm] in the nominal lift.													Q
(6) A change exceeding $\pm 5\%$ in gun-to-workpiece distance, or axis of beam angle related to work.	Q												
(7) A change exceeding $\pm 20\%$ in oscillation length or width from that qualified, or the addition of a cosmetic wash pass.	Q												
(8) A change in design or material of backing shoes.	Q	Q	Q										
(9) A change exceeding $\pm 20\%$ in the oscillation variables for mechanized or automatic welding.				T		T	T			T	T		

	E B W	E G W	E S W	F C A W	F S W	G M A W	G T A W	L B W	O F W	P A W	S A W	S M A W	S W
4.14.9 Other Variables (Cont'd)													
(10) A change exceeding $\pm 10\%$ in travel speed for mechanized or automatic welding.				C, H		C, H	C, H			C, H	C, H		
(11) A change from stringer bead to weave bead for manual welding.				C, H		C, H	C, H			C, H	C, H	C, H	
(12) A change from a stringer to a weave bead, but not vice versa, for M-23, M-24, M-26, and M-27 heat-treatable materials.						Q	Q			Q			
(13) A change from a stringer bead to a weave bead in vertical uphill welding.				T		T	T			T		T	
(14) A change in the nominal size or shape of the stud at the section to be welded.													Q
(15) A change in the type of fuel or type of flame.									Q				
(16) <u>A change in joint restraint fixtures (e.g., fixed anvil to self-reacting, and vice versa) or from single-sided to two-sided welding, and vice versa.</u>					Q								
(17) <u>A change in the welding control method (e.g., force control method to position control method, or vice versa, in the plunge direction; and force control method to travel control method, or vice versa, in the travel direction).</u>					Q								
(18) <u>A change in the rotating tool (see Figure 4.10).</u>					Q								
(a) <u>type or design "family" to another (e.g., threaded pin, smooth pin, fluted, self-reacting, retracting-pin, or other tool types)</u>													
(b) <u>configuration or dimensions beyond the following limits (as applicable):</u>													
(i) <u>shoulder diameter greater than 10%</u>													
(ii) <u>shoulder scroll pitch greater than 10%</u>													
(iii) <u>shoulder profile (e.g., addition or deletion of shoulder feature)</u>													
(iv) <u>pin diameter greater than 5%</u>													
(v) <u>pin length greater than the lesser of 5% of qualified pin length or 1% of base metal thickness (not minimum pin length for retracting-pin tools, and not applicable for self-reacting rotating tools)</u>													
(vi) <u>pin taper angle greater than 5°</u>													
(vii) <u>flute pitch greater than 5%</u>													
(viii) <u>pin tip geometry/shape</u>													
(ix) <u>thread pitch greater than 10% (as applicable)</u>													

	E B W	E G W	E S W	F C A W	F S W	G M A W	G T A W	L B W	O F W	P A W	S A W	S M A W	S W
4.14.9 Other Variables (Cont'd)													
(x) <u>flat design resulting in a change of the total flat surface area greater than 20%</u>					Q								
(xi) <u>number of flats</u>													
(xii) <u>cooling characteristics of the rotating pin (e.g., change from water-cooled to air-cooled, and vice versa)</u>													
(c) <u>pin material specification, nominal chemical composition, and minimum hardness</u>													
(19) <u>A change in the rotating tool operation beyond the following limits (as applicable) [see Figure 4.10]:</u>					Q								
(a) <u>decrease in rotation speed, or increase greater than 10%</u>													
(b) <u>direction of rotation</u>													
(c) <u>plunge force greater than 10% or plunge position set point greater than 5% when controlling the plunge direction (except during ramp-up and ramp-down when starting and stopping)</u>													
(d) <u>angular tilt greater than 1° in any direction</u>													
(e) <u>travel force or travel speed greater than 10% when controlling travel direction (except during ramp-up and ramp-down when starting and stopping)</u>													
(f) <u>range of relative motion between tool components when using self-reacting or retractable-pin tools</u>													
(g) <u>reduction in the smallest radius of travel path curvature that results in reversing the travel direction of the pin or the shoulder</u>													
(h) <u>manner or angle of intersection, or number of coincident intersections, within the same weld or between the weld and the HAZ of other welds</u>													

