



Specification for Fusion Welding for Aerospace Applications



American Welding Society®



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Specification for Fusion Welding for Aerospace Applications

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

Under the Direction of the
AWS Technical Activities Committee

Approved by the
AWS Board of Directors

Abstract

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



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Foreword

This foreword is not part of AWS D17.1/D17.1M:2010-AMD1, *Specification for Fusion Welding for Aerospace Applications*, but is included for informational purposes only.

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 It was subsequently revised and superseded by MIL-STD-1595A in 1983.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

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

In keeping with the welding and material technology advancements, this committee is committed to produce additional welding specifications as necessary, including Resistance Welding (RW) and Friction Stir Welding (FSW) to meet the demands of the ever-changing aviation and aerospace welding industry.

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

- (1) Renamed Applicable Documents to Normative References in Clause 2;
- (2) Relocated the Terms and Definitions from an Annex to Clause 3;
- (3) Updated the standard units of measure to reflect both U.S. Customary Units and the equivalent International System of Units (SI);
- (4) Updated Figure 5.1 to reflect space for bend test results and restrictions;
- (5) Updated 5.3.3.1 (2) and 5.3.3.1 (3) with notes for clarification purposes;
- (6) Updated inspection methods for Class A welds;
- (7) Inserted subclauses within Clause 5.4, Welding Procedure Specification (WPS) that more clearly address essential variables, test methods for WPS qualification, and test record forms (Figures 5.13 and 5.14);
- (8) Added Normative Annex C that covers bend testing criteria;
- (9) Added Informative References Annex D.

Underlined areas in text or tables indicate changes from the previous edition. A vertical line in the margin next to a figure, equation, or other item indicates a revision to that item from the previous edition.

Amendment

The following Amendment has been identified and is incorporated in this reprint.

AWS Standard: D17.1/D17.1M:2010
Amendment #: 1
Subject: Table 7.1 Acceptance Criteria in [mm], Face or Root Underfill (Groove Welds), Individual defect-maximum depth

**Table 7.1
Acceptance Criteria in [mm]**

Face or Root Underfill (Groove Welds)			
Individual defect - maximum depth	0.07 T or 0.030 [0.76] whichever is less	0.10 T or 0.050 [1.27] whichever is less	0.20 T or 0.070 [1.78] whichever is less

Errata

The following Errata have been identified and are incorporated in this reprint.

Page 7—**5.2.1 Physical Requirements.**—*Correct* “Alternately, the fabricator may establish other reasonable and appropriate physical requirements for welders and welding operators.” to “In addition, the fabricator may establish other reasonable and appropriate physical requirements for welders and welding operators.”

Page 9—**Figure 5.1, S.S. No.**—*Remove* “S.S. No.” from the top of the suggested test record form.

Page 11—**Table 5.2, Samples of Alloys Contained in Material Groups I through VIII^a**—*Correct* “Ti-6Al-4V 2/” to “Ti-6Al-4V”

Page 18—**Figure 5.7, 8[200]**—*Remove* “ ‘ “ after “8[200]”

Page 18—**Figure 5.7, Note**—*Correct* “Suggested dimension” to “Where member differ in thickness more than 10% of the thicker member, the cap sheet shall be the thicker member”

Page 18—**Figure 5.7, Footnote a**—*Correct* “Where member differ in thickness more than 10% of the thicker member, the cap sheet shall be the thicker member” to “Suggested dimension”

Page 22—**5.4.2 Procedure Qualification, Numbering sequence**—*Correct* “(8) filler metal used” to “(9) filler metal used”, “(9) joint design” to “(10) joint design”, “(10) electrical characteristics” to “(11) electrical characteristics”, “(11) preheat requirements” to “(12) preheat requirements”, “(12) postweld heat requirements” to “(13) postweld heat requirements”, and “(13) other variables required by the Engineering Authority” to “(14) other variables required by the Engineering Authority”

Page 26—**Table 6.1, Gas Requirements^a**—*Correct* Oxygen Specification “B-O-925” to “BB-O-925”

Page 34—**Table 7.1, Mismatch Between members after Welding**—*Correct* “Refer to Paragraph 6.14.4 & Figure 6.2 Includes A, B & C Class of Welds” to “Refer to Paragraph 7.5.2.1 & Figure 7.2 Includes A, B, & C Class of Welds”

Page 35—**Table 7.1, Acceptance Criteria in [mm], Discoloration^b—Titanium, Green, Class B** —*Correct* “Acceptance^a” to “Acceptance^c”

Page 35—**Table 7.1, Acceptance Criteria in [mm], Discoloration^b—Titanium, Green, Class C** —*Correct* “Acceptance^a” to “Acceptance^c”

Page 36—**Figure 7.1, WIDTH OF WELD FACE OR INDIVIDUAL SURFACE BEAD, W**—*Correct* “W > in. TO W < 1 in [25mm]” to “W > in [8mm] TO W < 1 in [25mm]”

Page 36—**Figure 7.1, Footnote a**—*Correct* “^a Refer to 4.3.8.2” to “^a Refer to 5.3.8.2”

Page 37—**Figure 7.2, Extra horizontal line within table**—*Remove horizontal line between* “OFW, SMAW, GTAW, GMAW” and “PAW, VP-PAW, FCAW, SAW”

Page 42—**9.2.4.4 NDE of Nonflight Hardware, (3) Class C Inspection (for structural welds only)** —*Correct* “All Class C inspections require only the visual inspection described in 9.6.3.” to “All Class C inspections require only the visual inspection described in 9.2.4.3.”

Page 49—**Figure A.1(d), Missing horizontal line within table**—*Add horizontal line between* “PAW^a” and “GMAW FCAW SAW”

Page 58—**Table A.1, Comparable Fillet Weld Size for Same Strength (in[mm])**—*Correct* “1.23 [21.2]” to “1.23 [31.2]”

Page 62—**Table C.1, Base Metal Group**—*Correct* “Ia” to “IA”, “Ib” to “IB”, “IIa” to “IIA”, “IIb” to “IIB”, “IIIB” to “IIIB”

Page 62—**Table C.1, Unified Number & Common Description**—*Remove* “S15500 & 15-5PH stainless steel”, “S17400 & 17-4PH stainless steel”, “S35000 & AM350 PH stainless steel”, “S35500 & AM355 PH stainless steel”, “S4500 & Custom 450”, “S45500 & Custom 455”

Page 65—**Table C.3, Missing line within table**—*Add vertical line between* “T1” and “W”, “Max.” and “Min.”, and “6” and “7”

Page 82—**G4.14 Welding and Weldments**—*Correct* “Figure 6.2 dictates maximum mismatch at the completed weld joint.” to “Figure 7.2 dictates maximum mismatch at the completed weld joint.”

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Table of Contents

	Page No.
<i>Personnel (Amendment)</i>	v
<i>Personnel (Original)</i>	vii
<i>Foreword</i>	ix
<i>List of Tables</i>	xv
<i>List of Figures</i>	xv
1. Scope and General Requirements	1
1.1 Scope	1
1.2 Classification	1
1.3 Approval	2
1.4 Mandatory Provisions and Authority	2
1.5 Standard Units of Measure	2
1.6 Safety and Health	2
2. Normative References	2
2.1 Government Documents	2
2.2 Nongovernment Documents	3
3. Terms and Definitions	4
4. Design of Welded Connections	6
4.1 Scope	6
4.2 Weldment Design Data	6
4.3 General Drawing Requirements	6
5. Welding Performance and Procedure Qualification	7
5.1 General Description	7
5.2 General Requirements (Performance)	7
5.3 Detailed Requirements (Performance)	8
5.4 Welding Procedure Qualification (Procedure)	22
6. Fabrication	24
6.1 Scope	24
6.2 Welding Consumables	24
6.3 Welding Equipment	27
6.4 Weld Settings	27
6.5 Preweld Cleaning and Other Preparation	27
6.6 Preweld Joint Preparation and Fit-up	27
6.7 Preheating and Interpass Temperature Control	28
6.8 Tack Welds	28
6.9 Weld Start and Run-Off Tabs	28
6.10 Weld Shielding for GTAW, GMAW, and PAW	28
6.11 Tungsten Electrodes	28
6.12 Filler Materials	29
6.13 Interpass Cleaning	29
6.14 Welding and Weldments	29
6.15 Postweld Cleaning	31
6.16 Postweld Processing	31

6.17	Weld Identification Requirements	31
6.18	Acceptance Inspection	31
6.19	Rework	31
6.20	Repair	32
6.21	Record Requirements	32
7.	Inspection	32
7.1	Qualification of Inspection Personnel	32
7.2	Vision Test	32
7.3	Visual Weld Inspection	32
7.4	Nondestructive Inspection	32
7.5	Acceptance Criteria	33
7.6	Inspection Records	37
8.	Repair of Existing Structures	37
8.1	Scope	37
8.2	Design	38
8.3	Welding Procedures	38
8.4	Welder and Welding Operator Qualification	39
8.5	Welding Equipment	39
8.6	Weld Repair Inspection	39
8.7	Grounding	39
8.8	Repair Documentation	39
9.	Nonflight Hardware	39
9.1	Scope	39
9.2	Exceptions and Additional Requirements	39
	Annex A (Normative) — Guidelines for Design, Analysis, and Fabrication of Weld Joints	45
	Annex B (Normative) — Effective Throat	59
	<u>Annex C (Normative) — Bend Testing Criteria</u>	61
	<u>Annex D (Informative) — Informative References</u>	69
	Annex E (Informative) — Safe Practices	71
	Annex F (Informative) — Guidelines for the Preparation of Technical Inquiries	75
	Annex G (Informative) — Commentary	77

List of Tables

Table	Page No.
5.1	Fusion Welding Processes. 8
5.2	Samples of Alloys Contained in Material Groups I through VIII. 10
5.3	Welding Position, Base Metal Form and Base Metal Qualified by Test Weld. 12
5.4	Other Welding Conditions Qualified by Test Weld 17
<u>5.5</u>	<u>PQR Test Requirements</u> 24
6.1	Gas Requirements 26
6.2	Recommended Shielding Gases for Welding 26
6.3	Preheat and Interpass Temperatures 29
6.4	Filler Metal for Welding Aluminum Alloys Using GMAW, GTAW, and PAW Processes. 29
6.5	Filler Metal for Welding Titanium Alloys Using GMAW, GTAW, and PAW Processes 29
6.6	Filler Metal for Welding Stainless Steels and Heat Resistant Alloys Using GMAW, GTAW, and PAW Processes. 30
7.1	Acceptance Criteria (in [mm]) 33
9.1	Industrial Codes and Specifications Suggested for Welding Aerospace Nonflight Hardware 40
A.1	Equivalent Fillet Weld Leg Size for Skewed T-Joints 58
C.1	Base Metals for Which Bend Testing is Not Applicable 62
C.2	Bend Specimen Thickness and Bend Radius (in) 63
C.2M	Bend Specimen Thickness and Bend Radius (mm) 64
C.3	Bend Specimens for Groove Welds in Tube. 65

List of Figures

Figure	Page No.
<u>5.1</u>	<u>Suggested Test Record Form</u> 9
5.2	Groove Weld in Sheet: Positions 1G, 2G, 3G, and 4G. 13
5.3	Fillet Weld in Sheet: Position 1F, 2F, 3F, and 4F. 14
5.4	Groove Weld in Tube Positions 1G, 2G, 5G, and 6G. 15
5.5	Fillet Weld in Tube: Positions 1F, 2F, 4F, and 5F 16
5.6	Groove Test Weld in Sheet 17
5.7	Fillet Test Weld in Sheet. 18
5.8	Groove Test Weld in Tube 19
5.9	Fillet Test Weld in Tube 19
5.10	Blank Locations for Metallographic Specimens in Fillet-Welded Sheet 20
5.11	Blank Locations for Metallographic Specimens in Fillet-Welded Tube. 20
5.12A	Incomplete Fusion at Root in Fillet Welds When Thickness of Both Members is Greater Than 0.063 in [1.6 mm] 21
5.12B	Incomplete Fusion at Root in Fillet Welds When Thickness of Any Member is Less Than or Equal to 0.063 in [1.6 mm]. 21
5.13	Welding Procedure Specification (WPS) Form 23
<u>5.14</u>	<u>Procedure Qualification Record (PQR) Form</u> 25
6.1	Joint Preparation in Joint Members of Unequal Thickness. 28
7.1	Acceptable and Unacceptable Weld Profiles 36
7.2	Mismatch Between Joint Members After Welding. 37
A.1(a)	Square Groove Butt Joints. 46

A.1(b)	Single-Bevel-Groove Weld Joints	47
A.1(c)	Single-V-Groove Weld Joints	48
A.1(d)	Single-J-Groove Weld Joints	49
A.1(e)	Single-U-Groove Weld Joints	50
A.1(f)	Double-Bevel-Groove Weld Joints	51
A.1(g)	Double-V-Groove Weld Joints	52
A.1(h)	Double-J-Groove Weld Joints	53
A.1(i)	Double-U-Groove Weld Joints	54
A.2	Two- and Three-Piece T-Weld Joints – Melt-through Welds.	55
A.3(a)	Flanged Joints	55
A.3(b)	Flanged Edge Joints (Nonstandard)	56
A.4	Fillet Weld Details	57
B.1	Effective Throat	59
C.1	<u>Bend Specimens in Groove Welded Tube</u>	67

Specification for Fusion Welding of Aerospace Applications

1. Scope and General Requirements

1.1 Scope. This specification contains requirements for fusion welding of aerospace hardware. It is to be used in conjunction with the Engineering Authority's design handbooks or their accepted data. When conformance to this specification is stipulated in contract documents, all provisions of this specification shall be complied with, except for those provisions that the Engineering Authority or contract documents specifically exempt, or those optional provisions that shall be applied when specified by the contract documents.

The following is a summary of the specification Clauses:

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

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

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

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

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

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

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

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

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

1.1.1 Flight Hardware. The fundamental premise of this specification is to provide general requirements for currently recognized aerospace fusion welding processes and materials. However, this specification provides for the application of new materials, new welding processes, or acceptance criteria for production welds differing from those defined in this specification. These new applications shall be documented by the proposer and approved by the Engineering Authority.

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

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

1.2 Classification. All welds produced in accordance with this specification shall be classified on the engineering drawings. Weld classifications shall be as follows: Class A, Class B, or Class C. These classifications refer to the level of inspection required and to the acceptance criteria. Alternate acceptance criteria and inspection methods may be applied if specified on the engineering drawing. The Engineering Authority shall also determine the weld procedure qualification requirements (see Annex G—Commentary).

1.2.1 Determining Classifications. The Engineering Authority must consider material and process aspects that affect mission or systems requirements. A weld joint may be zoned with multiple classifications.

1.2.2 Criteria. The Engineering Authority shall determine the weld procedure qualification requirements for all classifications in accordance with Clause 5. Should the Engineering Authority determine that alternate acceptance criteria are required for particular applications, weldment(s), or other circumstances, the criteria shall be specified on the engineering drawing.

1.3 Approval. All references to the need for approval shall be interpreted to mean approval by the Customer or the Engineering Authority. Hereinafter, the term “Engineering Authority” will be used and it is to be construed to mean the Customer or the Engineering Authority.

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

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

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

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

1.5 Standard 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.

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

In addition, users of electron beam welding equipment should follow with the safety requirements given in the latest edition of AWS C7.1, *Recommended Practices for Electron Beam Welding*; users of laser beam welding equipment should follow with the safety requirements given in the latest edition of AWS C7.2, *Recommended Practices for Laser Beam Welding, Cutting and Drilling* (see also Annex E).

NOTE: This specification may involve hazardous materials, operations, and equipment. The specification does not purport to address all of the safety problems associated with its use. It is the responsibility of the user to establish appropriate safety and health practices. The user should determine the applicability of any regulatory limitations prior to use.

2. Normative References

The following standards contain provisions which, through reference in this text, constitute mandatory provisions of this AWS standard. For undated references, the latest edition of the referenced standard shall apply. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply.

2.1 Government Documents

Federal and Military Specifications, Standards, and Handbooks:¹

1. BB-O-925, *Oxygen, Technical, Gas and Liquid*;
2. BB-A-106, *Acetylene, Technical, Dissolved*;
3. BB-C-101, *Carbon Dioxide, (CO₂): Technical and U.S.P.*;

¹ Unless otherwise indicated, Federal and Military Specifications, Standards, and Handbooks are published by DODSSP, 700 Robbins Avenue, Bldg. 4D, Philadelphia, PA 19111-5094.

4. BB-N-411, *Nitrogen, Technical*;
5. BB-H-886, *Hydrogen*;
6. BB-H-1168, *Helium, Technical*;
7. MIL-A-18455, *Argon, Technical*; and
8. Code of Federal Regulations, *Title 14, Aeronautics and Space*.²

2.2 Nongovernment Documents

Aerospace Industries Association (AIA) document:³

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

American National Standards Institute (ANSI) document:⁴

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

American Society of Mechanical Engineers (ASME) documents:⁵

1. ASME B31.1, *Code for Pressure Piping*; and
2. ASME B31.3, *Process Piping*.

American Society for Testing and Materials (ASTM) documents:⁶

1. ASTM E164, *Standard Practice for Ultrasonic Contact Examination of Weldments*;
2. ASTM E1742, *Practice for Radiographic Examination*;
3. ASTM E1417, *Standard Practice for Liquid Penetrant Examination*; and
4. ASTM E1444, *Standard Practice for Magnetic Particle Examination*.

American Welding Society (AWS) documents:⁷

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 A5.1/A5.1M, *Specification for Carbon Steel Electrodes, for Shielded Metal Arc Welding*;
4. AWS A5.5/A5.5M, *Specification for Low Alloy Steel Electrodes for Shield Metal Arc Welding*;
5. AWS A5.12M/A5.12 (ISO 6848 MOD), *Specification for Tungsten and Tungsten-Alloy Electrodes for Arc Welding and Cutting*;
6. AWS A5.20/A5.20M, *Specification for Carbon Steel Electrodes for Flux Cored Arc Welding*;
7. AWS A5.29/A5.29M, *Specification for Low Alloy Steel Electrodes for Flux Cored Arc Welding*;
8. AWS A5.30/A5.30M, *Specification for Consumable Inserts*;
9. AWS A5.32/A5.32M, *Specification for Welding Shielding Gases*;
10. AWS QC1, *Standard for AWS Certification of Welding Inspectors*; and

² The Code of Federal Regulations is published by U.S. Government Printing Office, Superintendent of Documents, P.O. Box 371954, Pittsburgh, PA 15250-7954.

³ AIA standards are published by the Aerospace Industries Association, 1000 Wilson Boulevard, Suite 1700, Arlington, VA 22209-3928.

⁴ ANSI Z49.1 is published by the American Welding Society, 550 N.W. LeJeune Rd, Miami, FL 33126.

⁵ ASME standards are published by the American Society of Mechanical Engineers, 3 Park Ave., New York, NY 10016.

⁶ ASTM standards are published by the American Society for Testing and Materials, 100 Barr Harbor Drive, West Conshohocken, PA 19428-2950.

⁷ AWS standards are published by the American Welding Society, 550 N.W. LeJeune Rd, Miami, FL 33126.

11. AWS B5.2 *Specification for the Qualification of Weld Inspector Specialists and Welding Inspector Assistants*.
Compressed Gas Association (CGA) documents:⁸

1. CGA G-1.1, *Commodity Specification for Acetylene*;
2. CGA G-4.3, *Commodity Specification for Oxygen*;
3. CGA G-5.3, *Commodity Specification for Hydrogen*;
4. CGA G-6.2, *Commodity Specification for Carbon Dioxide*;
5. CGA G-9.1, *Commodity Specification for Helium*;
6. CGA G-10.1, *Commodity Specification for Nitrogen*; and
7. CGA G-11.1, *Commodity Specification for Argon*.

3. Terms and Definitions

The weld terms used in this specification shall be interpreted in conformance with the definitions given in the latest edition of AWS A3.0M/A3.0, *Standard Welding Terms and Definitions Including Terms for Adhesive Bonding, Brazing, Soldering, Thermal Cutting, and Thermal Spraying*, supplemented by the following terms and definitions:

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

all-weld-metal tensile test specimen. A test specimen with the reduced section composed wholly of weld metal.

CAGE. The Commercial and Government Entity (CAGE) database provides listings of firms that manufacture or distribute items procured by the U.S. government.

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

concavity. The maximum distance from the face of concave fillet weld perpendicular to a line joining the weld toes.

critical. Welds made to critical structures shall have a stress analysis performed to determine the adequacy of the repair based on the location of the weld and type of weld. Consideration shall be given to prevent the weld from becoming a metallurgical or mechanical notch in critical structure.