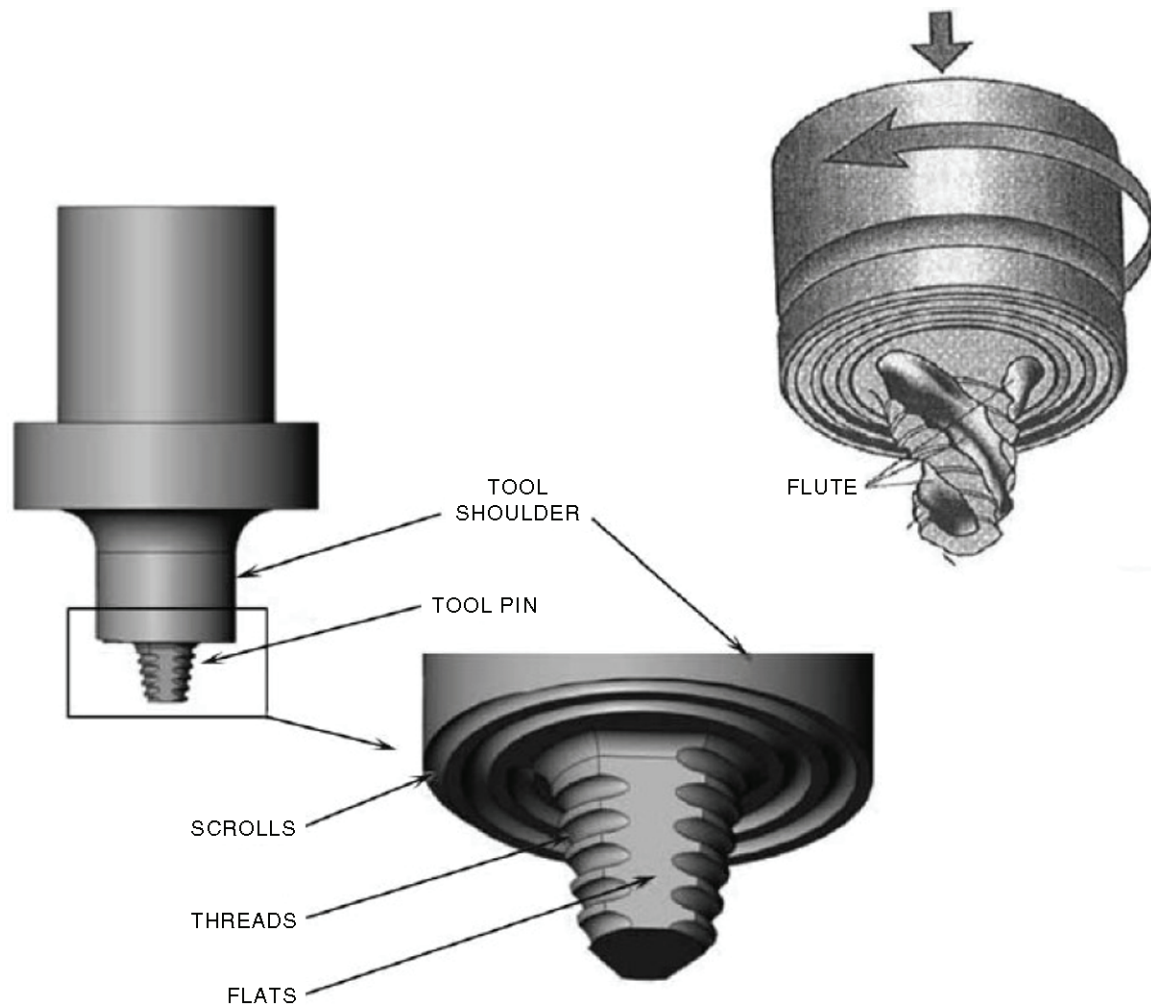


Figure 4.10—Rotating Tool Design Characteristics (FSW) [see 4.14.9 (18) and (19)]