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

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

damage tolerance. The ability of the aerospace flight hardware to resist failure due to the presence of flaws, cracks, or other damage for a specified period of unrepaired usage.

damage tolerant structure. Structure in which the crack propagation rate is slow enough for at least two inspections to be feasible between crack initiation and functional failure.

durability. The ability of the airframe or engine to resist cracking (including vibration, corrosion and hydrogen induced cracking), corrosion, deterioration, thermal degradation, delamination, wear, and the effects of foreign and domestic object damage for a specified period of time.

durability critical component. A component whose failure or deterioration will result in a significant maintenance burden but will not impair flight safety.

⁸ CGA standards are published by the Compressed Gas Association, Inc., Crystal Gateway 1, Suite 501, 1235 Jefferson Davis Highway, Arlington, VA 22202.

effective throat. The minimum distance from the root of the weld to its face less any reinforcement (see preferred term, **theoretical throat**). (Same definition as provided by AWS D1.1/D1.1M but differs from the AWS A3.0M/A3.0 definition.)

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

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

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

failure mode. The specific engineering mechanism of failure which leads to a particular functional failure.

Federal Supply Code for Manufacturers (FSCM). (See preferred term **CAGE**)

fracture critical. A part which, by fracture mechanics analysis, has a service life factor of less than 2.0 times the vehicle life cycle requirements and failure of which would cause loss of the vehicle or crew. Also, a part that is a pressure vessel or a rotating machinery component.

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

mission critical. An item whose failure generates a significant operational impact by jeopardizing the ability to successfully complete the assigned mission. Included in this classification are parts, which have failure effects that adversely impact air vehicle survivability or mission effectiveness or both.

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

noncritical. Welds used for the repair of noncritical structures may have a stress analysis performed at the discretion of the Engineering Authority if the weld repair is located in an area that may cause failure of the noncritical structure or loss of performance of the system.

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

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

pad-up. See preferred term **weld land**.

rejectable discontinuity. A discontinuity that by nature or accumulated effect (e.g., total crack length) renders a part or product unable to meet minimum requirements.

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

semicritical. Welds made to semicritical structures shall have a stress analysis performed prior to welding the structure.

semicritical structure. Failure of the component would reduce the overall efficiency of the system but loss of the system or endangering personnel would not be experienced. Additionally, a semicritical structure or component is not "critical" and is considered fail safe.

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

T-Joint. A joint between two or three members located approximately at right angles to each other in the form of a T.

underfill. A condition in which the weld face or root surface extends below the adjacent surface of the base metal.

weld land. The buildup of section thickness at the weld joint that provides an improvement in joint efficiency. Weld lands may also be used to provide filler metal in autogenous welds where postweld joint thickness equals base metal thickness.

Welding symbols shall be those shown in the latest edition of AWS A2.4, *Standard Symbols for Welding, Brazing and Nondestructive Examination*.

4. Design of Welded Connections

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

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

4.3 General Drawing Requirements

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

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

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

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

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

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

4.3.5 Inspection Requirements. The engineering drawings shall define weld inspection requirements using weld classification or tailoring of the default (weld classification) inspection methods and acceptance criteria. A single weld may employ more than one set of inspection requirements through the use of separate zones applied to the weld. Clause 7 provides the default inspection methods and acceptance criteria.

5. Welding Performance and Procedure Qualification

5.1 General Description. This clause establishes the requirements for performance and procedure qualification. It also contains provisions for maintenance of welder/welding operator qualification and the various methods that may be used to qualify welding procedures.

5.1.1 Welder and Welding Operator Functional Descriptions

5.1.1.1 Welder. Welder functional description is defined in AWS A3.0M/A3.0.

5.1.1.2 Welding Operator. Welding operator functional description is defined in AWS A3.0M/A3.0.

5.2 General Requirements (Performance)

5.2.1 Physical Requirements. Welders and welding operators shall have vision acuity of 20/30 or better in either eye, and shall be able to read the Jaeger No. 2 Eye Chart at 16 in [400 mm]. Corrected or uncorrected vision may be used to achieve eye test requirements. If corrected vision is required to pass eye test requirements, then that fact shall be notated on qualification. Vision shall be tested to these requirements at least every two years. In addition, the fabricator may establish other reasonable and appropriate physical requirements for welders and welding operators.

5.2.2 Qualification Requirements. To achieve qualified status, welders and welding operators shall demonstrate their skill by producing acceptable test welds per the requirements of 5.3.8. Test welds should not be required for those welds that will not be required in production welding. Qualifications, certifications, requalifications, and recertifications given under this specification do not transfer from one fabricator to another.

5.2.2.1 Welders. The correlation factors between test welds and production welds shall be based on the following essential variables:

- (1) welding process (see 5.3.1)
- (2) base metal composition group (see 5.3.2)
- (3) base metal thickness (see 5.3.3)
- (4) welding position (see 5.3.4)
- (5) base metal form, sheet or tube (see 5.3.5)
- (6) type of weld, groove or fillet
- (7) other welding conditions (see 5.3.6)

Filler metal used for test welds shall be the same as those commonly used in production welding of the base metal.

5.2.2.2 Welding Operators. The correlation between test welds and production welds shall be based as a minimum on the first three essential variables given in 5.2.2.1.

5.2.3 Qualification/Certification Validity

5.2.3.1 Initial Validity. Successful completion of welder and welding operator qualification tests shall be valid justification for issuance of certification for a period of at least two years from the date qualification test results are issued.

5.2.3.2 Extended Validity. The qualification time limits of 5.2.3.1 may be extended indefinitely provided an auditable record is maintained from the date of the initial qualification that verifies that the welder/welding operator has used the process within a six-month period to weld applications normally welded by the certified individual.

5.2.3.3 Disqualification. Disqualification and revocation of welder certification shall result under any one or more of the following conditions:

- (1) A welder or welding operator has not performed the qualification tests successfully within the previous two years and an auditable record has not been maintained, as required in 5.2.3.2.
- (2) The evidence of the individual's performance required by 5.2.3.2 is not recorded and maintained by the fabricator to document welder performance.
- (3) The welder or welding operator has failed the vision requirements or has not passed the required exam within the previous two years.
- (4) Other reasonable and appropriate physical requirements established by the fabricator cannot be met.

- (5) There is a specific reason to question the ability of a welder or welding operator to meet the requirements for qualification.

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

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

5.2.5 Test Records. The fabricator shall complete a test record containing the essential variables listed in paragraph 5.2.2.1 or 5.2.2.2, detailing the limits of the welder or welding operator qualification. In addition, other conditions and restrictions, such as corrective lenses, shall be listed on the test record form. These records shall be retained for the period of time specified in the contract or, if no retention time is specified, the period of record retention shall be for the duration of the qualification.

5.2.5.1 Test Record Forms. Suggested content of test record forms is provided in Figure 5.1.

5.3 Detailed Requirements (Performance)

5.3.1 Welding Process. For welders and welding operators, a test weld made with a given welding process of Table 5.1 qualifies only that welding process. This qualification clause only applies to welding processes included in Table 5.1.

5.3.2 Base Metals. For welders and welding operators, a test weld made in a base metal included in one of the base metal groups of Table 5.2 qualifies only that base metal group, except as modified in 5.3.2.1.

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

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

5.3.3 Base Metal Thickness. The qualification limits, with regard to base metal thickness (sheet thickness or tube wall thickness), are given below for welders and welding operators. These limits apply to both groove welds and fillet welds.

5.3.3.1 Qualified Thickness Range

- (1) A test weld with a base metal thickness of t shall qualify welds with a thickness range of 0.67t to 4t, except that when the test weld thickness is equal to or greater than 1 in [25 mm], the qualification range is 0.67t to unlimited. Two test welds shall qualify welds with all intermediate thicknesses.
- (2) Qualification for sheet or tube fillet welds in material 0.063 in [1.6 mm] thickness (sheet or tube wall) or less requires a fillet weld test. A groove weld test cannot be used to qualify fillet welds in this thickness range.

NOTE: Tube fillet weld qualifications are based on tube thickness only, not mating sheet thickness.

- (3) Qualification for tube welding on tubes of 1 in [25 mm] OD or less requires qualification of a tube weld. The tube weld qualification is for any tube size equal to or larger than the OD of the tested tube weld.

NOTE: Qualification for tube welding on tube one inch [25mm] or greater may be qualified using sheet.

**Table 5.1
Fusion Welding Processes**

Process	Abbreviation
Oxyfuel welding	(OFW)
Shielded metal arc welding	(SMAW)
Submerged arc welding	(SAW)
Gas tungsten arc welding	(GTAW)
Gas metal arc welding	(GMAW)
Flux cored arc welding	(FCAW)
Plasma arc welding	(PAW)
Electron beam welding	(EBW)
Laser beam welding	(LBW)

QUALIFICATION TEST RECORD

Name: _____ Id _____
 Joint welding procedure: _____ Welder Welding operator

TEST-WELD

Base metal description: _____ Group No. _____
 Welding process: _____ Single weld Double weld
 Current: AC DCEN DCEP Backing: Yes No
 Vertical: Down Up Penetration: Complete Partial

	Position		Dimension, in [mm]
Sheet groove	1G <input type="checkbox"/> 2G <input type="checkbox"/> 3G <input type="checkbox"/> 4G <input type="checkbox"/>		T _____
Tube groove	1G <input type="checkbox"/> 2G <input type="checkbox"/> 5G <input type="checkbox"/> 6G <input type="checkbox"/>	O.D. _____	T _____
Sheet fillet	1F <input type="checkbox"/> 2F <input type="checkbox"/> 3F <input type="checkbox"/> 4F <input type="checkbox"/>		T _____
Tube fillet	1F <input type="checkbox"/> 2F <input type="checkbox"/> 4F <input type="checkbox"/> 5F <input type="checkbox"/>	O.D. _____	T _____

TEST RESULTS

Visual Pass Fail
 Radiographic NA Pass Fail
 Metallographic NA Pass Fail
 Bend NA Pass Fail

QUALIFIED

Base Metal Group No. _____ Single weld Double weld
 Current: AC DCEN DCEP Backing: With Without
 Vertical: Down Up Penetration: Complete Partial

		T, in [min]		O. D., in [mm]
	Position	Min	Max	Min
Sheet groove	1G <input type="checkbox"/> 2G <input type="checkbox"/> 3G <input type="checkbox"/> 4G <input type="checkbox"/>	_____	_____	
Tube groove	1G <input type="checkbox"/> 2G <input type="checkbox"/> 5G <input type="checkbox"/> 6G <input type="checkbox"/>	_____	_____	_____
Sheet fillet	1F <input type="checkbox"/> 2F <input type="checkbox"/> 3F <input type="checkbox"/> 4F <input type="checkbox"/>	_____	_____	
Tube fillet	1F <input type="checkbox"/> 2F <input type="checkbox"/> 4F <input type="checkbox"/> 5F <input type="checkbox"/>	_____	_____	_____

Restrictions: _____

The above named individual is qualified in accordance with AWS D17.1 within the above limits for the welding process used for this test weld.

Date of Test Weld: _____ Signed by: _____
Qualifier

Figure 5.1—Suggested Test Record Form

Table 5.2
Samples of Alloys Contained in Material Groups I Through VIII^a

Group	Materials
IA	Carbon and Alloy Steels: <ul style="list-style-type: none"> ● Wrought Carbon Steel: (bar, sheet, plate and shapes): A36, A53, A106, A131, A139, A284, A441, A515, A516, A570, A572, A588, and the AISI carbon steels with a nominal carbon of 0.40 weight percent or less (1005–1040) ● Cast Carbon Steels: A216, A352, A389, A487 ● Cast Low Alloy Steels: A217, A389, A 487 ● Heat Treatable Carbon and Low Alloy Structural Steel^b: A514, A517, A537, A633^c ● High Strength Boiler Plate and Forgings^a: A302, A508, A533 ● Ultra High Strength Steels: 18 Ni Maraging steels, 9 Ni–4 Co steels
IB	Heat Treatable Alloy Steels: <ul style="list-style-type: none"> ● 4130^c, 4135, 4140, 4340, 8630, D6AC, 300M, H11
IIA	Stainless Steels: <ul style="list-style-type: none"> ● Austenitic Stainless Steels: 201, 202, 301, 302, 303, 304, 308, 309, 310, 316, 317, 321, 330, 347, 348, 19-9DL, 19-9DX, 21-6-9 ● Ferritic Stainless Steels: 405, 406, 409, 429, 430, 434, 436, 439, 441, 442, 446 ● Martensitic Stainless Steels: 403, 410, 414, 416, 420, 422, 431, 440
IIB	Precipitation Hardenable Stainless Steels: <ul style="list-style-type: none"> ● PH13-8Mo, 15-5PH, PH15-7Mo, AM-350, AM-355, A-286, 17-4PH, 17-7PH^c, Custom®450 and 455
IIIA	Nickel and Nickel Base Alloys: <ul style="list-style-type: none"> ● Nickel 200 and 201 ● Monel® 400 ● Hastelloy® B, B2, C, C4, G, G2, N, X, 276 ● Inconel® 600 and 625^c, 800, 800H, 825 ● Carpenter® Cb3 ● Haynes 20 Mod.
IIIB	Precipitation Hardening Nickel and Nickel Base Alloys: <ul style="list-style-type: none"> ● Monel® K500 ● Inconel® 601, 706, 718^c, X750, 901, 903, 907, 909 ● Rene® 41, 77, 80 ● Udimet® 700
IV	Non Heat Treatable Aluminum Alloys: <ul style="list-style-type: none"> □ 1060, 1100, 3003, 3004, 5052, 5083, 5086^c, 5154, 5254, 5454, 5456, 5652 Heat Treatable Aluminum Alloys: <ul style="list-style-type: none"> □ 355, 356, 357, 2014, 2219, 6061^c, 6063
V	Magnesium Alloys: <ul style="list-style-type: none"> □ AM100A, AZ31B^c, AZ61A, AZ80A, AZ91A, AZ92A, EZ33A, HM21A, HK31A, HM31A, HZ32A, LA141A, ZH62A, QE22A
VI	Titanium Alloys: <ul style="list-style-type: none"> □ CP Titanium (25, 40, 55), □ Ti-5Al-2.5Sn □ Ti-6Al-2Sn-4Zr-2Mo □ Ti-8Al-1Mo-1V

Table 5.2 (Continued)
Samples of Alloys Contained in Material Groups I through VIII^a

	<ul style="list-style-type: none"> □ Ti-6Al-2Cb-1Ta-1Mo □ Ti-6Al-2Sn-4Zr-6Mo □ Ti-3Al-2.5V □ Ti-6Al-4V^c, Ti6Al-6V-2Sn □ Ti-3Al-8V-6Cr-4Mo-4Zr □ Ti-6Al-2Sn-3Zr-2Cr-2Mo □ Ti-15V-3Cr-3Mo-3Sn
VII	Cobalt Base Alloys: <ul style="list-style-type: none"> □ Stellite® 6, 21, 23, 27, 30, 31 □ HS188®^c, L605, S816
VIII	Alloys that do not conform to Groups I–VII: ^d <ul style="list-style-type: none"> □ Refractory alloys (Cb, Mo, W) □ Reactive alloys (Zr) □ Magnet alloys □ Copper alloys

This table lists a sampling of the alloys contained within the Material Groups established by this document. Except as marked in Group VIII, alloys not listed may be assigned to the Materials Group by the Engineering Authority.

^a “These are sample alloys. Whenever alloy trade names are suggested those alloy trade names are the property of their owners” Where trade mark names are used, the trademark will be identified by a trademark symbol.

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

^c Recommended alloy for qualification of this alloy group.

^d Each alloy in this group requires separate qualification.

5.3.4 Welding Position

5.3.4.1 Welders. The welding positions qualified by a given test weld position, to be found at the left of Table 5.3, are denoted by an “X” in the table. The welding positions are designated, identified, and illustrated in Figures 5.2, 5.3, 5.4, and 5.5.

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

5.3.5 Base Metal Form and Weld Type

5.3.5.1 Welders. The base metal forms and weld types qualified by a given test weld, to be found at the left of Table 5.3, are denoted by an “X” in the table.

5.3.5.2 Welding Operators A test weld of any base metal form of any weld type shall qualify for all base metal forms and all weld types. A tube test weld of any outside diameter shall qualify for tubes of any outside diameter.

5.3.6 Other Welding Conditions. In addition to the welding process, base metal composition, base metal thickness, welding position, base metal form, and type of weld, other welding conditions which require a correlation between the test weld and the production welds are given in Table 5.4.

5.3.6.1 Welders. The welding conditions qualified by the given test weld conditions to be found at the left of Table 5.4 are denoted by an “X” in the table.

5.3.6.2 Welding Operators. The welding condition restrictions of Table 5.4 do not apply to the qualification of welding operators.

5.3.7 Test Welds. One test weld shall be required for each combination of welding conditions, as given in 5.2.2.1 and 5.2.2.2, being qualified. Test welds shall be made in accordance with a written welding procedure.

Table 5.3
Welding Position, Base Metal Form and Base Metal Qualified by Test Weld^a

Test Weld		Psn	Qualified Position															
			Sheet								Tube							
			Groove				Fillet ^b				Groove ^c				Fillet ^b			
Form	Weld type	1G	2G	3G	4G	1F	2F	3F	4F	1G	2G	5G	6G	1F	2F	4F	5F	
Sheet	Groove	1G	X				X	X			X				X			
		2G	X	X			X	X			X	X			X			
		3G	X		X		X	X	X		X				X			
		4G	X			X	X	X		X					X			
Sheet	Fillet	1F				X								X				
		2F				X	X							X	X			
		3F				X	X	X						X				
		4F				X	X		X					X	X	X		
Tube	Groove	1G	X				X	X			X			X	X			
		2G	X	X			X	X			X	X		X	X			
		5G	X		X	X	X		X	X	X		X		X		X	X
		6G	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Tube	Fillet	1F				X								X				
		2F				X	X							X	X			
		4F				X	X		X					X	X	X		
		5F				X	X	X	X					X	X	X	X	

^a Welding Position, base metal form, and base metal qualified by test weld. Use of heat sinks or backing is optional. However, qualification using heat sinks of backing does not qualify for welding without heat sinks or backing.

^b Qualification for sheet or tube fillet welds in material 0.063 in [1.6 mm] in thickness (sheet or tube wall) or less requires a fillet weld test. A groove weld test cannot be used to qualify fillet welds in this thickness range.

^c A sheet test weld qualifies for tube welds 1 in [25 mm] in O.D. or greater.

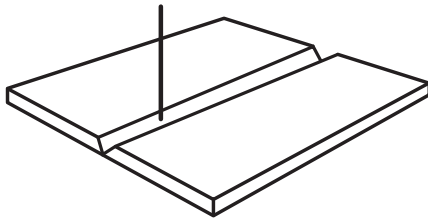
5.3.7.1 Groove Test Weld in Sheet. The test weld is a butt joint in sheet as described in Figure 5.6.

5.3.7.2 Fillet Test Weld in Sheet. The test weld is a T-joint in sheet as described in Figure 5.7.

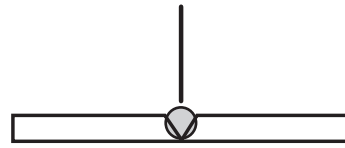
5.3.7.3 Groove Test Weld in Tube. The test weld is a butt joint in tube as described in Figure 5.8.

5.3.7.4 Fillet Test Weld in Tube. The test weld is a tube to sheet joint as described in Figure 5.9.

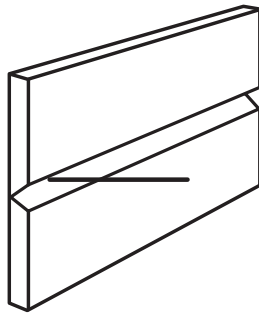
5.3.7.5 Special Applications. When none of the test welds described above are applicable to a given production weld, a special welder or welding operator qualification limited to the specific application may be achieved with a test weld consisting of the given production weld or a test weld representative of the given production weld. The qualification is limited to the welding conditions of the test weld with regard to welding process, base metal composition, base metal thickness, welding position, base metal form, type of weld, and the other welding conditions of 5.3.6. The required inspection, examination, and acceptance criteria shall be consistent with 5.3.8 or with production part criteria.



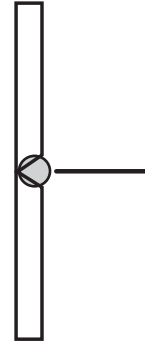
1G



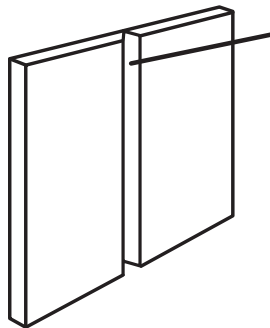
Flat position. The welding position used to weld from the upper side of the joint; the face of the weld is approximately horizontal.