4.15 Additional Procedure Qualification Variables for Hybrid Welding

The following procedure qualification variables are in addition to the welding variables for each welding process used during hybrid welding provided in 4.14:

- (1) an addition or deletion of welding processes used in a hybrid welding process from those used during qualification
- (2) a change in the process sequence used in a hybrid welding process from that used during qualification
- (3) a change in the process separation used in a hybrid welding process greater than 10% from that used during qualification (e.g., measured at the weld surface, measured between the welding torch and laser)
- (4) a change in any angle, between each individual welding process used in a hybrid welding process and the material to be welded, of greater than 10° from that used during qualification
- (5) a change in the height between the individual welding process used in a hybrid welding process and the material surface or a change in the height between the hybrid welding process and the material surface greater than 10% from that used during qualification

5. Performance Qualification

5.1 General

The purpose of welder qualification testing is to determine the ability of welders to produce a sound weld in the welding test positions. The purpose of welding operator qualification tests is to determine the ability of welding operators to operate mechanized or automatic equipment.

5.1.1 Qualification of welders and welding operators requires that a test coupon shall be made according to a Standard Welding Procedure Specification (SWPS) or a qualified welding procedure specification (WPS). The test coupon shall be prepared and tested in accordance with the requirements of this specification. If the WPS requires preheat or PWHT, they may be omitted at the discretion of the Qualifier.

5.1.2 Welders and welding operators currently qualified to earlier editions of AWS B2.1 are also qualified to this edition.

5.1.3 Personnel currently qualified by the Employer to meet the requirements of other codes or specifications are considered qualified under AWS B2.1 provided the basis for their qualification meets all requirements of this specification. However, the limits of qualification shall be in accordance with 5.6, Performance Qualification Variables. In such cases, a certification form shall be initiated and signed by the Employer attesting to compliance with this specification. If an existing form is used, the certifying statement shall be added or appended. If a new form is issued, it shall reference any prior certification form which shall be attached to or traceable from the new form.

5.1.4 Qualification testing using one of two methods is permitted:

- (1) Qualification by Standard Test (see 5.2)
- (2) Qualification by Workmanship Test (see 5.3). For selection of performance qualification methods, see Figure 5.1.