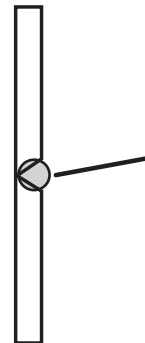
2G



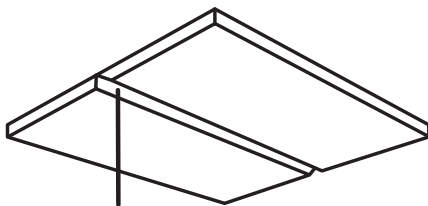
Horizontal position. The position of welding in which the axis of the weld lies in an approximately horizontal plane and the face of the weld lies in an approximately vertical plane.



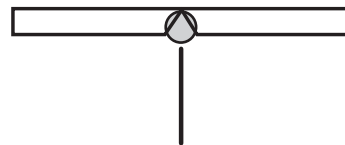
3G



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

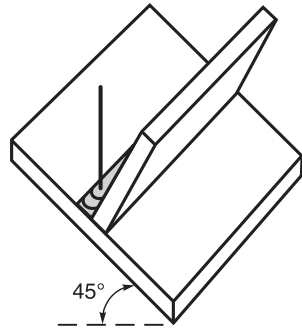


4G

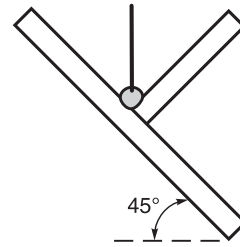


Overhead position. The position in which welding is performed from the underside of the joint.

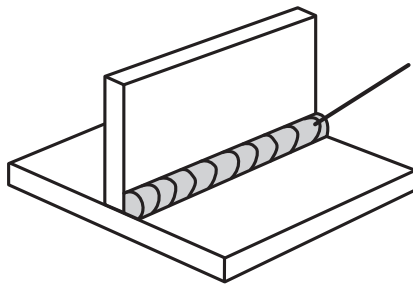
Figure 5.2—Groove Weld in Sheet: Positions 1G, 2G, 3G, and 4G



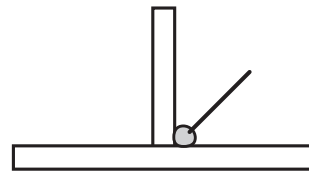
1F



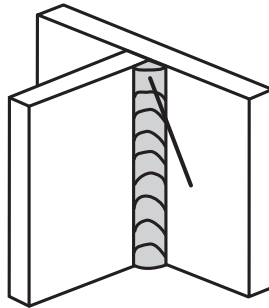
Flat position. The welding position used to weld from the upper side of the joint; the face of the weld is approximately horizontal.



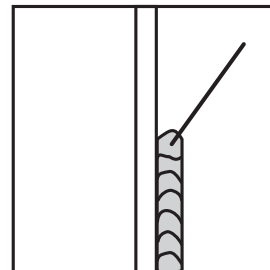
2F



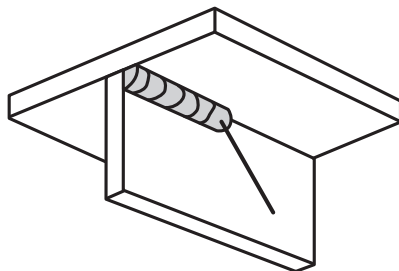
Horizontal position. The position in which welding is performed on the upper side of an approximately horizontal surface and against an approximately vertical surface.



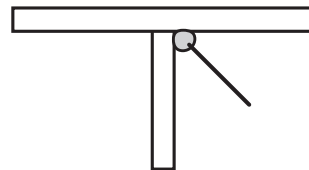
3F



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

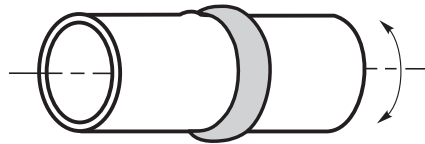


4F

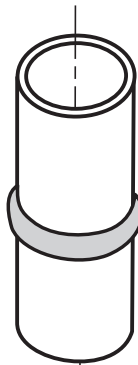


Overhead position. The position in which welding is performed from the underside of the joint.

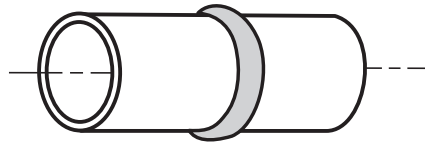
Figure 5.3—Fillet Weld in Sheet: Positions 1F, 2F, 3F, and 4F

**1G**

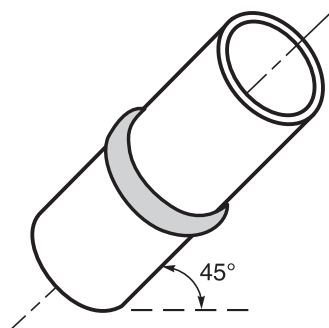
Horizontal rolled position. The position of a pipe joint in which the axis of the pipe is approximately horizontal, and welding is performed in the flat position by rotating the pipe.

**2G**

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

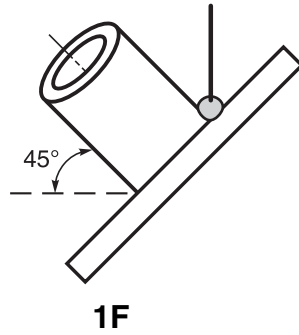
**5G**

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

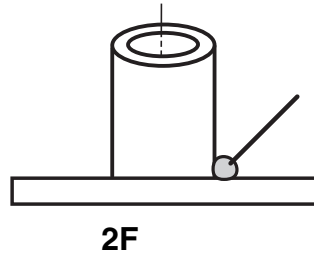
**6G**

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

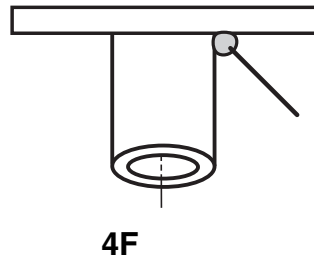
Figure 5.4—Groove Weld in Tube: Positions 1G, 2G, 5G, and 6G



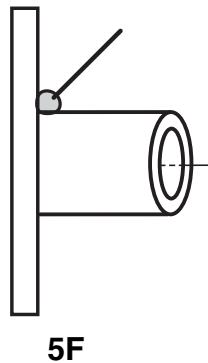
Flat position. The welding position used to weld from the upper side of the joint; the face of the weld is approximately horizontal and the pipe is rotated during welding.



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



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



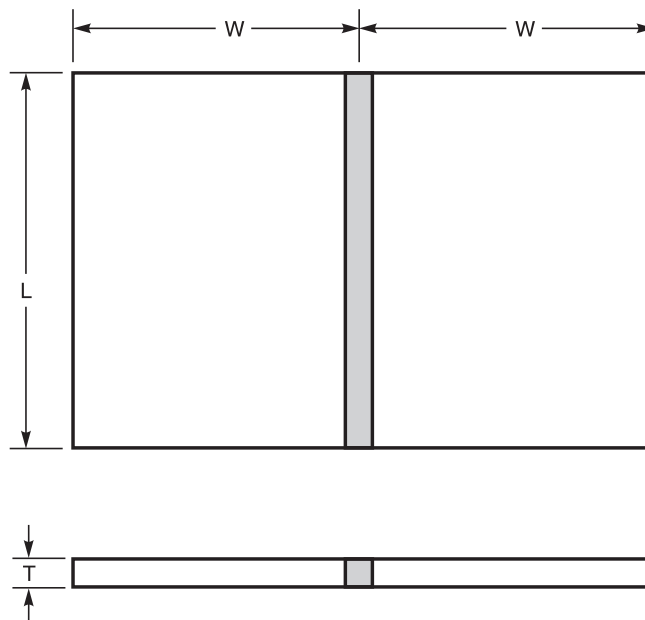
Multiple Position. The position in which the axis of the pipe is approximately horizontal and the pipe is not rotated during welding.

Figure 5.5—Fillet Weld in Tube: Positions 1F, 2F, 4F, and 5F

**Table 5.4
Other Welding Conditions Qualified by Test Weld**

Test Weld	Qualified							
	Backing		Groove Weld				Current Type ^a	
	With	Without	Single	Double	Complete Penetration	Partial Penetration	AC	DC
With Backing	X							
Without Backing	X	X						
Single Welded Groove Weld			X	X				
Double Welded Groove Weld				X				
Complete Penetration Weld					X	X		
Partial Penetration Weld						X		
AC Welding							X	
DC Welding								X

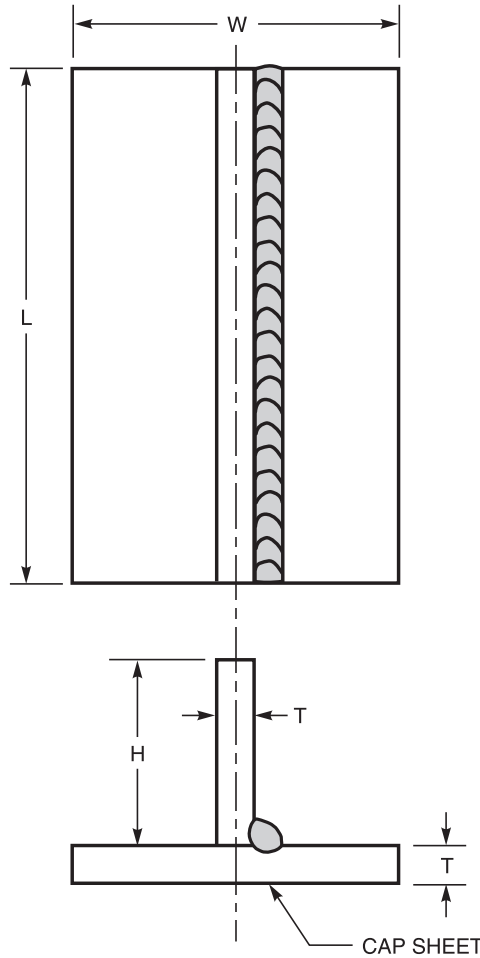
^a When Applicable



Base Metal Thickness (in [mm])	Minimum Dimensions (in [mm])	
T	W ^a	L
≤ 0.063 [1.6]	2 [50]	5 [125]
> 0.063 [1.6]	3 [75]	8 [200]

^a Suggested Dimension

Figure 5.6—Groove Test Weld in Sheet



Base Metal Thickness (in [mm])		Minimum Dimensions (in [mm])		
T	W ^a	L	H	
≤ 0.063 [1.6]	4 [100]	5 [125]	2[50]	
> 0.063 [1.6]	6 [150]	8 [200]	3[75]	

^a Suggested dimension.

Note: Where member differ in thickness more than 10% of the thicker member, the cap sheet shall be the thicker member.

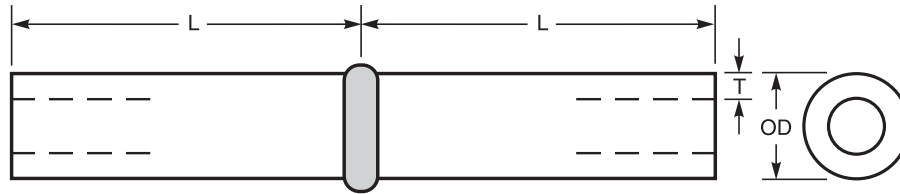
Figure 5.7—Fillet Test Weld in Sheet

5.3.8 Inspection and Examination Requirements

5.3.8.1 Inspection. Test welds shall be accepted or rejected in accordance with the criteria for Class A welds in Table 7.1, except a 0.5 in [13 mm] discard may be taken at the ends of groove and fillet weld coupons in sheet or plate. Inspection methods shall be performed as follows:

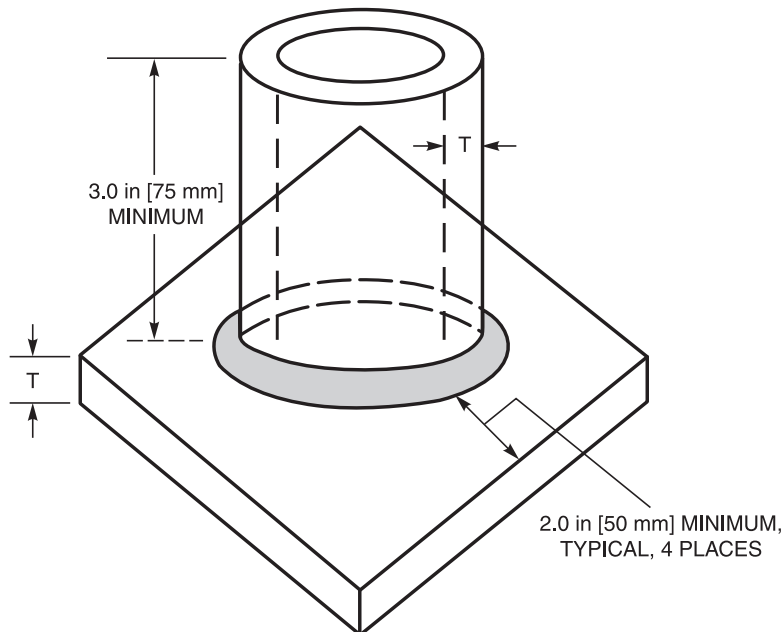
- (1) External weld quality shall be evaluated in the as-welded condition using visual inspection.
- (2) Internal weld quality shall be evaluated using radiographic inspection methods for groove welds and metallographic examination for fillet welds. Bend testing, in accordance with AWS B4.0 or Annex C, may be substituted for radiograph examination of groove welds and metallographic examination of fillet welds.

5.3.8.2 Metallographic Examination. Metallographic examination using magnification of 10X–100X shall be used in place of radiographic examination for fillet welds. Blanks shall be removed in accordance with Figure 5.10 and 5.11 for



<u>Base Metal Thickness (in [mm])</u>	<u>Minimum Dimensions (in [mm])</u>
T	L
≤ 0.063 [1.6]	2 [50]
> 0.063 [1.6]	3 [75]

Figure 5.8—Groove Test Weld in Tube



Note: Where the members differ in thickness equal to or more than 10% of the thicker member, the sheet shall be the thicker member.

Figure 5.9—Fillet Test Weld in Tube

fillet welds in sheet or tube. When the base metal thickness is equal to or less than 0.063 in [1.6 mm], sections of specimen marked “M” shall be allowed lack of root fusion not to exceed 0.1 times the fillet weld leg length (see Figure 5.12B). All fillet test welds greater than 0.063 in [1.6 mm] shall exhibit complete joint fusion (root fusion) on both cross section surfaces of specimen marked “M” (see Figure 5.12A). All other acceptance criteria for Class A welds apply.

5.3.8.3 Referee Interpretation. Test welds with NDE indications that are not clearly interpreted as rejectable may, at the sole discretion of the Engineering Authority, be subjected to supplementary testing consisting of metallographic examination, bend testing, or both, at the location of the indication, regardless of material group. Test methods and acceptance criteria shall be at the discretion of the Engineering Authority, and should be in concert with the metallurgical inspection requirements of this specification and the bend test methods of AWS B4.0. When no evidence of a defective weld is discovered in these supplementary tests, the test weld, all test results and all inspection results, including radiographic film, should be considered acceptable by the Engineering Authority.

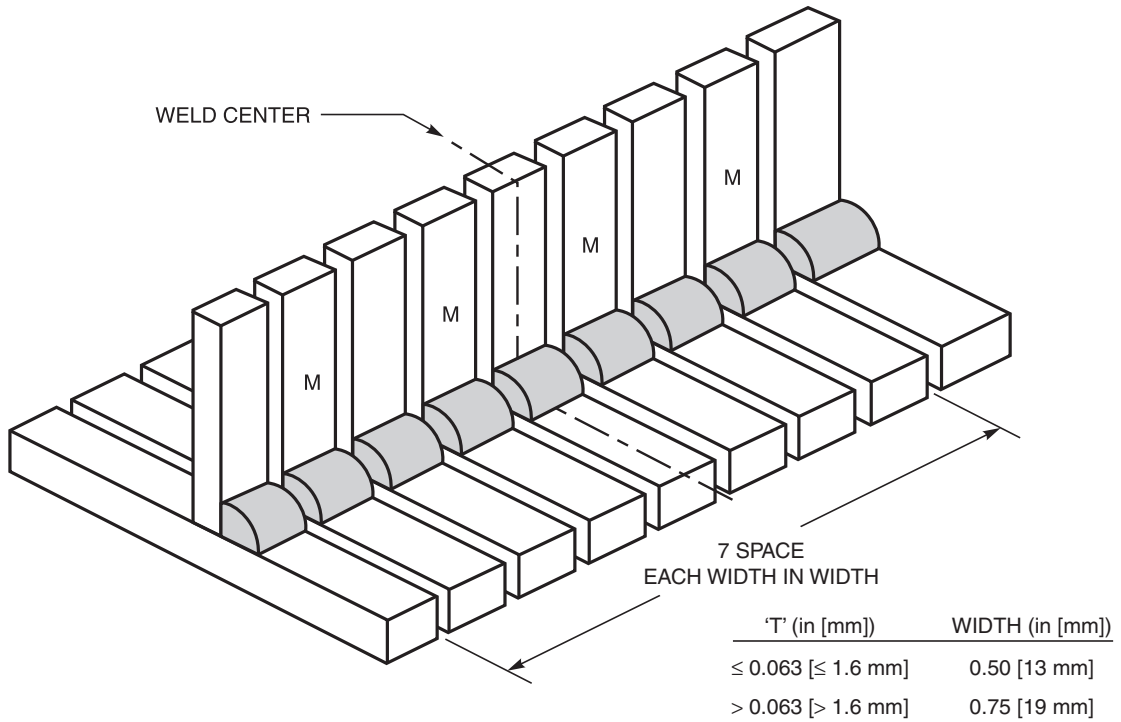


Figure 5.10—Blank Locations for Metallographic Specimens in Fillet-Welded Sheet

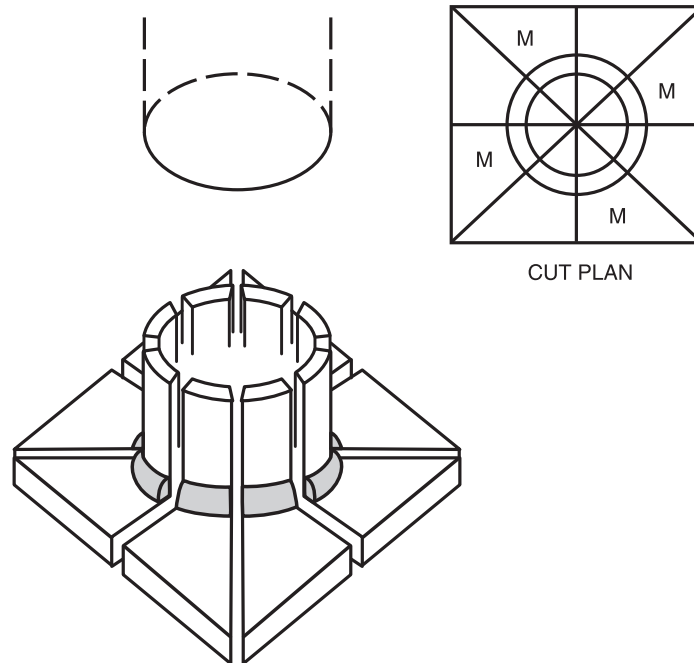
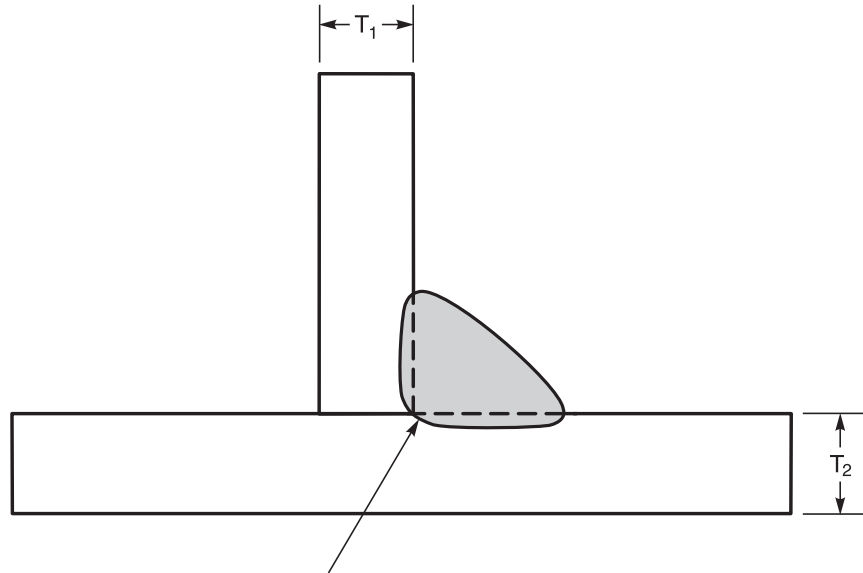


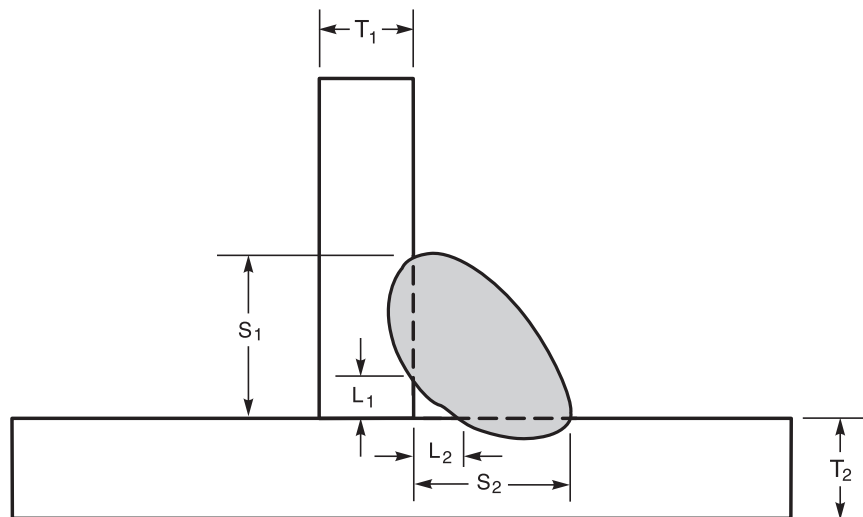
Figure 5.11—Blank Locations for Metallographic Specimens in Fillet-Welded Tube



Notes:

1. When thickness of both members (T_1 and T_2) is >0.063 in. [1.6 mm], there shall be an evidence of melting and fusing of both members at the corner and weld metal penetration beyond the junction of two members.
2. When thickness of either member (T_1 or T_2) is ≤ 0.063 in. [1.6 mm], requirement of Figure 5.12B shall be met

Figure 5.12A—Incomplete Fusion at Root in Fillet Welds When Thickness of Both Members is Greater Than 0.063 in [1.6 mm]



Legend:

- L_1 = Measured incomplete fusion at the root in vertical member
- L_2 = Measured incomplete fusion at the root in horizontal member
- S_1 = Measured leg size in vertical member
- S_2 = Measured leg size in horizontal member.

Notes:

1. When thickness (T_1 or T_2) of any member is ≤ 0.063 in [1.6 mm], L_1 shall be $\leq 0.1 \times S_1$ and/or L_2 shall be $\leq 0.1 \times S_1$
2. When thickness (T_1 or T_2) of both members is >0.063 in [1.6 mm], requirement of Figure 5.12A shall be met.

Figure 5.12 B—Incomplete Fusion at Root in Fillet Welds When Thickness of Any Member is Less Than or Equal to 0.063 in [1.6 mm]

5.4 Welding Procedure Qualification (Procedure)

5.4.1 Written Welding Procedure. All welds produced to the requirements of this specification shall be accomplished in accordance with a written welding procedure. Guidelines for written welding procedure contents for typical welding processes covered by this document are suggested in AWS B2.1. The final decision on specific format and content shall be at the discretion of the Engineering Authority.

5.4.1.1 Welding Procedure Specification (WPS). The Welding Procedure Specification (WPS), shall include the essential variables specified in paragraph 5.4.2. The WPS may be documented on a drawing, shop router, work order, or document similar to the recommended form referenced in Figure 5.13.

5.4.2 Procedure Qualification. Procedures for Class A and B welds shall be qualified. Qualification of weld settings for manual welds is not required unless specified by the Engineering Authority. Class C welds do not require procedure qualification. The correlation between test welds and production welds shall be based on the following essential variables:

- (1) welding process
- (2) base metal composition group
- (3) base metal thickness
- (4) welding position
- (5) base metal form, sheet or tube
- (6) type of weld, groove or fillet
- (7) type of shielding used
- (8) electrode type/geometry (GTAW/PAW)
- (9) filler metal used
- (10) joint design
- (11) electrical characteristics
- (12) preheat requirements
- (13) postweld heat requirements
- (14) other variables required by the Engineering Authority

5.4.2.1 Procedure Qualification Record (PQR). The fabricator shall establish a system of records to document the welding procedure. The record shall include but not be limited to:

- (1) Method of Qualification
- (2) Test Methods
- (3) Procedures
- (4) Acceptance Criteria
- (5) Test Results
- (6) Acceptance

5.4.2.2 Test Methods for Welding Procedure Specification Qualification. Unless otherwise specified or modified by the Engineering Authority, the following tests listed in Table 5.5 are required for weld procedure qualification. The test results shall be recorded on the Procedure Qualification Record (PQR).

5.4.3 Method of Procedure Qualification. Welding procedure qualification may be accomplished in accordance with the requirements of AWS B2.1 as deemed applicable by the Engineering Authority.

WELDING PROCEDURE SPECIFICATION (WPS)

Company Name _____
Welding process(es) _____
Supporting PQR No.(s) _____

JOINT DESIGN

Type: _____
 Single Double Weld
 Backing: Yes No
 Backing Material: N/A
 Root Opening _____ Root Face Dimension _____
 Groove Angle _____ Radius (J-U) _____
 Back Gouging Yes No Method _____

BASE METALS

Material Spec. _____
 Type or Grade _____
 Thickness: Groove _____ Fillet _____
 Diameter _____

FILLER METALS

Specification _____

SHIELDING

Flux _____ Gas _____
 Composition _____
 Electro-Flux (Class) _____ Flow Rate _____
 _____ Gas Cup Size _____

PREHEAT

Preheat Temp., Min _____
 Inter-pass Temp., Min _____ Max _____

Identification #

Revision _____ Date _____ By _____
 Authorized By _____ Date _____
 Type Manual Semi-Automatic
 Mechanized Automatic

Position _____

ELECTRICAL CHARACTERISTICS

General Characteristics _____

 Current AC DCEP DCEN Pulsed
 Other _____

Tungsten Electrode (GTAW/PAW)

Size: _____
 Type: _____

TECHNIQUE

Stringer or Weave Bead _____
 Multi-pass or Single Pass (per side) _____
 Number of Electrodes _____
 Peening _____
 Inter-pass Cleaning _____
 Other _____

POSTWELD HEAT

Temp _____
 Time _____

WELDING PROCEDURE

Pass or Weld Layers	Process	Filler Metals		Current			Travel Speed*	Joint Details
		Class	Diam	Type & Polarity	Amps or Wire Feed Speed*	Volts*		
					*	*	*	

* N/A for manual process. These settings are not visible to the welder with the Hood Down

Figure 5.13—Welding Procedure Specification (WPS) Form

Table 5.5
PQR Test Requirements

Test	Groove Weld	Fillet Weld	Stud Weld	Weld Cladding
Visual Inspection per Clause 7	Yes	Yes	Yes	Yes
Tension Test	(Note a)	(Note a)	Yes or Torque ^b	
Macro –Examination	(Note a)	Yes	Yes ^a	
Bend Test	(Note c)	(Note c)		
Fracture Toughness Test	(Note a)			
Penetrant Examination	Yes	Yes	Yes	Yes
Magnetic Particle Examination	(Note a)	(Note a)	(Note a)	(Note a)
Radiographic Examination	(Note a)	(Note a)	(Note a)	(Note a)
Chemical Analysis				(Note a)

^a When specified in the engineering documents or by the Engineering Authority.

^b Minimum values shall be determined by the Engineering Authority

^c The use of a macro examination in lieu of bend testing shall be permitted only if the material is such that the specimen cannot be bent within dimensional limitations in AWS B4.0, *Standard Practice for Examination of Welds*, or Annex C.

5.4.4 Alternate Methods of Procedure Qualification. In lieu of 5.4.3, welding procedure qualification may be accomplished by welding at least one procedure qualification test weldment consisting of any of the following:

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

The Engineering Authority shall provide the test methods and acceptance criteria for the test weldments to be used when qualifying weld procedures.

5.4.5 Use of Existing Qualification. Alternatively, and in lieu of 5.4.2, an existing qualified welding procedure may be accepted as equivalent to the requirement of this specification at the sole discretion of the Engineering Authority.

5.4.6 WPS and PQR Test Record Forms. Suggested content or format test record forms for both Welding Procedure Specification (WPS) and Procedure Qualification Record (PQR) forms are shown in Figures 5.13 and 5.14. These forms may be modified as required to meet the requirements of the weld procedure and manufacturing facility.

6. Fabrication

6.1 Scope. This clause establishes requirements for the fabrication of weldments.

6.2 Welding Consumables

6.2.1 Identification (Bare Welding Wire and Welding Rods, Electrodes, Inserts, and Fluxes). Consumables used in welding shall be identified using an established standard or specification or by a standard specified in the procurement specification. If the identification marking is destroyed or missing, the consumable shall not be used. When specified on the engineering drawing or a contract document, traceability of the consumables shall be maintained throughout the welding process.

Procedure Qualification Record (PQR)

TENSILE TEST

Specimen No.	Width, in [mm]	Thickness, in [mm]	Area, in [mm ²]	Ultimate Tensile Load, lb [kg]	Ultimate unit Stress, psi [MPa]	Character of Failure and Location

BEND TEST

Specimen No.	Type of bend	Result	Remarks

VISUAL INSPECTION: Visual Inspection per Clause 7 of AWS D17.1/D17.1M

Table 7.1 _____ Radiographic-Ultrasonic Examination
 Pass _____ RT Report no. _____ Result _____
 Fail _____ UT Report no. _____ Result _____
 Appearance _____

FILLET WELD TEST RESULTS

Minimum Size Multiple Pass Maximum Size Single Pass
 Macro-etch Macro-etch
 1 _____ 3 _____ 1 _____ 3 _____
 2 _____ 4 _____ 2 _____ 4 _____

Other Tests (as applicable):

Magnetic Particle (MT) _____
 Dye Penetrant _____

Welder's Name _____ ID # _____ Stamp # _____

Tests Conducted by _____ Laboratory: _____
 Test Number _____
 Per _____

The undersigned hereby certifies that the requirements in this record are correct and that the test welds were prepared, welded, and tested in accordance with the requirements of AWS D17.1.

Signed _____
Manufacturer or Contractor
 Title _____
 Date _____

Figure 5.14—Procedure Qualification Record (PQR) Form

6.2.2 Storage and Use

6.2.2.1 Filler Metals. Welding filler materials shall be stored in a clean and dry environment. Filler metal types shall not be commingled during storage or use. Heating may be employed as necessary to prevent moisture accumulation. Low hydrogen SMAW and FCAW electrodes shall be handled and stored according to manufacturer's recommendations or according to AWS A5.1/A5.1M, A5.5/A5.5M, A5.20/A5.20M, or A5.29/A5.29M, as appropriate.

6.2.2.2 Welding Fluxes. Fluxes shall be labeled and segregated by type and/or by their particular application. To prevent moisture pickup fluxes shall be stored in sealed containers or be kept in a suitably clean and dry environment. Clean unfused flux may be reused after reconditioning according to the manufacturer's recommendations.

6.2.3 Gases

6.2.3.1 Gas Procurement Specification. Welding and shielding gases shall be procured to the requirements of Table 6.1 or to the requirements of AWS A5.32/A5.32M. Gases may be procured to the alternate specifications in Table 6.1, with the approval of the Engineering Authority.

6.2.3.2 Shielding Gas(es). When the welding process requires the use of a shielding gas, the gases or gas mixtures designated in Table 6.2 are recommended for each of the different base materials. When parts are welded using a qualified Welding Procedure Specification (WPS), the chemical composition, volume percentage, and flow rate of each gas shall be as specified in the qualified WPS.

**Table 6.1
Gas Requirements^a**

Gas	Specification	Alternate Specification
Argon	MIL-A-18455	CGA G-11.1
Helium	BB-H-1168	CGA G-9.1
Oxygen	BB-O-925, Type I OR II	CGA G-4.3
Nitrogen	BB-N-411, Type I OR II, Class 1, Grade B	CGA G-10.1
Hydrogen	BB-H-886, Type I OR II	CGA G-5.3
Acetylene	BB-A-106, Grade B	CGA G-1.1
Carbon Dioxide	BB-C-101, grade B	CGA G-6.2
Gas Mixtures	The purity of the gases in the mixture shall be as specified for the individual gas listed above. Composition of the gas mixture shall be as specified by the <u>Engineering Authority</u> .	

^a Refer to paragraph 6.2.3.1

**Table 6.2
Recommended Shielding Gases for Welding^a**

Material	Gas ^b							
	Ar	He	Ar-He	Ar-O ^c	Ar-H	N	CO ₂	Ar-CO ₂
Aluminum and Its Alloys	X	X	X					
Cobalt and Its Alloys	X	X	X		X			
Copper and Its Alloys	X	X	X					
Magnesium and Its Alloys	X	X	X					
Nickel and Its Alloys	X	X	X					
<u>Stainless Steel</u> Alloys	X	X	X	X		(Note d)		
Plain Carbon Steels	X	X	X	X			(Note e)	(Note e)
Low Alloy Steels	X	X	X	X				(Note e)
Titanium and Its Alloys	X	X	X					

^a Refer to paragraph 6.2.3.2.

^b Gas Compositions and mixtures shall comply with Table 6.1.

^c 8 % oxygen maximum.

^d Recommended for backing only.

^e Only recommended on plain carbon steels or low alloy steels with a maximum of 0.25% nominal carbon.

6.3 Welding Equipment. Welding equipment (such as welding machines, welding torches, regulators, filler material feeders, etc.) shall be capable of producing welds that meet the acceptance criteria specified in Clause 7. Welding equipment shall not be used without needed repairs or adjustments when a welder, welding operator, or welding engineer has a concern about the capability of the equipment to operate satisfactorily. The welding equipment shall be capable of maintaining weld quality and consistency.

6.3.1 Calibration

6.3.1.1 Meters, Gages, and Dials. Meters, gages, and dials installed on automatic, mechanized, or robotic welding apparatus shall be calibrated using an established procedure.

6.3.1.2 Gas Flow Meters and Pressure Gages. Gas flow meters and pressure gages are for reference only. They do not require calibration.

6.3.1.3 Calibration Procedures. The fabricator shall establish and document applicable calibration procedures.

6.3.1.4 Calibration Period. Required calibrations shall be performed at an interval of two (2) years or less. Required calibrations shall also be performed when meters, gages and dials have been affected by repairs made to automatic, mechanized, or robotic welding apparatus.

6.4 Weld Settings. When parts are welded using a qualified WPS, weld settings shall be within the limits specified in the WPS.

6.4.1 Reproducibility Tests for Qualified Machine Welding Settings

6.4.1.1 Applicability of Requirements. These requirements are applicable to automatic, mechanized, and robotic equipment only. The reproducibility test shall be performed according to 6.4.1.2 when either of the following is encountered:

- (1) The equipment fails to produce acceptable weld quality using the settings of a qualified WPS.
- (2) A major component of the equipment is either repaired or replaced (as determined by the fabricator).

6.4.1.2 Test Requirements. The reproducibility test shall be performed according to a written procedure. The written procedure shall establish welding parameters, test specimen configuration, and acceptance criteria for the welded test specimen(s).

6.5 Preweld Cleaning and Other Preparation

6.5.1 Surface Cleaning. All surfaces to be welded and surfaces that may affect quality of the resulting weld (e.g., welding filler materials and fixtures) shall be free from slag, surface oxides, scale, protective finishes, oils, grease, dirt, or any other contaminants. Chemical methods (e.g., alkaline cleaning, solvent wipe, or etching) or mechanical methods (e.g., wire brushing, scraping, abrasive blasting, or machining) shall be used before welding, as needed, to assure compliance to these requirements.

CAUTION: Chlorinated solvents or methyl alcohol shall not be used when cleaning titanium or titanium alloys.

CAUTION: Austenitic stainless steel wire brushes or carbon steel wire brushes may be used on carbon or low alloy steels. Only austenitic stainless steel wire brushes shall be used on all other materials being welded. Once an individual wire brush is used on a certain material group (e.g., titanium, aluminum, nickel-base alloys), it shall be suitably identified and used only on that material group.

6.5.2 Contamination of Cleaned Surfaces. Previously cleaned surfaces shall be protected from contamination. If contamination does occur, the surfaces shall be cleaned again by one of the methods specified in 6.5.1 before welding.

6.6 Preweld Joint Preparation and Fit-up

6.6.1 Joint Preparation. The edge of each joint member shall be prepared as specified by the weld symbols on the engineering drawing.

NOTE: Annex A provides guidelines for joint preparation.

6.6.2 Fit-up Gap. Unless otherwise specified on the Engineering drawing, fit-up tolerances shall be in accordance with Annex A.

6.6.3 Flange Joint Fit-up. Flange joint fit-up shall be in accordance with the weld symbols on the engineering drawing.

NOTE: Annex A provides guidelines for the flange joint fit-up.

6.6.4 Joint Members of Unequal Thickness

6.6.4.1 Joint Member Preparation. Joint members shall be prepared as shown in Figure 6.1 when the following conditions exist:

- (1) a full penetration weld is specified on the engineering drawing
- (2) both joint members exceed 0.125 in [3.2 mm] in thickness
- (3) the thickness ratio between joint members meets or exceeds: 1.5:1

6.7 Preheating and Interpass Temperature Control. Preheating and interpass temperature shall be established for materials susceptible to cracking during or after welding. Temperatures which are found to reduce the tendency to form cracks shall be included in the WPSs and employed when welding production hardware.

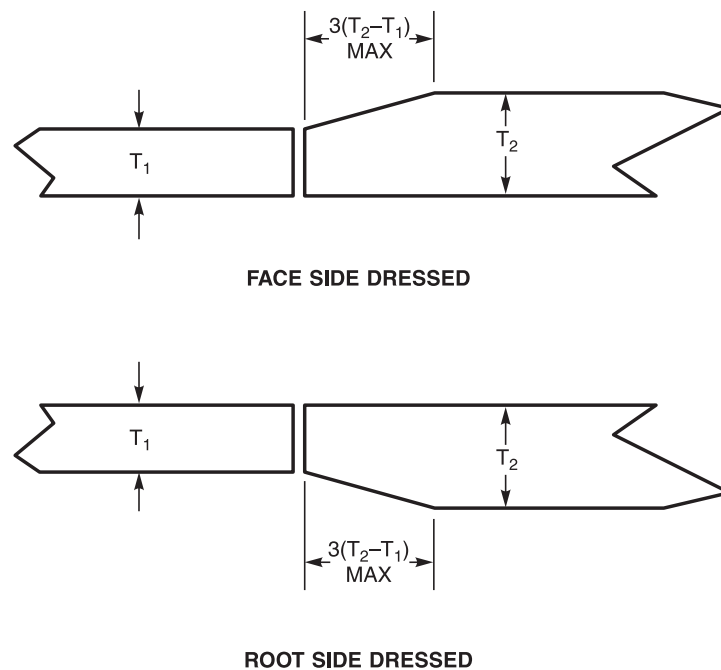
NOTE: Table 6.3 provides recommended preheat and interpass temperatures for some materials.

6.8 Tack Welds. Filler material used for tack welds shall be the same as that used for subsequent welding unless otherwise specified on the engineering drawing or listed in the qualified and Engineering Authority approved WPS. Tack welds shall be consumed during subsequent welding unless removed in other processing. The requirements of 6.6 and 6.7 will be considered during the tack welding operations.

6.9 Weld Start and Run-Off Tabs. Weld start and run-off tabs, when used, shall be composed of the same alloy as the joint members. They shall be welded with the same filler material as that filler material specified on the engineering drawing or the qualified and Engineering Authority approved WPS.

6.10 Weld Shielding for GTAW, GMAW, and PAW. The weld and the heat-affected zones (including deposited weld metal behind the weld pool in reactive materials, such as titanium and its alloys) shall be protected from oxidation during welding. The shielding method shall be included in the WPS. Back-up shielding gas shall be used during the welding of the reactive materials, such as titanium and its alloys. Back-up gas shall be as specified in the qualified WPS.

6.11 Tungsten Electrodes. Tungsten electrodes, when required, shall be in accordance with AWS A5.12M/A5.12 (ISO 6848 MOD), *Specification for Tungsten and Tungsten-Alloy Electrodes for Arc Welding and Cutting.*



Note: Refer to 6.6.4.1.