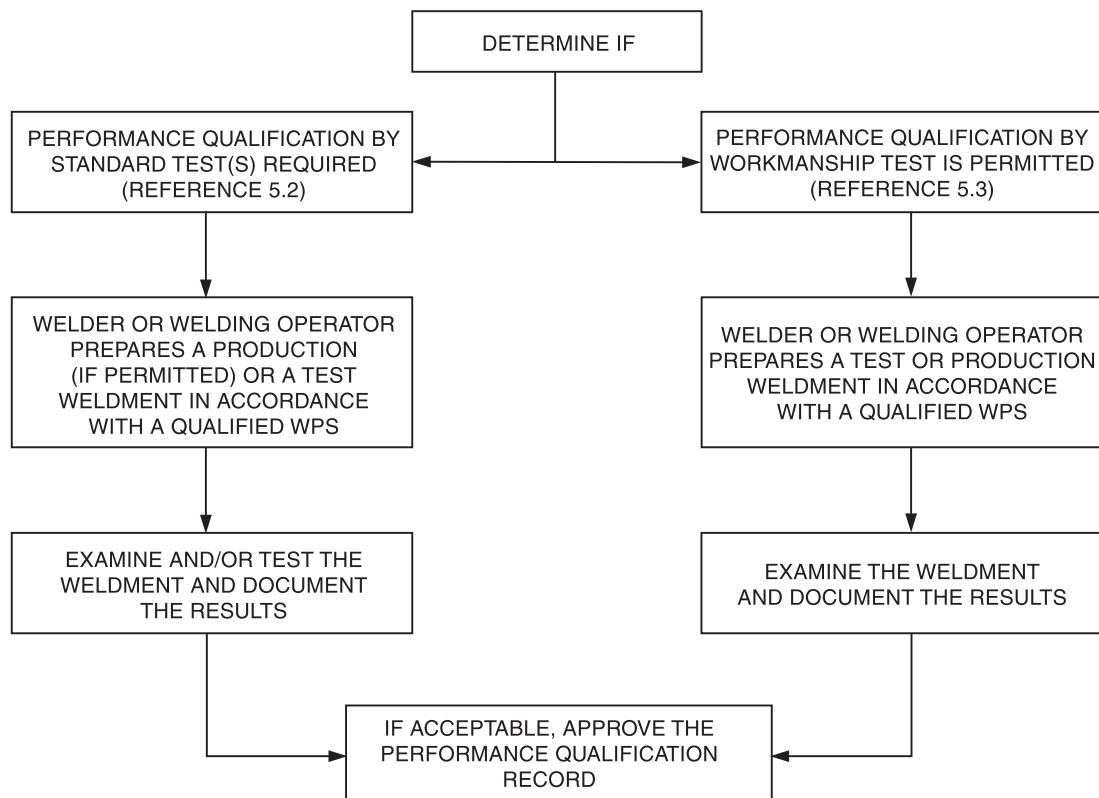
5.1.5 A Standard Test shall qualify the individual to perform production welding where either a Standard Test or a Workmanship Test is specified. Where the Referencing Document permits qualification by visual examination, a Workmanship Test may qualify a welder or welding operator for production welding.

5.1.6 A Workmanship Test is permitted on a production coupon, if such qualification is also permitted by the Referencing Document. Qualification by Standard Test is also permitted to be performed on a production weld where Table 5.1 permits the use of radiography in lieu of bend tests. Production radiography shall meet the requirements of 5.5.2, Radiographic Examination.

5.1.7 The welder or welding operator undertaking performance qualification tests shall be under the full supervision and control of the Qualifier during the welding of test coupons.

5.1.8 The qualification test for each welder or welding operator shall be documented by the Qualifier for both acceptable and unacceptable tests (see example in Annex F). There is no required format for Performance Qualification Test Records (PQTR). Any PQTR form may be used. Documentation shall:

- (1) Identify the WPS used;
- (2) Address each of the qualification variables in 5.6, Performance Qualification Variables;
- (3) Identify test and examination methods used and results; and
- (4) Identify the limits of qualification for the welder or welding operator.



Note: Figure 5.1 is provided to aid the user in determining the type of examinations or tests that are required to qualify a welder or welding operator using this specification.

**Figure 5.1—Selection of Performance Qualification Method—
Workmanship Test or Standard Test (see 5.1.4)**

**Table 5.1
Examination Requirements for Performance Qualification^d (see 5.1.6 and 5.2.1)**

Type of Test	Pipe or Plate Less than 1/16 in [1.5 mm]		Pipe or Plate Equal to or Greater than 1/16 in [1.5 mm]		Surfacing		
	Groove	Fillet	Groove	Fillet	Cladding	Hardfacing	Stud Welding
Visual Examination	Yes	Yes	Yes	Yes	Yes	Yes	
Radiography	Yes ^a (in lieu of bends)		Yes ^a (in lieu of bends)				
Bend Test	Yes ^a		Yes ^a		Yes		<u>Yes^e</u>
Break Test ^c		Yes		Yes ^c			
Macro-Examination ^b				Yes ^c		Yes	

^a Radiography may be substituted for bend testing for the SMAW, GTAW, GMAW (except short-circuiting), FCAW, PAW, and SAW processes, as applicable, for qualifications on all base metals except M-51 to M-55 and M-61 to M-62. GTAW tests in M-51 to M-55 and M-61 to M-62 may be qualified with radiography.