Figure 6.1—Joint Preparation in Joint Members of Unequal Thickness

6.12 Filler Materials. Any welding process requiring filler material shall only be performed using the filler material specified on the engineering drawing or on the qualified and the Engineering Authority approved WPS. When a filler material is not specified, welding shall not be performed until Engineering Authority provides pertinent filler material information. This requirement is not applicable to autogenous welds (welds made without filler material). The filler material information provided in Tables 6.4, 6.5, and 6.6 is for general guideline use and shall not be used for filler metal selection without direction from the Engineering Authority.

6.13 Interpass Cleaning. Interpass cleaning shall be performed using one of the mechanical methods specified in 6.5.1.

6.13.1 Interpass Cleaning of Titanium and Titanium Alloys. Interpass cleaning of titanium or titanium alloy parts shall only be performed following visual inspection and acceptance of the surface discoloration to the requirements of Table 7.1.

6.14 Welding and Weldments. The welding of joint members and the resulting weldment shall comply with the requirements specified in the following subclauses:

Table 6.3
Preheat and Interpass Temperatures^a

Base Metal Being Welded	Recommended Preheat and/or Interpass Temperature
Carbon and Alloy steel with carbon equivalent 0.35% or greater ^b	600° F Maximum ^{b,c} [315.5° C Maximum]
Magnesium alloys in condition F	450° F to 500° F [232° C to 260° C]
Magnesium alloys in condition T	250° F to 300° F [121° C to 149° C]

^a Refer to 6.7

^b The method provided in AWS D1.1/D1.1M may be used to determine carbon equivalent, preheat temperature and interpass temperature.

^c This is a maximum temperature. Depending upon part configuration and weld environment, user should establish any temperature to or below this temperature suitable for use in production welding.

Table 6.4
Filler Metal for Welding Aluminum Alloys Using GMAW, GTAW, and PAW Processes^a

Base Metal	Filler Material	Filler Material Specification
1100	ER1100 or ER4043	AWS A5.10/A5.10M
3003	ER1100 or ER4043	AWS A5.10/A5.10M
2219	ER2319	AMS 4191 or AWS A5.10/A5.10M
5052	ER5356 or ER 4043	AWS A5.10/A5.10M
6013	ER4043	AWS A5.10/A5.10M
6061	ER4043 or ER 5356	AWS A5.10/A5.10M

^a Refer to G4.12 and 6.12.

Table 6.5
Filler Metal for Welding Titanium Alloys Using GMAW, GTAW, and PAW Processes^a

Base Metal	Filler Material	Filler Material Specification
Commercially Pure Titanium	CP	AMS 4951
	ERTi-4	AWS A5.16/A5.16M
3Al-2.5V Ti	ERTi-3Al-2.5V	AWS A5.16/A5.16M
5Al-2.5Sn Ti	5Al-2.5Sn	AMS 4953
	ERTi-5Al-2.5Sn	AWS A5.16/A5.16M
6Al-4V or 6Al-4VELI	6-4	AMS 4956
	ERTi-6Al-4V	AWS A5.16/A5.16M

^a Refer to G4.12 and 6.12.

Table 6.6
Filler Metal for Welding Stainless Steels and Heat Resistant Alloys
Using GMAW, GTAW, and PAW Processes^a

Base Metal	Filler Material	Filler Material Specification
304L and 316L	ER308L	AWS A5.9/ <u>A5.9M</u>
321 and 347	ER321 or ER347	AWS A5.9/ <u>A5.9M</u>
A286	A286	AMS 5804 or AMS 5805
21-6-9	ER219	AWS A5.9/ <u>A5.9M</u>
PH13-8Mo	WPH 13-8Mo ELC	AMS 5840
PH15-7Mo	WPH 15-7Mo-VM	AMS 5812
PH 15-5	15-5PH or ER630	AMS 5826 or AWS A5.9/ <u>A5.9M</u>
PH 17-4	WPH 17-4 or ER630	AMS 5825 or AWS A5.9/ <u>A5.9M</u>
PH 17-7	PH 17-7	AMS 5824
	WPH 15-7Mo-VM	AMS 5812
Inconel® 600	ERNiCrFe-5	AWS A5.14/ <u>A5.14M</u>
Inconel® 625	Inconel® 625	AMS 5837
	Hastelloy® W or ERNiMo-3	AMS 5786 or AWS A5.12M/ <u>5.12</u>
Inconel® 718	Inconel® 718	AMS 5832
Inconel® X750	ERNiCrFe-7	AWS A5.14/ <u>A5.14M</u>

^a Refer to G4.12 and 6.12.

6.14.1 Weld Settings. Before starting a welding cycle, the settings on the welding equipment shall be set to those listed in the qualified WPS.

6.14.1.1 Arc Strike. The welding arc shall not be struck on any portion of the base metal away from the surfaces to be joined. When indication of an arc strike or an arc burn is present in an area other than the deposited weld metal, the weldment shall be rejected as required in Clause 7.

6.14.2 In-Process Correction. Any correction of a weld made by the welder before submitting the weldment for acceptance inspection in accordance with Clause 7 is an in-process correction. The correction shall not change the metallurgical or physical condition of the base metal. The correction shall occur before subjecting the weld to any heat treat operations. Before initiating in-process correction, surfaces to be welded shall be cleaned to remove oxide and other contaminants in accordance with 6.5.1.

6.14.2.1 Welds Made Using Filler Material. For welds made using filler material the following applies:

- (1) An undercut, underfill, or crater (without crack) shall be considered as a surface depression and corrected by depositing filler material (the same as used in making the original weld) that fairs smoothly into the weld and the base metal.
- (2) An overlap, weld reinforcement, or other protruding indication may be removed by a metal removal method that will not degrade the material's properties. Corrections shall be performed in such a manner that the weld size and base metal thickness will remain within drawing tolerances. The corrected weld bead shall comply with Clause 6.14.3.

6.14.2.2 Mechanized, Automatic, or Autogenous Welds. In-process corrections using nonmanual or autogenous welds may be performed providing the same process and parameters are used as used in original weld. Any other process or parameters are only allowed when the engineering drawing or contract document allows such correction.

6.14.2.3 Allowed Number of In-Process Correction Attempts. One in-process correction attempt is allowed in each individual flaw location. When the in-process correction requires more than one attempt at the same flaw location, the combination of corrections shall be qualified as the original weld (with WPS and supporting PQR) or approved by the appropriate Material Review Board.

6.14.2.4 Documentation of In-process Correction. The in-process correction history shall be documented when required by the Engineering Authority. The method and extent of documentation shall be that agreed upon by the Engineering Authority and the fabricator.

6.14.3 Removal of Weld Reinforcement. Weld reinforcement removal shall be accomplished using methods that do not reduce the thickness of the base metal. Weld reinforcement shall only be removed for one or more of the following reasons:

- (1) When specified by the engineering drawing notes or weld symbol. (The removal shall not exceed limits specified on the engineering drawing or any other contractual document).
- (2) When necessary to aid in the interpretation of nondestructive inspection indications. Remaining reinforcement shall be visually evident above the surface plane of the adjacent joint member and extend throughout the weld bead width. The weld toe area shall comply with the requirements of Clause 7.
- (3) When fit or function of the final assembly dictate material removal. Remaining reinforcement shall be visually evident above the surface plane of the adjacent joint member and extend throughout the weld bead width. The weld toe area shall comply with the requirements of Clause 7.

6.15 Postweld Cleaning. The completed weldment shall be free of spatter, flux, scale, slag, or other foreign matter. Removal of such material during the postweld cleaning operation shall not reduce the weld bead size or base metal thickness below engineering drawing tolerances.

6.15.1 Postweld Cleaning of Welded Titanium or Titanium Alloy Parts. Postweld cleaning of welded titanium or titanium alloy parts shall only be performed after completion of a visual inspection and acceptance of the surface discoloration in accordance with Table 7.1.

6.16 Postweld Processing. Stress relieving, heat treatment, or any other postweld processing of the weldment shall be as specified on the engineering drawing or the qualified WPS.

6.17 Weld Identification Requirements

6.17.1 Interim Identification. Each welder/welding operator shall identify his work by interim marking the weldment or by marking the applicable shop planning paperwork. Alternate tracking methods may be used with approval from the Engineering Authority. The interim identification shall remain next to or with the weld through final inspection. Marking methods and materials used shall neither be detrimental to the base metal nor interfere with subsequent operations.

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

- (1) date of welding
- (2) welder's signature or individually assigned stamp or code
- (3) date of weld inspection
- (4) weld inspector's signature or individually assigned stamp or code

6.18 Acceptance Inspection. The completed weldment shall be submitted to the fabricator's quality assurance organization or its designee for an acceptance inspection. The acceptance inspection shall be performed in accordance with Clause 7.

6.19 Rework. Rework is any corrective action made to a weldment in the as-welded condition following acceptance inspection. The corrective action shall bring the weldment into full conformance with the engineering drawing and the requirements of this specification. Except as specified herein, every requirement of 6.14 applies for rework.

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

6.19.2 Root Area Rework. A weld with inadequate penetration or incomplete fusion at the root may be corrected by welding from the root side. Proper preparation of the root side shall be performed to obtain sound metal prior to welding. The prepared surface shall smoothly fair into all surfaces to be fused in the rework.

6.19.3 Documentation of Rework. All operations involved in rework shall be documented using a method approved by the Engineering Authority.

6.19.4 Inspection of the Rework. The reworked weldment shall be submitted for an acceptance inspection in accordance with Clause 7.

6.20 Repair. Repair is any corrective action on a part directed by the Customer or its designee (Material Review Board). Repairs may be made to repair discrepancies in welds or to correct other defects.

6.20.1 Repair Instructions. The Engineering Authority or its designee shall provide detailed instructions for the repair that include but are not limited to:

- (1) allowed number of weld corrections during the repair
- (2) required documentation
- (3) details for each operation (including acceptance inspection) involved in the repair

6.21 Record Requirements. Each contractor shall maintain records of consumables, calibration, in-process correction, rework, and repair according to the requirements specified herein. The records shall be kept for a minimum of seven years or a time period as specified by the Engineering Authority. The written records shall be made available to the Engineering Authority upon request.

7. Inspection

7.1 Qualification of Inspection Personnel

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

7.1.2 Visual Weld Inspectors. Personnel performing visual weld inspections shall be certified to the requirements of AWS QC1 or by experience, training, and testing requirements defined in AWS B5.2 and approved by the Engineering Authority.

7.2 Vision Test. NDE and visual weld inspection personnel shall pass an annual eye examination. The eye examination shall be administered by trained personnel designated by the responsible Level III or by qualified medical personnel. The standard of acceptance for the visual examination shall be, natural or corrected, near distance acuity such that the individual is capable of reading one of the following: Jaeger J1 at 12 in [300 mm], Jaeger J2 at 16 in [400 mm], or the Snellen English at 12 in [300 mm]. Other equivalent vision tests may be substituted providing the equivalence is verified by a licensed optometrist. Far vision shall be 20/30 or better, natural or corrected in either eye.

7.3 Visual Weld Inspection. All welds shall be visually inspected for conformance to drawing requirements.

7.4 Nondestructive Inspection. NDT inspections are required to be performed using written procedures approved by an NDT Level III inspector certified in the appropriate inspection method.

7.4.1 Penetrant Inspection (PT). All nonferromagnetic Class A and Class B welds shall be penetrant inspected using an approved Type I penetrant system, any method, sensitivity level 2 or better, and with or without developer per ASTM E1417. Ferrous Class A and Class B welds shall be penetrant inspected when specified on the drawing or in the contract. Class C nonferrous and ferrous welds shall be penetrant inspected when specified on the drawing or in the contract. Penetrant inspection shall be in accordance with ASTM E 1417, or equivalent.

7.4.2 Magnetic Particle Inspection (MT). All ferromagnetic Class A and Class B welds shall be magnetic particle inspected using a wet fluorescent continuous method in accordance with ASTM E 1444 or equivalent, unless penetrant inspection is required by the drawing or contract. Class C ferromagnetic welds shall be magnetic particle inspected when specified on the drawing or in the contract.

7.4.3 Radiographic Inspection (RT). All Class A groove welds shall be radiographically inspected in accordance with ASTM E 1742 or equivalent, unless ultrasonic inspection is required by the drawing or in the contract. When radiographic inspection of fillet welds or partial penetration groove welds is required, the acceptance criteria of the root shall be determined by the Engineering Authority. Class B and Class C welds shall be radiographically inspected when specified on the drawing or in the contract.

7.4.4 Ultrasonic Inspection (UT). Ultrasonic inspection may be used in lieu of radiographic inspection when specified by the drawing, in the contract, or by the Engineering Authority. Ultrasonic inspections shall be in accordance with AMS-STD-2154, or equivalent. When immersion ultrasonic inspection is indicated, an approved standard shall be determined by the Engineering Authority.

7.4.5 Proof Testing (PRT). Proof testing may be used in conjunction with or in lieu of inspection methods listed in 7.4.1, 7.4.2, 7.4.3, and 7.4.4 when required by the drawing, in the contract, or when directed by the Engineering Authority (see Annex G—Commentary).

7.4.6 Other Nondestructive Tests. Nondestructive tests, procedures, techniques, equipment, or materials (e.g., Acoustic Emission, Electromagnetic or Eddy Current, Leak, Neutron Radiographic, etc.) not specifically addressed in this document may be used in conjunction with those stated on drawing or in the contract. When one or more of these inspection methods are indicated, an approved standard shall be determined by the Engineering Authority.

7.5 Acceptance Criteria

7.5.1 General. The dimension of any discontinuity shall be defined by its largest dimension. Two or more discontinuities shall be treated as one when the spacing between them is less than the dimension of the larger discontinuity. Discontinuities that will be removed in subsequent machining shall not be cause for rejection. Any weldment with unacceptable discontinuities which has gone through a subsequent manufacturing operation that affects the metallurgical characteristics (other than hydrogen embrittlement relief) or that cannot be rewelded without affecting final metallurgical or surface characteristics shall be rejected. Removal of unacceptable weld metal is allowed provided that the minimum weld size is met. Incidental removal of base metal during discontinuity removal is acceptable provided minimum thickness requirements and any other engineering requirement (e.g., surface roughness) are met. In the case of weldments with variations in cross section along the joint, the thickness shall be considered to be the minimum thickness at the discontinuity.

7.5.2 Acceptable Welds. Welds shall be acceptable if they satisfy the conditions of Table 7.1. Welds not meeting these requirements shall be rejected.

Table 7.1
Acceptance Criteria in [mm]

Discontinuity	Class A	Class B	Class C
Cracks	None	None	None
Overlap (Cold Lap)	None	None	None
Incomplete Fusion	None	None	None
Incomplete Penetration^a	None	None	None
Porosity—Surface			
Individual size maximum	0.25 T or 0.030 [0.76], whichever is less	0.33 T or 0.060 [1.50], whichever is less	0.50 T or 0.090 [2.30], whichever is less
Spacing minimum	8 times the size of the larger adjacent imperfection	4 times the size of the larger adjacent imperfection	2 times the size of the larger adjacent imperfection
Accumulated length in any 3 in [75 mm] of weld maximum	1 T or 0.12 [3.00], whichever is less	1.33 T or 0.24 [6.00], whichever is less	2 T or 0.36 [9.00], whichever is less
Porosity—Subsurface			
Individual size maximum	0.33 T or 0.060 [1.50], whichever is less	0.50 T or 0.090 [2.30], whichever is less	Not applicable
Spacing minimum	4 times the size of the larger adjacent imperfection	2 times the size of the larger adjacent imperfection	Not applicable
Accumulated length in any 3 in [75mm] of weld maximum	1.33 T or 0.24 [6.00], whichever is less	2 T or 0.36 [9.00], whichever is less	Not applicable

Table 7.1 (Continued)
Acceptance Criteria in [mm]

Discontinuity	Class A	Class B	Class C
Inclusions			
Individual size maximum	0.33 T or 0.060 [1.50], whichever is less	0.50 T or 0.090 [2.30], whichever is less	Not applicable
Spacing minimum	4 times the size of the larger adjacent imperfection	2 times the size of the larger adjacent imperfection	Not applicable
Accumulated length in any 3 in [75mm] of weld—maximum	1.33 T or 0.24 [6.00], whichever is less	2 T or 0.36 [9.00], whichever is less	Not applicable
Undercut			
For the full length of weld maximum depth	0.002 [0.05]	0.015 T or 0.002 [0.05], whichever is greater	0.025 T or 0.002 [0.05], whichever is greater
Individual defect maximum	0.07 T or 0.030 [0.76], whichever is less	0.10 T or 0.050 [1.27], whichever is less	0.20 T or 0.070 [1.78], whichever is less
Accumulated length in any 3 in [75mm] of weld maximum	0.20 [5.08]	0.60 [15.24]	1.00 [25.4]
Face or Root Underfill (Groove Welds)			
For the full length of weld – maximum depth	0.005 [0.130]	0.015 T or 0.005 [0.130] whichever is greater	0.025 T or 0.005 [0.130] whichever is greater
Individual defect – maximum depth	0.07 T or 0.030 [0.76] whichever is less	0.10 T or 0.050 [1.27] whichever is less	0.20 T or 0.070 [1.78] whichever is less
Accumulated length in any 3 in [75 mm] of weld – maximum	0.20 [5.10]	0.60 [15.2]	1.00 [25.4]
Craters			
Maximum depth	0.20 T or 0.03 [0.80] whichever is less	0.20 T or 0.05 [1.30] whichever is less	0.20 T or 0.05 [1.30] whichever is less
Maximum length	1 T	1 T	2 T
Arc Strikes / Gouge Marks	Unacceptable	Unacceptable	No stated requirement
Weld Reinforcement – machine welds			
Material to 0.375 [9.53] and under	1/3 T or 0.030 [0.76] whichever is greater	No stated requirement	No stated requirement
Material greater than 0.375 [9.53]	0.125 [3.18] maximum	No stated requirement	No stated requirement
Melt-Through	See Figures A.2, A.3(a), A.3(b)	See Figures A.2, A.3(a), A.3(b)	See Figures A.2, A.3(a), A.3(b)
Weld Reinforcement—manual welds			
Material up to 0.125 [3.18]	1 T maximum	No stated requirement	No stated requirement
Material 0.125 to 0.510 [3.18 to 12.9]	1/3 T or 0.100 [2.54], whichever is greater	No stated requirement	No stated requirement
Material greater than 0.510 [12.9]	0.170 [4.32] maximum	No stated requirement	No stated requirement
Mismatch Between Members after Welding	Refer to Paragraph 7.5.2.1 & Figure 7.2 Includes A, B & C Class of welds		
Fillet Welds			
Weld Profiles	See Figure 7.1	See Figure 7.1	See Figure 7.1

**Table 7.1 (Continued)
Acceptance Criteria in [mm]**

Discontinuity	Class A	Class B	Class C
Fillet Weld Size – when fillet weld size is stated on the drawing			
Minimum size	As shown by the welding symbol	As shown by the welding symbol	As shown by the welding symbol
Fillet Weld Size – minimum size when fillet weld size is not stated on the drawing			
Minimum size – single side fillet	1.5 T	1.5 T	1.5 T
Minimum size – double side fillet	1 T	1 T	1 T
Fillet Weld Size – maximum fillet weld size larger than that stated on the drawing			
Material up to 0.090 [2.30]	2 times the fillet weld <u>size</u>	2 times the fillet weld <u>size</u>	2 times the fillet weld <u>size</u>
Material 0.091 to 0.156 [2.30 to 3.96]	1.5 times the fillet weld <u>size</u>	1.5 times the fillet weld <u>size</u>	1.5 times the fillet weld <u>size</u>
Material 0.157 to 0.750 [4.00 to 19.05]	1.25 times the fillet weld <u>size</u>	1.25 times the fillet weld <u>size</u>	1.25 times the fillet weld <u>size</u>
Material greater than 0.751 [19.10]	1.1 times the fillet weld <u>size</u>	1.1 times the fillet weld <u>size</u>	1.1 times the fillet weld <u>size</u>
Discoloration^b—Titanium			
Bright Silver	Acceptable	Acceptable	Acceptable
Silver	Acceptable ^c	Acceptable ^c	Acceptable ^c
Light Straw	Acceptable ^c	Acceptable ^c	Acceptable ^c
Dark Straw	Acceptable ^c	Acceptable ^c	Acceptable ^c
Bronze	Acceptable ^c	Acceptable ^c	Acceptable ^c
Brown	Acceptable ^c	Acceptable ^c	Acceptable ^c
Violet	Reject ^d	Acceptable ^c	Acceptable ^c
Green	Reject ^d	Acceptable ^c	Acceptable ^c
Blue	Reject ^d	Reject ^e	Reject ^e
Gray	Reject ^f	Reject ^f	Reject ^f
White	Reject ^f	Reject ^f	Reject ^f
Discoloration—Stainless Steel, Nickel and Cobalt Alloys			
All oxidation colors, except for Black	Acceptable	Acceptable	Acceptable
Black	Reject	Reject	Reject
Discoloration—Steel			
All oxidation colors, except for Black	Acceptable	Acceptable	Acceptable
Black	Reject	Reject	Reject

^a For groove weld only.

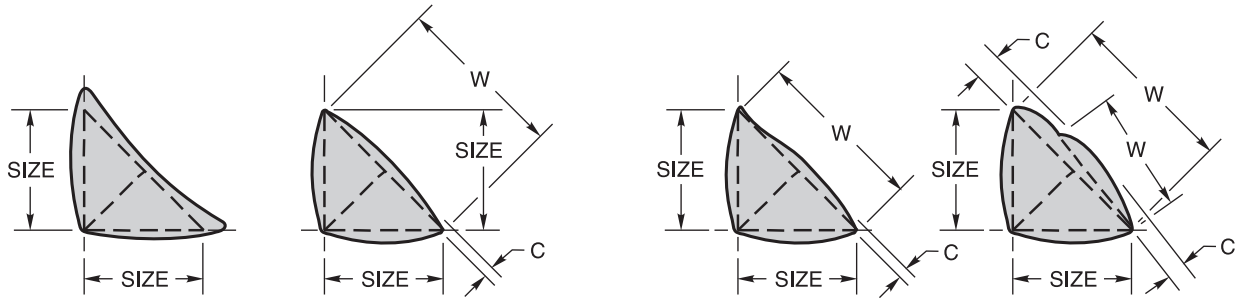
^b Discoloration comes in various shades, tones, and hues.

^c Discoloration must be removed prior to additional welding.

^d On the weld and in the HAZ up to 0.030 in [0.76 mm] beyond the weld.

^e Blue discoloration is rejectable if additional welding is to be performed. Blue discoloration is acceptable on finish welds but must be removed prior to subsequent processing.

^f Discoloration is rejectable unless it can be proven that embrittlement has not occurred. This proof must be provided through direct testing, such as microhardness.

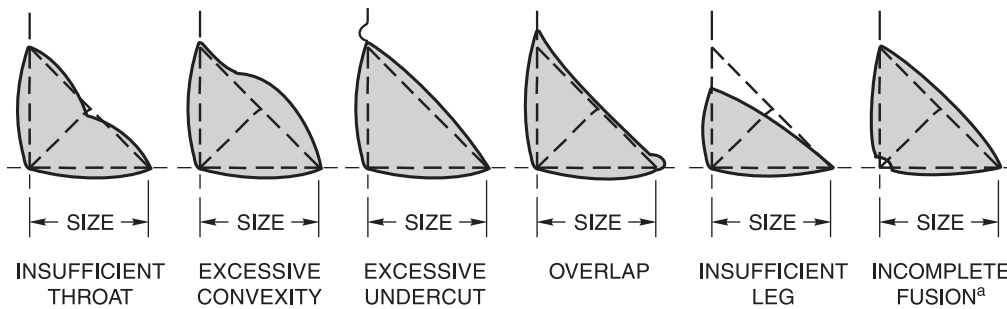


(A) DESIRABLE FILLET WELD PROFILES

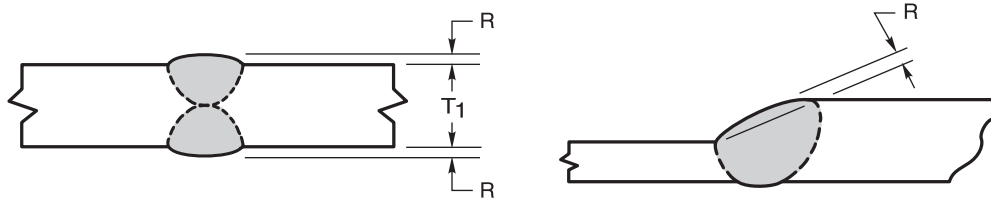
(B) ACCEPTABLE FILLET WELD PROFILES

Note: Convexity, C, of a weld or individual surface bead with dimension W shall not exceed the value of the following table:

WIDTH OF WELD FACE OR INDIVIDUAL SURFACE BEAD, W	MAX CONVEXITY, C
$W \leq 5/16$ in [8 mm]	1/16 in [1.6 mm]
$W > 5/16$ in [8 mm] TO $W < 1$ in [25 mm]	1/8 in [3 mm]
$W \geq 1$ in [25 mm]	3/16 in [5 mm]



(C) UNACCEPTABLE FILLET WELD PROFILES

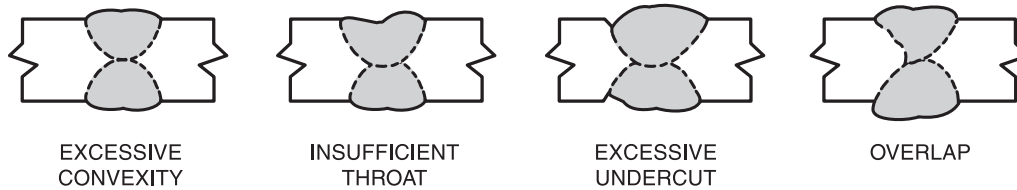


BUTT JOINT—
EQUAL THICKNESS PLATE

BUTT JOINT (TRANSITION)—
UNEQUAL THICKNESS PLATE

Note: Reinforcement R shall not exceed 1/8 in [3 mm].

(D) ACCEPTABLE GROOVE WELD PROFILE IN BUTT JOINT



(E) UNACCEPTABLE GROOVE WELD PROFILES IN BUTT JOINTS

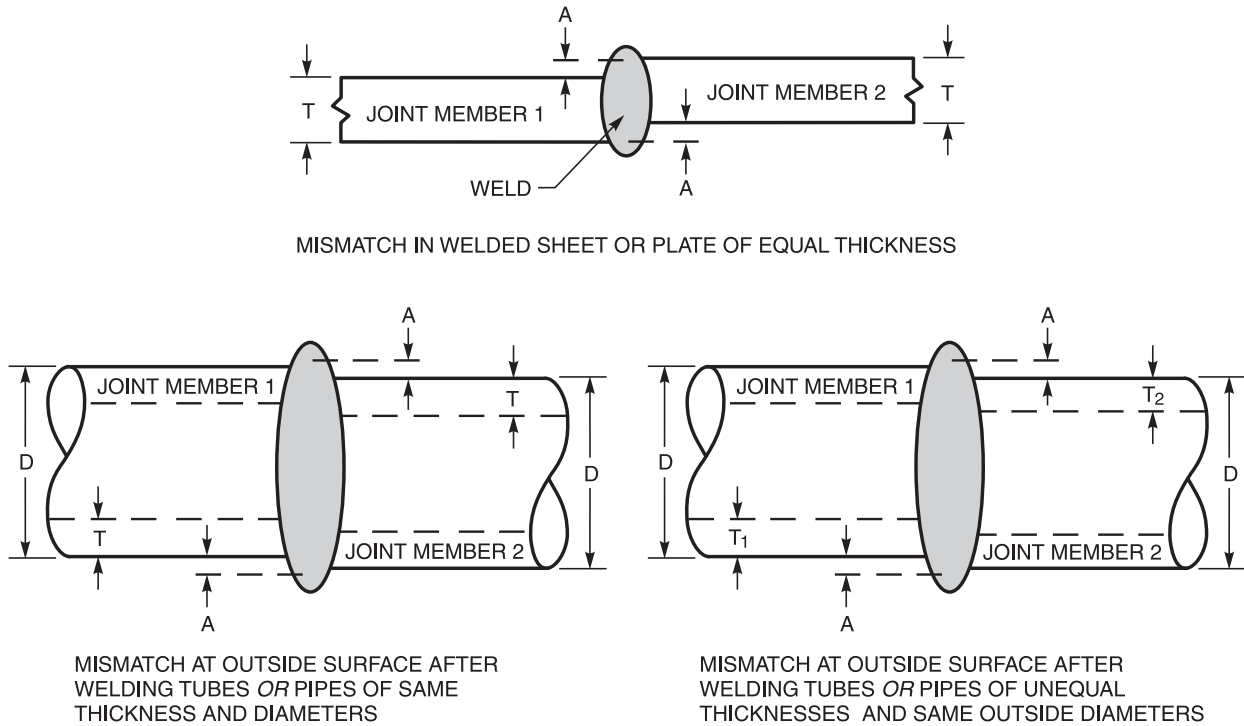
^a Refer to 5.3.8.2.

Figure 7.1—Acceptable and Unacceptable Weld Profiles

7.5.2.1 Mismatch. Unless otherwise specified on the engineering drawing or in any other contractual document, the maximum mismatch between joint members after welding shall meet the requirements of Figure 7.2.

7.5.2.2 Angular Distortion or Peaking. Unless otherwise specified on the engineering drawing or in any other contractual document, the angular distortion or peaking present upon completion of welding shall be within five degrees of the angle shown on the engineering drawing.

7.6 Inspection Records. The retention of inspection records shall be as defined by the applicable contract.



Note: Dimension 'A' in above figures shall comply with the table. Refer to 6.1.4.4.

Welding Process	Thickness of Thinnest	Mismatch
	'T'	'A' (Maximum)
OFW, SMAW, GTAW, GMAW,	$T \leq 0.125$ in [3.2 mm]	T or 0.040 in [1.0 mm], whichever is less
PAW, VP-PAW, FCAW, SAW	$T > 0.125$ in [3.2 mm]	0.040 in [1.0 mm]
LASER AND ELECTRON BEAM	$T \leq 0.250$ in [6.4 mm]	0.010 in + $0.1 \times T$ [0.25 mm + $0.1 \times T$]
	$T > 0.250$ in [6.4 mm]	0.040 in [1.0 mm]

Figure 7.2—Mismatch Between Joint Members After Welding

8. Repair of Existing Structures

8.1 Scope. This clause of the specification provides the requirements and applicability for weld repair procedures. Additionally, this Clause applies only to the weld repair of in-service (existing) aerospace flight hardware and shall not be used for corrections encountered during original manufacturing. Welding procedure specifications used for the repair of existing structures and components shall meet the requirements of government approved Original Equipment Manufacturers

(OEMs) or the appropriate repair manuals. Depending on the criticality of the weld repair, the stress analysis of the repair area and the repair procedure shall be approved by the appropriate governmental agency prior to weld repair.

8.2 Design. Repairs to existing structures shall be performed in accordance with the current regulatory requirements. Welding Procedures and stress analysis are required for critical and semicritical structures. Documentation of stress analysis results shall be made available to the customer as defined by contract, or 7 years, whichever is longer.

8.2.1 Classification. The Engineering Authority shall classify the repair weld by considering the process controls, inspection, and acceptance criteria as described in Clause 1.2 of this specification. The classification selected may be more stringent than the original design but shall not be classified to lesser than the original design unless both a stress analysis and mechanical testing data or component qualification has been performed. The stress analysis supporting the reduction of the weld classification shall be approved by the Engineering Authority per 8.2.

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

8.2.2.1 Critical. Welds made to critical structures shall have a stress analysis performed to determine the adequacy of the repair based on the location of the weld and type of weld. Consideration shall be given to prevent the weld from becoming a metallurgical or mechanical notch in critical structures.

8.2.2.2 Semicritical. Welds made to semicritical structures shall have a stress analysis performed prior to welding the structure.

8.2.2.3 Noncritical. Welds used for the repair of noncritical structures may have a stress analysis performed at the discretion of the Engineering Authority. Consideration should be given to performing a stress analysis if the weld repair is located in an area that may cause failure of the noncritical structure or loss of performance to the system.

8.3 Welding Procedures

8.3.1 Qualification. Welding procedures shall be qualified per Clause 5, and as modified herein. A previously qualified weld procedure may have the qualification extended for repair welding when authorized by the Engineering Authority.

8.3.1.1 Procedure qualifications for weld repair of critical and semicritical structures shall be limited to the same base metal type, filler metal, and welding process used for the actual repair.

8.3.1.2 Qualifying a welding procedure for weld repair of noncritical structures may be required at the discretion of the Engineering Authority.

8.3.2 Techniques. Welding techniques that contribute to the required design strength shall be included as essential variables of the weld repair procedure of critical and semicritical structures. This includes, but is not limited to specifying and changing any of the following essential and nonessential variables:

- (1) Essential Parameters or Heat Input
- (2) Bead Width
- (3) Reinforcement
- (4) Welding Sequence
- (5) Position
- (6) Filler Metal Strength
- (7) Process
- (8) Preweld and Postweld Heat Treatments or aging
- (9) Preheat and Interpass Temperatures

Welding procedures that require qualification for purposes of developing a special technique shall have the welding techniques described in detail and shall become a part of the essential variables of the welding procedure subject to requalification.

8.4 Welder and Welding Operator Qualification

8.4.1 Welders and Welding Operators shall be qualified per Clause 5 to perform welding using the equipment specified by the welding procedure.

8.5 Welding Equipment

8.5.1 Equipment. Machine or automatic welding equipment shall be satisfactorily tested per Clause 6 prior to performing welding repairs to aerospace structures and components. This includes the use of lasers, electron beam or other high energy welding processes.

8.6 Weld Repair Inspection. Repair welding acceptance criteria shall be defined by the Engineering Authority or service manuals. As a minimum, the repair weld and the area within 0.5 in [12.5 mm] of the repair weld shall be inspected.

8.6.1 Visual Examination. All repair welds shall have a visual examination (VT) performed by qualified personnel prior to performing other NDE techniques.

8.6.2 Surface Inspections. All repair welds shall have a final PT or MT inspection in accordance with the appropriate industry or customer specification (contingent upon magnetic properties regardless of criticality).

8.6.3 Internal Inspection. All repair welds to critical and semicritical structures regardless of the class of the weld shall have either RT or UT performed in accordance with the appropriate industry or customer specification.

8.7 Grounding. Prior to welding on aircraft, an electrical ground path shall be approved by the Engineering Authority.

8.8 Repair Documentation

8.8.1 All repair welds made to critical and semicritical structures shall be documented with the following information:

- (1) Location(s) (Drawing Number that will adequately identify the structure, using frame number, distance from identifiable lofting dimensions, etc.)
- (2) Repair dimensions and extent of repair(s)
- (3) Base and Filler Metal(s)
- (4) Process(es)
- (5) Procedure(s)
- (6) Welder(s)
- (7) Inspection Method(s) and Result(s)

8.8.2 Record Maintenance. Records of weld repairs shall be maintained in accordance with the requirements of the appropriate regulatory agency.

9. Nonflight Hardware

9.1 Scope. This Clause establishes the minimum requirements for the design and fusion welding, with the exclusion of pressure vessels, of nonflight hardware. One of the following three options shall be used in the implementation of this Clause, as determined by the Engineering Authority:

- (1) The suggested codes and specifications listed in Table 9.1.
- (2) The suggested codes and specifications listed in Table 9.1 with the exceptions and additions specified in this Clause.
- (3) The requirements of Clauses 4-7 of this specification, with the exceptions and additions specified in Clause 9.

9.2 Exceptions and Additional Requirements. The following exceptions and additions are to be used with the applicable codes and specifications listed in Table 9.1, or with the requirements of Clauses 4–7 of this specification, when either option has been specified by the Engineering Authority.

9.2.1 Joint Classifications. The Engineering Authority shall specify the required weld design and inspection classification(s) on the engineering drawing. For structural welds, the design classifications shall be in accordance with

Table 9.1
Industrial Codes and Specifications Suggested for Welding Aerospace Nonflight Hardware

Specification	Title
AWS D1.1/D1.1M	Structural Welding Code—Steel
AWS D1.2/D1.2M	Structural Welding Code—Aluminum
AWS D1.3/D1.3M	Structural Welding Code—Sheet Metal
AWS D1.4/D1.4M	Structural Welding Code—Reinforcing Steel
AWS D1.5M/D1.5	Bridge Welding Code
AWS D1.6/D1.6M	Structural Welding Code—Stainless Steel
AWS D1.9/D1.9M	Structural Welding Code—Titanium
AWS D3.6M	Specification for Underwater Welding
AWS D9.1M/D9.1	Sheet Metal Welding Code
AWS D14.1/D14.1M	Specification for Welding Industrial and Mill Crane and Other Material Handling Equipment
AWS D14.3/D14.3M	Specification for Welding Earthmoving, Construction, and Agricultural Equipment
AWS D14.4/D14.4M	Specification for Welded Joints in Machinery and Equipment
AWS D14.5/D14.5M	Specification for Welding of Presses and Press Components
AWS D14.6/D14.6M	Specification for Welding of Rotating Elements of Equipment
<u>AWS D14.7/D14.7M</u>	<u>Recommended Practice for Surfacing and Reconditioning of Industrial Mill Rolls</u>
<u>AWS D14.8M (ISO/TR 17844:2004 IDT)</u>	<u>Standard Methods for the Avoidance of Cold Cracks</u>
AWS D15.1/D15.1M	Railroad Welding Specification for Cars and Locomotives
ASME B31.1	Code for Pressure Piping
ASME B31.3	Process Piping
AWWA STD 100	Standard for Welded Steel-Elevated Tanks, Standpipes, and Reservoirs for Water Storage American Water Works Association (AWWA)

the appropriate code or specification listed in Table 9.1, while the inspection classification shall be as follows: Class A, Class B, or Class C, in accordance with Clause 9.2.4.4. For welds in pressurized piping and tubing, the design and inspection classifications shall be in accordance with the applicable code or specification listed in Table 9.1 and with 9.2.4.4. The supplemental requirements of 9.2.4.4 pertain to the level of inspection required; the inspection procedures and acceptance criteria shall be in accordance with the applicable code or specification listed in Table 9.1. In cases where the codes and specifications in Table 9.1 do not address the specific materials being welded, Table 7.1 may be used for determining the inspection acceptance criteria.

9.2.2 Qualification

9.2.2.1 General Requirements. The fabricator shall be responsible for qualification of welders, welding operators, tack welders, and welding procedures prior to engaging in tacking and welding operations. Welders, welding operators, and tack welders may be qualified by the fabricator or an independent testing agency.

9.2.2.2 Performance Qualification. As an alternate to the requirements of the codes and specifications listed in Table 9.1, welders, welding operators and tack welders engaged in the structural welding of nonflight hardware may be qualified in accordance with AWS B2.1

NOTE: This alternative does not extend to welders, welding operators and tack welders engaged in the welding of pressurized piping and tubing in accordance with any applicable Clause of ASME B31.1 or B31.3.

9.2.2.3 Procedure Qualification. As an alternate to the requirements of the codes and specifications listed in Table 9.1, welding procedures to be used for the fabrication of Class A and Class B structural welds in nonflight hardware may be qualified in accordance with AWS B2.1.

NOTE: This alternative does not extend to welding procedures used for the welding of pressurized piping and tubing in accordance with any applicable Clause of ASME B31.1 or B31.3.

9.2.3 Fabrication

9.2.3.1 Calibration. Welding equipment calibration requirements for automated, machine, or robotic welding shall be in accordance with 6.3.1.

9.2.3.2 Welding Consumables

- (1) **Identification.** The identification requirements for welding consumables shall be in accordance with 6.2.1.
- (2) **Storage.** The storage requirements for welding consumables shall be in accordance with 6.2.2.
- (3) **Consumable Inserts.** Consumable inserts shall be in accordance with AWS A5.30. Consumable inserts shall be of the same nominal composition as the filler metal to be used. No additional filler metal shall be added to a root pass when using a consumable insert.
- (4) **Backing Rings in Pipe and Tubing for Fluid Applications.** With the exception of welds designated for ASME B31.3, Category D fluid service, backing rings shall not be used.
- (5) **Shielding and Backing Gas.** Shielding and backing gas requirements shall be in accordance with 6.2.3, and as follows: Inert gas backing is required for all joints when consumable inserts are used. The root of full penetration welds shall be suitably protected from oxidation or atmospheric contamination for the following material groups: aluminum, aluminum alloys, nickel, nickel alloys, stainless steels, titanium, and titanium alloys.

Inert gas backing should be maintained for the root pass and subsequent passes until the joint is completed, or a minimum of 0.2 in [5 mm] of weld metal thickness has been deposited.

9.2.3.3 Preweld and Interpass Cleaning. Preweld and interpass cleaning requirements shall be in accordance with 6.5.

9.2.3.4 Preheating, Interpass Heating and Postweld Heating. Heating and maintaining the proper temperature specified on the engineering drawing or by the WPS may be accomplished by any suitable method capable of providing a uniform temperature throughout the part for a distance at least equal to the thickness of the thickest member (but not less than 3 in [76 mm] in all directions from the point of welding. For field applications, it is preferred that induction coils or resistance heating braided “blankets” be used. When preheating is required, the joint shall be preheated prior to any welding, including tack welding. Temperatures shall be measured by suitable temperature-indicating methods that are accurate within $\pm 25^{\circ}\text{F}$ [14°C].