^b The use of a macro examination in lieu of bend tests shall be permitted only for welds made in M-26, M-81, and M-83 base materials.

^c The requirement for a break test and macro is waived for welders who successfully complete fillet procedure qualification tests (where shear tests, plus visual and macro examinations are used).

^d See Table 5.2.

^e Each stud (five) shall be tested either by hammering over until one-fourth of its length is flat on the test piece or by bending the stud to an angle of at least 15° and returning it to its original position using a test jig and an adapter location dimension that are in accordance Annex A, Figure A.5D.

5.1.9 Acceptance of test results is the responsibility of the Qualifier. Qualification records shall be signed and dated by the Qualifier. Qualification records shall reference and may include mechanical test and nondestructive examination test reports that are signed by others. Retention of mechanical test and nondestructive examination test reports is not required after acceptance by the Qualifier.

5.1.10 A welder or welding operator who fails the performance test may be retested at the option of the Qualifier, using (1) or (2) below:

(1) If a retest is permitted by the Qualifier without further training or practice, it shall consist of two test coupons for each position failed. Both test coupons shall be acceptable for the welder or welding operator to qualify.

(2) Provided there is evidence satisfactory to the Qualifier that the welder or welding operator has had further training or practice, one test weld for each position failed is permitted.

5.1.11 The performance qualification of a welder or welding operator shall be affected when one of the following conditions occur:

(1) When he or she has not welded with a process during a period exceeding 6 months, his or her qualifications for that process shall expire.

(2) Requalification as a result of (1) is permitted by having the welder or welding operator make one test coupon using the same process. If the test coupon meets the requirements of this specification, then all of the welder's or welding operator's previous qualifications for that process, for materials, thicknesses, product forms, and other variables are reinstated.

(3) When there is a specific reason to question his or her ability to make welds that meet the specification, the qualifications which support the welding he or she is doing shall be revoked. All other qualifications not questioned remain in effect.

(4) Requalification as a result of (3) is permitted by having the welder or welding operator successfully complete performance qualification test(s) that support the qualification(s) questioned.

5.1.12 Completion of an acceptable procedure or performance qualification test shall qualify the welder or welding operator who welded the test coupon within the limits of performance qualification variables specified in 5.6, Performance Qualification Variables.

5.1.13 Successful qualification using the test WPS shall also qualify an individual to weld with any other WPS using the same process and within the limits of performance variables in 5.6, Performance Qualification Variables. Qualification as a welder does not qualify the individual as a welding operator or vice versa.

5.1.14 Qualification on a complete joint penetration groove weld also qualifies the welder or welding operator for partial joint penetration groove welds, fillet welds and tack welds. Qualification on a fillet weld qualifies only for fillet welding and tack welding.

5.1.15 Welders qualified on a groove weld are also qualified to perform weld build up of surfaces to replace or repair base material with similar composition weld metal within the limits of 5.6.1.1, Welders. Cladding qualification qualifies only for cladding. Hardfacing qualification qualifies only for hardfacing.

5.1.16 Stud welding qualification qualifies only for stud welding.

5.1.17 Performance qualification requirements for cast iron and for reinforcing bar are covered in AWS D11.2, *Guide for Welding Iron Castings*, and in AWS D1.4/D1.4M, *Structural Welding Code—Reinforcing Steel*, respectively.

5.2 Qualification by Standard Test

5.2.1 Qualification requires completion of a standard test coupon in accordance with a qualified WPS, evaluation of the test coupon by the methods listed in Table 5.1, and acceptance of the coupon in accordance with the criteria of 5.5, Examination Procedures and Acceptance Criteria. The number of bend tests required for each position and product form is shown in Table 5.2.