9.2.3.5 Filler Metals. Filler metal requirements shall be in accordance with 6.12.

9.2.3.6 Tack Welds. Tack welds shall be used as required and shall be made by a qualified welder, welding operator, or tack welder. Tack welds shall be spaced symmetrically around or along the joint whenever possible. Chipping or grinding shall be blended to fair smoothly with the base metal. Tack welds that contain cracks or visible porosity shall not be fused with the root pass and shall be removed in accordance with 9.7.

9.2.3.7 Weld Bead Initiation and Termination. Weld start and run-off tabs on which the welding arc can be started or extinguished shall be used whenever practicable and shall be of the same material as the parts being welded. When start or run-off tabs cannot be used, the initiation and termination points of each weld bead shall be chipped or ground as necessary to remove any visible defects in the weld metal before depositing any subsequent weld beads. In addition, ground area shall be blended to fair smoothly with the adjacent base metal. Weld beads shall not terminate at inside corners or notches, or in other critical areas such as changes in welding direction or sudden changes in section thickness.

9.2.3.8 Backgouging. All groove welded joints that are to be welded from both sides and require 100 % penetration shall be back gouged to sound metal prior to the welding of the second side. Whenever possible, two or three passes shall be deposited on the first side prior to the gouging of the backside. Backgouging to sound metal may be done by machining, chisel, grinder, arc gouging or by other appropriate methods. Gouged areas shall be blended to fair smoothly with the adjacent metal.

9.2.3.9 Postweld Cleaning. Postweld cleaning requirements shall be in accordance with 6.15.

9.2.3.10 Identification of Welds. Appropriate records shall be maintained that identify the welds made by each qualified welder and welding operator. These records shall be made available to the Engineering Authority when required by contract documentation.

9.2.4 Inspection

9.2.4.1 General. The fabricator is responsible for the performance of all inspections, tests, and quality control requirements as specified herein. The fabricator may utilize his own or any other testing laboratory acceptable to and approved by the Engineering Authority for the performance of all required destructive and nondestructive inspections.

The visual and nondestructive inspections described herein shall apply to completed welds and the adjacent base metal up to a minimum of 0.5 in [13 mm] from both sides of the edge of the deposited weld metal. Welds that do not satisfy the acceptance criteria of the appropriate code or specification listed in Table 9.1 shall be reworked in accordance with 9.7.

9.2.4.2 Qualification of NDE Personnel. NDE personnel qualification requirements shall be in accordance with 7.1.

9.2.4.3 Visual Inspection. All welds shall be visually inspected for conformance to the drawing requirements and to the requirements of either the appropriate code or specification listed in Table 9.1, or the requirements of Table 7.1.

9.2.4.4 NDE of Nonflight Hardware

- (1) **Class A Inspection (for structural welds only).** In addition to the required visual inspection, all Class A inspections shall require 100% radiographic testing (RT) and either 100% magnetic particle testing (MT) or 100% liquid penetrant testing (PT) in accordance with the appropriate codes or specifications listed in Table 9.1. Ultrasonic testing (UT) may be used in lieu of RT at the Engineering Authority's discretion.
- (2) **Class B Inspection (for structural welds only).** In addition to the required visual inspection, all Class B inspections shall require either 100% MT or 100% PT in accordance with the appropriate codes or specifications listed in Table 9.1. When producing multipass welds in thick sections, it is recommended that the root pass, final pass, and each 0.5 in [13 mm] interval of thickness be inspected. In addition to the normal interpass cleaning requirements for multipass welds, all liquid penetrant materials and/or metal particles shall be removed after each such inspection. RT may be used at the Engineering Authority's discretion.
- (3) **Class C Inspection (for structural welds only).** All Class C inspections require only the visual inspection described in 9.2.4.3. MT and/or PT may be used at the Engineering Authority's discretion.
- (4) **Welds in Piping and Tubing for Fluid Service.** When this specification is used in conjunction with ASME B31.3 only, all piping and tubing welds shall undergo NDE in accordance with the following paragraphs in addition to the required visual inspections:
 - (a) **Normal Fluid Service.** All welds classified for Normal Fluid Service shall require 10% random RT; if any of the tested welds are found to be unacceptable, an additional randomly selected 10% (minimum) of the production welds shall be tested. If any of the tested welds in the second sampling are found to be unacceptable, then a 100% inspection of the remaining production welds is required.
 - (b) **Severe Cyclic Conditions.** All welds classified as subjected to Severe Cyclic Conditions shall require 100% RT and either 100% PT or 100% MT.
 - (c) **Category M Fluid Service.** All welds classified for Category M Fluid Service shall require 100% RT and either 100% PT or 100% MT.
 - (d) **High Pressure Fluid Service.** All welds classified for High-Pressure Fluid Service shall require 100% RT and either 100% PT or 100% MT.
 - (e) **Category D Fluid Service.** All welds classified for Category D Fluid Service shall require either 100% MT or 100% PT.
- (5) **In-Process Examination for Automatic Gas Tungsten Arc Welding (GTAW).** With the exception of welds designated for High Pressure and Category M Fluid Service per ASME B31.3, an in-process examination may be substituted for the required RT of piping and tubing welds made using a fully automatic GTAW process only. In addition to the in-process examination requirements defined in ASME B31.3, the following additional requirements shall be satisfied:
 - (a) The in-process examination shall be applied to all welds.
 - (b) The automatic GTAW process parameters shall be strictly monitored and recorded; if these parameters exceed plus or minus 10% of the qualified values established during the welding procedure qualification, the affected weld shall require RT. The process parameters to be monitored and recorded shall include the following:
 - (a) Arc current
 - (b) Pulse high (amperes)
 - (c) Pulse low (amperes)
 - (d) Pulse high (time)

- (e) Pulse low (time)
 - (f) Start slope
 - (g) Finish slope
 - (h) Rotation delay
 - (i) Head speed (rpm)
 - (j) Shielding and backup gas flow rate
 - (k) Arc voltage
 - (l) Tungsten electrode (position, length, bevel, land, arc length)
- (c) Welds classified as subjected to Severe Cyclic Conditions shall require 100% PT or 100% MT.

NOTE: All NDE materials (e.g., liquid penetrants, developers, ultrasonic couplants, etc.) that are to be applied to surfaces that will be exposed to oxygen (gaseous or liquid) or hypergols in-service shall be compatible with that service fluid. Oxygen compatibility shall be determined in accordance with procedures approved by the Engineering Authority.

9.2.4.5 Alternate Inspection Methods. In cases where the joint configuration makes it impractical to obtain a satisfactory radiograph (e.g., a fillet weld) a satisfactory alternate method of NDE shall be approved by the Engineering Authority. If PT or MT is proposed to be used in lieu of RT, then the root pass, final pass, and each 0.5 in [13 mm] interval of thickness shall be inspected. In addition to the normal interpass cleaning requirements for multipass welds, all liquid penetrant materials and/or metal particles shall be removed after each such inspection. In cases where adequate postweld inspection cleaning is difficult to achieve (e.g., inner lines of vacuum-jacketed systems; intermediate passes of multipass welds in aluminum), PT may be selectively omitted if approved by the Engineering Authority (e.g., a visual inspection, RT, and a proof test of an inner line in a vacuum-jacketed cryogenic system could be considered sufficient without PT). Also, PT of just the final pass of a multipass aluminum weld could be considered sufficient. The necessity of selectively omitting PT, as well as the necessity and acceptability of any proposed alternate NDE methods, should be agreed upon by the fabricator and the Engineering Authority.

9.2.4.6 Proof Testing. Proof testing may be used in conjunction with or in lieu of the required NDE if approved by the Engineering Authority.

9.2.4.7 Etching for PT. Weldments in soft metals (i.e., aluminum alloys, magnesium alloys, etc.) that are machined, ground, sanded, abraded, or otherwise mechanically worked to cause smearing or disruption of the metal surface shall be etched to remove the masking material prior to penetrant application. Etching is not required for those features such as close tolerance surfaces, faying surfaces, etc., where the function of the component or assembly would be degraded.

9.2.4.8 Penetrant Inspection (PT) Allowable Type. Welds may be penetrant inspected using any approved Type I or II penetrant systems.

9.2.5 Weld Rework

9.2.5.1 Discontinuity Removal. Portions of weld and/or base metal containing rejectable discontinuities shall be removed to sound metal. The use of mechanical means (e.g., grinding, chipping, or machining) is preferred. After the removal of any metal containing discontinuities, and prior to re-welding, the joint shall be re-inspected to ensure that the discontinuities have been completely removed, using the same inspection method and acceptance criteria used to detect the original discontinuity.

9.2.5.2 Rework Procedure. The rework welding procedure shall be the same as the original qualified WPS or an approved qualified repair process, recognizing that the cavity to be repaired may differ in contour and dimensions from the original joint. With the exception of Class C structural welds and Category D Fluid Service welds (per ASME B31.3), no more than two attempts shall be made to rework a weld discontinuity; further rework attempts require the approval of the Engineering Authority. The completed reworked weld shall be inspected to the same requirements and acceptance criteria as the original weld.

9.2.5.3 Rework Records. The fabricator shall prepare and maintain records of all weld reworks in Class A and B welds and shall make these records available to the Engineering Authority.

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Annex A (Normative)

Guidelines for Design, Analysis, and Fabrication of Weld Joints

This annex is part of AWS D17.1/D17.1M:2010-AMD1, *Specification for Fusion Welding for Aerospace Applications*, and includes mandatory elements for use with this standard.

A1. Scope

The following information and figures are provided as standard design information. These joint designs and dimensions are based on widespread use in the aerospace industry with satisfactory results. However, it is incumbent upon the Engineering Authority, that if these designs are used, sufficient engineering analysis is performed for the application.

Fabricators—The Engineering Authority may require fabricators to comply with the requirements of this Annex for fit-up.

A2. Groove Welds

The designer may use the standard joint details given in Figure A.1 for complete joint penetration groove welds and Figure A.2 for complete penetration groove welds in two- and three-piece tee joints.

A2.1 Groove Weld Effective Area. The effective area is the effective weld length multiplied by the weld size. The effective weld length for any groove weld, perpendicular or nonperpendicular (square or skewed), should be the width of the part joined perpendicular to the direction of stress. The weld size of a complete joint penetration groove weld should be the thickness of the thinner part joined. Weld reinforcements do not increase the effective area of the weld.

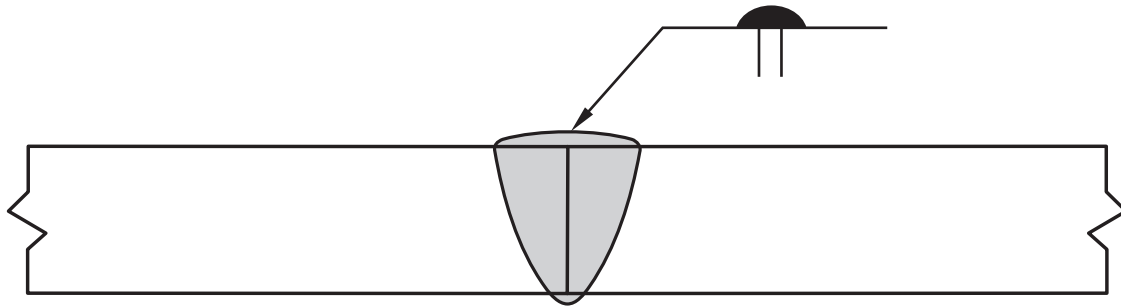
A3. Edge Welds in Flanged Joints

A3.1 The designer may use the standard joint details given in Figure A.3.

A4. Fillet Welds

A4.1 Fillet Weld Size. The efficiency of the weld joint is based on the strength of the weaker member being joined. It is based on member thickness multiplied by the base metal ultimate tensile strength. To achieve 100 % joint efficiency, using an equivalent strength filler metal, the weld size must be a minimum of 70 % of the base metal thickness for a double sided weld, and 140 % for a single sided weld. The suggested minimum weld size for a single fillet weld is 1.5 times the thickness of the thinner member being joined. The suggested minimum weld size for double fillet welds is 1.0 times the thickness of the thinner member being joined. However, when dynamic loading conditions are present, the Engineering Authority should assure that the required fillet weld size is suitable for the design application.

For lap and corner joints, when the maximum size fillet weld is required, a convex fillet, the size of the thinnest member should be specified on the drawing ($E = S$). See Figure A.4.



Weld Process	Base Metal Thickness "T" (in [mm])	Max Root Opening [R] (in [mm])	Material	Remarks
GTAW	0.090 [2.3] max	1/2 T or 0.045 [1.1], whichever is less	Any	Manual GTAW
	0.125 [3.2] max	1/4 T or 0.030 [0.76], whichever is less	Any	Mechanized GTAW
	0.25 [6.4] max		Al or Ti	Mechanized GTAW
PAW	0.375 [9.5] max	1/4 T or 0.030 [0.76], whichever is less	Al or Ti	Mechanized PAW
		0.040 [1.0] max	Al or Ti	Mechanized VP-PAW
EBW	≤ 0.030 [0.76] 0.031–0.100 [0.79–2.54] 0.101–0.200 [2.56–5.08] 0.201–0.300 [5.10–7.62] 0.301–0.400 [7.64–10.16] >0.400 [10.16]	0.002 [0.05] 0.005 [0.13] 0.007 [0.18] 0.008 [0.20] 0.009 [0.23] 0.010 [0.25]	Any	
LBW		1/8 T or 0.005 [0.13], whichever is less	Any	

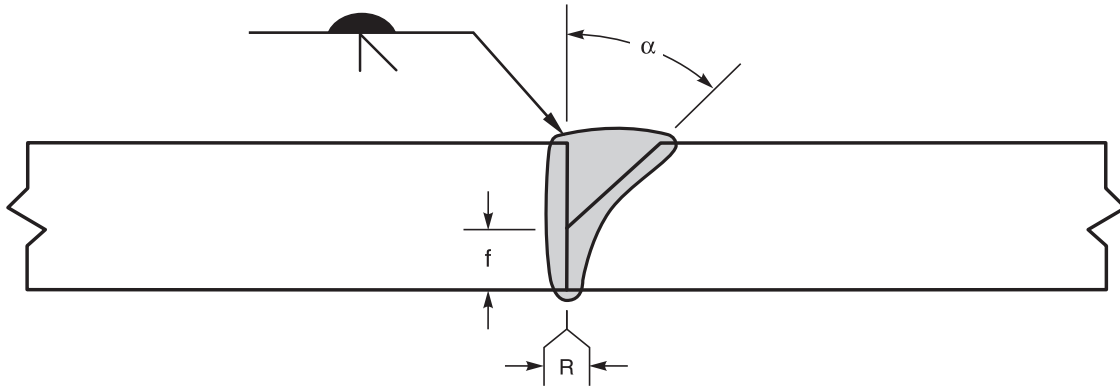
Figure A.1(a)—Square Groove Butt Joints

The relationship of the effective throat to weld size is shown in Figure A.4. Correction factors for fillet welds in skewed T-joints are given in Table A.1 for dihedral angles (Ψ) between 60 degrees and 135 degrees.

A4.2 Fillet Weld Effective Throat

A4.2.1 Calculation. The effective throat of a fillet weld is the shortest distance from the joint root to the weld face. For design purposes, the effective throat and the theoretical throat are identical when the root gap is zero and no joint penetration has occurred. No strength allowance should be given in the design calculations for root penetration unless a combination groove and fillet weld is specified for the joint.

A4.2.2 Shear Stress. Stress on the effective throat of a fillet weld is considered as shear stress regardless of the load direction.



Weld Process	Base Metal Thickness [T] (in [mm])	Root Opening [R] (in [mm]) Max.	Root Face [f] (in [mm])	Groove Angle [α] (degrees)
GTAW	0.060–0.500 [1.5–12.7]	≤ 0.030 [0.76]	0.030 [0.76] +0.030 [0.76] –0.000 [0.00]	60° +10° –5°
PAW ^a	0.060–0.500 [1.5–12.7]	≤ 0.030 [0.76]	0.03 [0.76] +0.030 [0.76] –0.000 [0.00]	60° +10° –5°
GMAW FCAW SAW	0.060 [1.5] – unlimited	≤ 0.030 [0.76]	0.06 [1.5] +0.030[0.76] –0.000 [0.00]	45° +10° ^b 60° –5° ^c

^a Non-keyhole mode only

^b Applicable to ferrous, heat resistant and magnesium alloys

^c Applicable to aluminum and titanium alloys

Figure A.1(b)—Single-Bevel-Groove Weld Joints

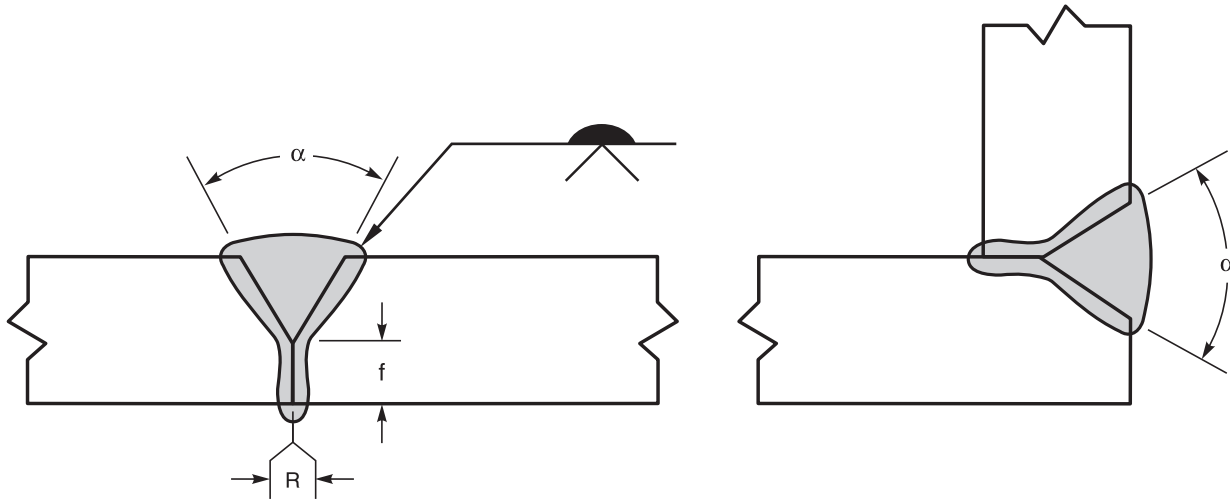
A4.3 Fillet Weld Length

A4.3.1 Effective Length (Straight). The effective length of a fillet weld should be the overall length of the full-size fillet including boxing. No reduction in effective length should be made for either the start of the weld or the end, in the design calculations.

A4.3.2 Effective Length (Curved). The effective length of a curved fillet weld should be measured along the centerline of the effective throat. If the weld area of a fillet weld in a hole or a slot computed from this length is greater than the area of the hole in the plane of the faying surface, then the area of the hole should be used as the effective area of the fillet weld.

A4.3.3 Fillet Weld Minimum Length. The minimum effective length of a fillet weld should be at least four times the nominal size.

A4.4 Fillet Weld Effective Area. The effective area should be the effective length multiplied by the effective throat.



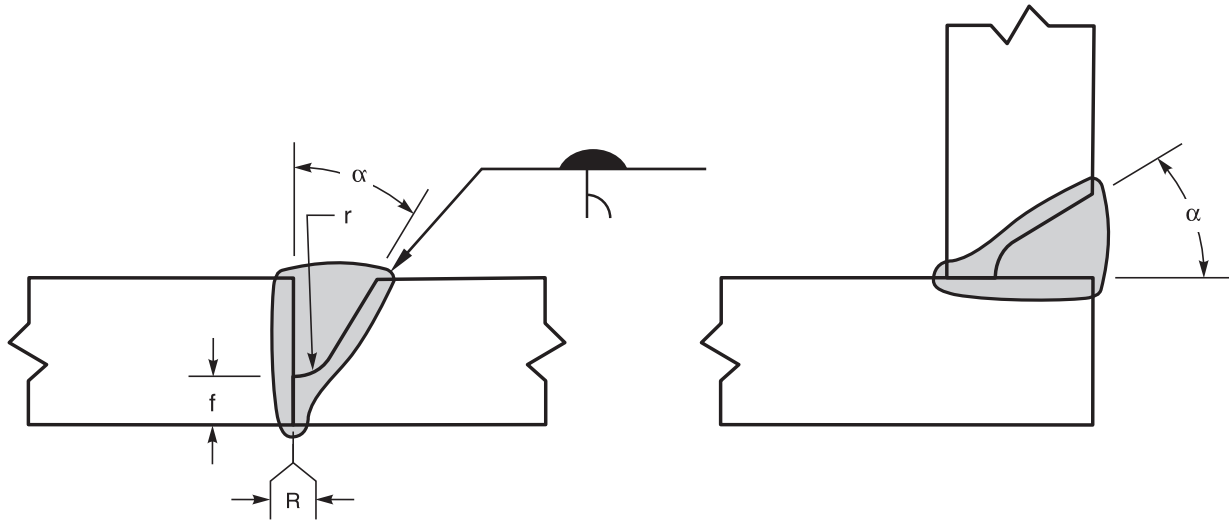
Weld Process	Base Metal Thickness [T] (in [mm])	Max. Root Opening [R] (in [mm])	Root Face [f] (in [mm])	Groove Angle [α]
GTAW	0.060–0.500 [1.5–12.7]	≤ 0.030 [0.76]	0.030 [0.76] +0.030 [0.76] –0.000 [0.00]	60° +10° –5°
PAW ^a	0.060–0.500 [1.5–12.7]	≤ 0.030 [0.76]	0.030 [0.76] +0.030 [0.76] –0.000 [0.00]	60° +10° –5°
GMAW FCAW SAW	0.060 [1.5] – unlimited	≤ 0.030 [0.76]	0.060 [1.5] +0.030 [0.76] –0.000 [0.00]	45° +10° –5° ^b 60° +10° –5° ^c

^a Non-keyhole made only.

^b Applicable to ferrous, heat-resistant alloys, and magnesium.

^c Applicable to aluminum and titanium alloys.

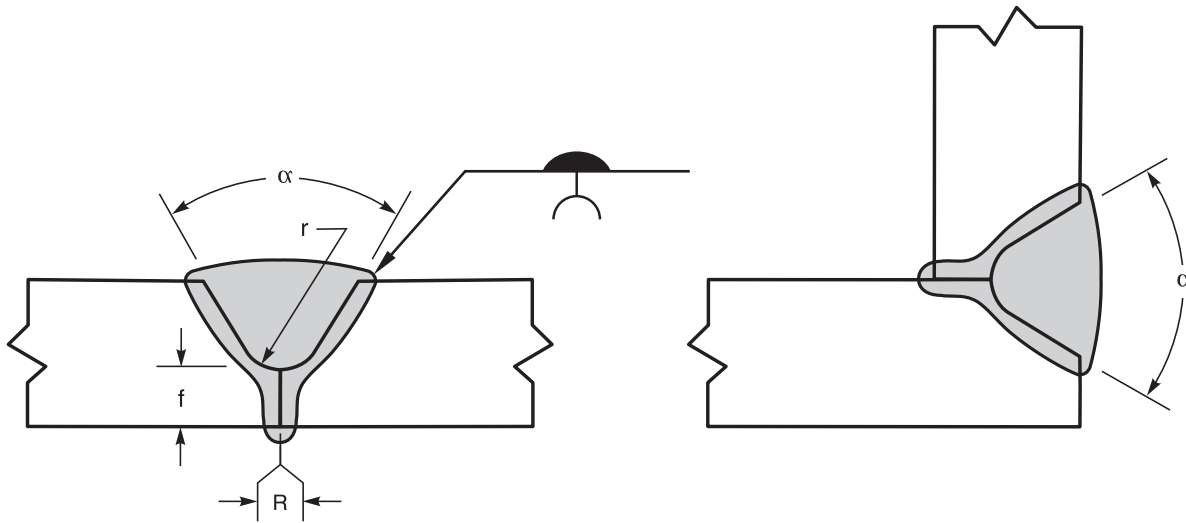
Figure A.1(c)—Single-V-Groove Weld Joints



Weld Process	Base Metal Thickness [T] (in [mm])	Max Root Opening [R] (in [mm])	Root Face [f] (in [mm])	Groove Angle [α] (degrees)	Groove Radius (r) (in [mm])
GTAW	0.501–0.700 [12.7–17.8]	≤ 0.030 [0.76]	0.030 [0.76] +0.030 [0.76] -0.000 [0.00]	30° +10° -5°	0.38 [9.65] +0.030 [0.76] -0.010 [0.25]
	>0.700 [17.8]	≤ 0.030 [0.76]	0.030 [0.76] +0.030 [0.76] -0.000 [0.00]	30° +10° -5°	0.44 [11.18] +0.030 [0.76] -0.010 [0.25]
PAW ^a	0.501–0.700 [12.7–17.8]	≤ 0.030 [0.76]	0.030 [0.76] +0.030 [0.76] -0.010 [0.025]	30° +10° -5°	0.38 [9.65] +0.030 [0.76] -0.010 [0.25]
	>0.700 [17.8]	≤ 0.030 [0.76]	0.030 [0.76] +0.030 [0.76] -0.010 [0.025]	30° +10° -5°	0.44 [11.18] +0.030 [0.76] -0.010 [0.25]
GMAW FCAW SAW	0.501–0.700 [12.7–17.8]	≤ 0.030 [0.76]	0.060 [1.5] +0.030 [0.76] -0.030 [0.76]	30° +10° -5°	0.38 [9.65] +0.030 [0.76] -0.010 [0.25]
	>0.700 [17.8]	≤ 0.030 [0.76]	0.060 [1.5] +0.030 [0.76] -0.030 [0.76]	30° +10° -5°	0.44 [11.18] +0.030 [0.76] -0.010 [0.25]

^a Non-keyhole mode only.

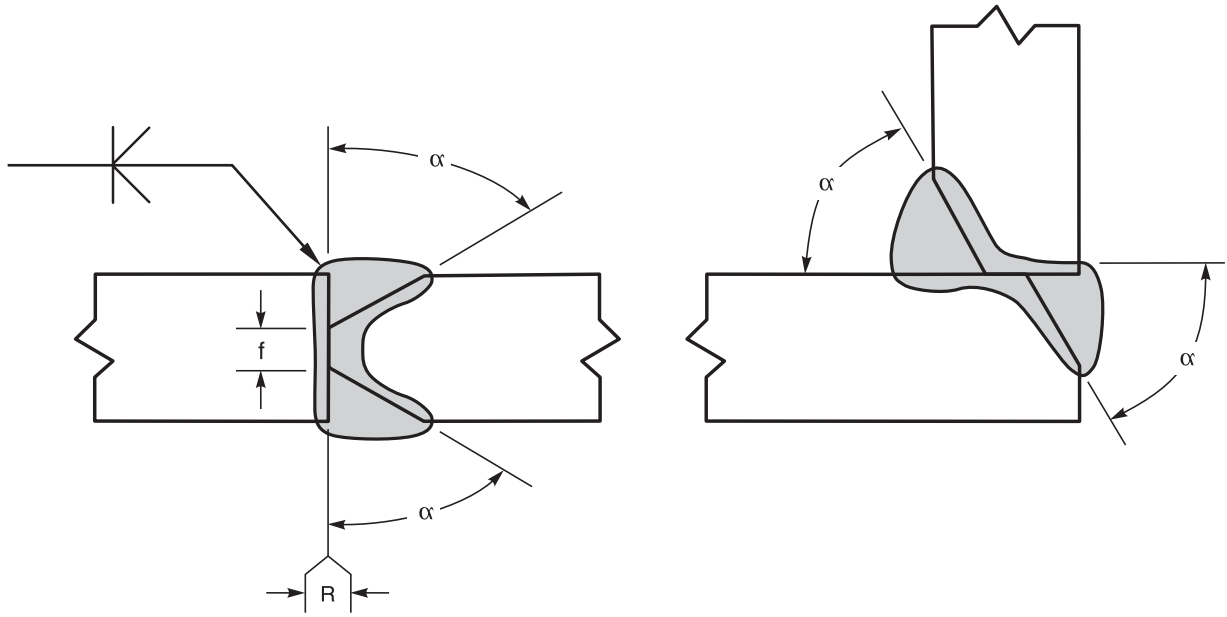
Figure A.1(d)—Single-J-Groove Weld Joints



Weld Process	Base Metal Thickness [T] (in [mm])	Max Root Opening [R] (in [mm])	Root Face [f] (in [mm])	Groove Angle [α] (degrees)	Groove Radius (r) (in [mm])
GTAW	> 0.400 [10.16]	≤ 0.030 [0.76]	0.030 [0.76] + 0.030 [0.76] - 0.000 [0.00]	20° +10° - 5°	0.250 [6.4] + 0.030 [0.76] - 0.010 [0.25]
PAW ^a	> 0.400 [10.16]	≤ 0.030 [0.76]	0.030 [0.76] + 0.030 [0.76] - 0.000 [0.00]	20° +10° - 5°	0.250 [6.4] + 0.030 [0.76] - 0.010 [0.25]
GMAW FCAW SAW	> 0.400 [10.16]	≤ 0.030 [0.76]	0.060 [1.5] + 0.030 [0.76] - 0.010 [0.25]	20° +10° - 5°	0.250 [6.4] + 0.030 [0.76] - 0.010 [0.25]

^a Non-keyhole mode only.

Figure A.1(e)—Single-U-Groove Weld Joints



Weld Process	Base Metal Thickness [T] (in [mm])	Max Root Opening [R] (in [mm])	Root Face [f] (in [mm]) ^a	Groove Angle [α] (degrees)
GTAW ^b	0.250–1.000 [6.4–25.4]	≤ 0.030 [0.76]	0.030 [0.76] + 0.030 [0.76] – 0.010 [0.25]	60° + 10° – 5°
PAW ^{c,b}	0.250–1.000 [6.4–25.4]	≤ 0.030 [0.76]	0.030 [0.76] + 0.030 [0.76] – 0.010 [0.25]	60° + 10° – 5°
GMAW ^b FCAW SAW	0.250–1.000 [6.4–25.4]	≤ 0.030 [0.76]	0.060 [1.5] + 0.030 [0.76] – 0.010 [0.25]	45° + 10° – 5° ^d 60° + 10° – 5° ^e

^a Applies to complete joint penetration groove welds only. Root face height for partial joint penetration groove welds is governed by joint strength requirements.

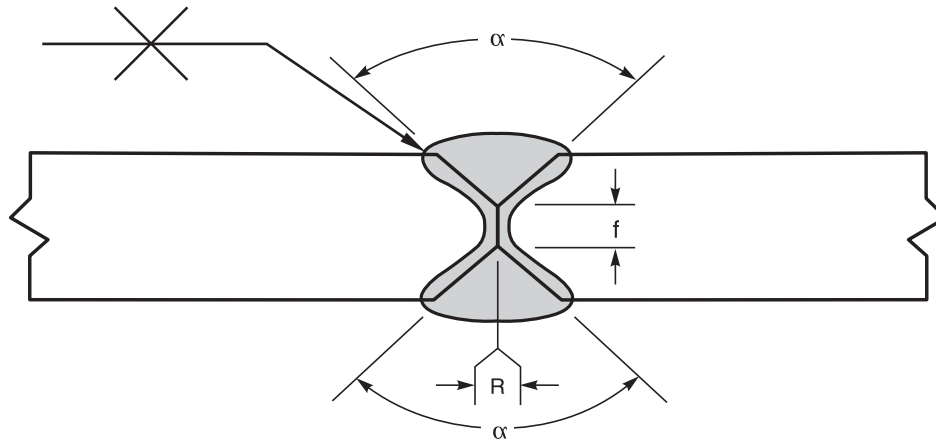
^b Back-gouging to sound metal required before welding second side.

^c Non-keyhole mode only.

^d Applicable to ferrous, heat resistant, and magnesium alloys.

^e Applicable to aluminum and titanium alloys.

Figure A.1(f)—Double-Bevel-Groove Weld Joints



Weld Process	Base Metal Thickness [T] (in [mm])	Max Root Opening [R] (in [mm])	Root Face [f] (in [mm]) ^a	Groove Angle [α]
GTAW (5)	0.250–1.000 [6.4–25.4]	≤ 0.030 [0.76]	0.030 [0.76] +0.030 [0.76] -0.010 [0.25]	60° +10° -5°
PAW ^{b,c}	0.250–1.000 [6.4–25.4]	≤ 0.030 [0.76]	0.030 [0.76] +0.030 [0.76] -0.010 [0.25]	60° +10° -5°
GMAW ^c FCAW SAW	0.250–1.000 [6.4–25.4]	≤ 0.030 [0.76]	0.060[1.5] +0.030[0.76] -0.010 [0.25]	45° +10° -5° ^d 60° +10° -5° ^e

^a Applies to complete joint penetration groove welds only. Root face height for partial joint penetration groove welds is governed by joint strength requirements.

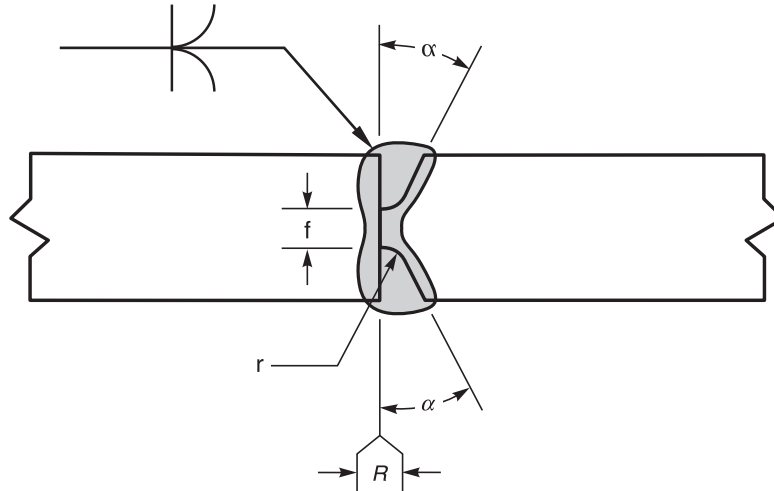
^b Non-keyhole mode only.

^c Backgouging to sound metal required before welding second side.

^d Applicable to ferrous, heat resistant alloys, and Magnesium.

^e Applicable to Aluminum and Titanium alloys.

Figure A.1(g)—Double-V-Groove Weld Joints



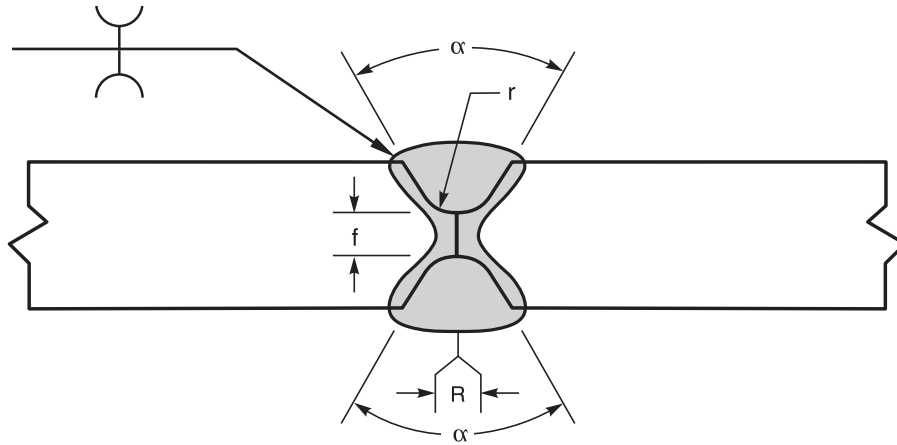
Weld Process	Base Metal Thickness [T] (in [mm])	Max Root Opening [R] (in [mm])	Root Face [f] (in [mm]) ^a	Groove Angle [α]	Groove Radius [r] (in [mm])
GTAW ^b	0.501–1.400 [12.7–35.56]	≤ 0.030 [0.76]	0.040 [1.01] + 0.030 [0.76] – 0.010 [0.25]	30° +10° – 5°	0.380 [9.65] + 0.030 [0.76] – 0.010 [0.25]
	≥ 1.400 [35.56]	≤ 0.030 [0.76]	0.060 [1.5] + 0.030 [0.76] – 0.010 [0.25]	30° +10° – 5°	0.380 [9.65] + 0.030 [0.76] – 0.010 [0.25]
PAW ^{c,b}	0.501–1.400 [12.7–35.56]	≤ 0.030 [0.76]	0.040 [1.01] + 0.030 [0.76] – 0.010 [0.25]	30° +10° – 5°	0.380 [9.65] + 0.030 [0.76] – 0.010 [0.25]
	≥ 1.400 [35.56]	≤ 0.030 [0.76]	0.060 [1.5] + 0.030 [0.76] – 0.010 [0.25]	30° +10° – 5°	0.380 [9.65] + 0.030 [0.76] – 0.010 [0.25]
GMAW ^b FCAW SAW	0.501–1.400 [13.01–35.56]	≤ 0.030 [0.76]	0.080 [2.03] + 0.030 [0.76] – 0.010 [0.25]	30° +10° – 5°	0.380 [9.65] + 0.030 [0.76] – 0.010 [0.25]
	≥ 1.400 [35.56]	≤ 0.030 [0.76]	0.120 [3.05] + 0.030 [0.76] – 0.010 [0.25]	30° +10° – 5°	0.380 [9.65] + 0.030 [0.76] – 0.010 [0.25]

^a Applies to complete penetration groove welds only. Root face height for partial joint penetration groove welds is governed by joint strength requirements.

^b Backgouging to sound metal required before welding second side.

^c Non-keyhole mode only.

Figure A.1(h)—Double-J-Groove Weld Joints



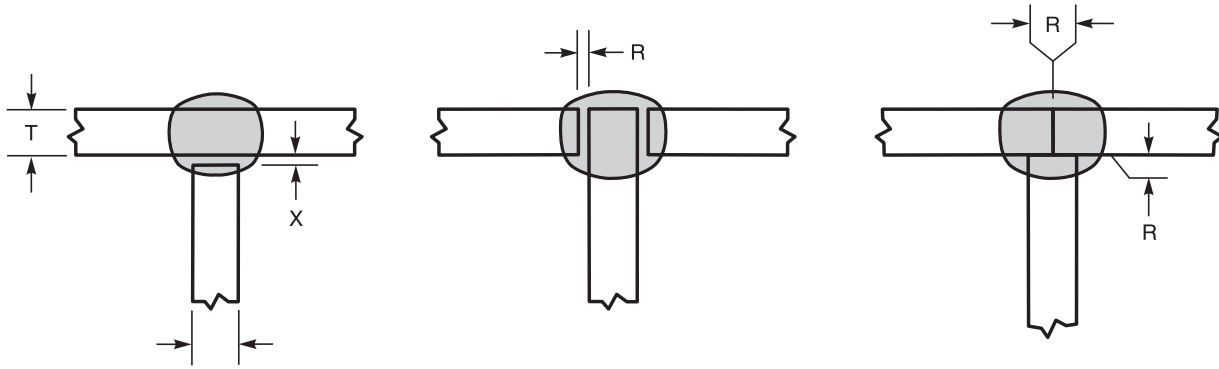
Weld Process	Base Metal Thickness [T] (in [mm])	Max Root Opening [R] (in [mm])	Root Face [f] (in [mm]) ^a	Groove Angle [α]	Groove Radius [r] (in [mm])
GTAW ^b	0.501–0.800 [12.7–20.3]	≤ 0.030 [0.76]	0.040 [1.0] + 0.030 [0.76] – 0.010 [0.25]	20° + 10° – 5°	0.250 [6.4] + 0.030 [0.76] – 0.010 [0.25]
	≥ 0.800 [20.3]	≤ 0.030 [0.76]	0.060 [1.5] + 0.030 [0.76] – 0.010 [0.25]	20° + 10° – 5°	0.250 [6.4] + 0.030 [0.76] – 0.010 [0.25]
PAW ^{b,c}	0.501–0.800 [12.7–20.3]	≤ 0.030 [0.76]	0.040 [1.0] + 0.030 [0.76] – 0.010 [0.25]	20° + 10° – 5°	0.250 [6.4] + 0.030 [0.76] – 0.010 [0.25]
	≤ 0.800 [20.3]	≤ 0.030 [0.76]	0.060 [1.5] + 0.030 [0.76] – 0.010 [0.25]	20° + 10° – 5°	0.250 [6.4] + 0.030 [0.76] – 0.010 [0.25]
GMAW ^c FCAW SAW	0.501–0.800 [12.7–20.3]	≤ 0.030 [0.76]	0.080 [2.0] + 0.030 [0.76] – 0.010 [0.25]	20° + 10° – 5°	0.250 [6.4] + 0.030 [0.76] – 0.010 [0.25]
	≥ 0.800 [20.3]	≤ 0.030 [0.76]	0.120 [3.0] + 0.030 [0.76] – 0.010 [0.25]	20° + 10° – 5°	0.250 [6.4] + 0.030 [0.76] – 0.010 [0.25]

^a Applies to complete joint penetration groove welds only. Root face height for partial joint penetration groove welds is governed by joint strength requirements.

^b Backgouging to sound metal required before welding second side.

^c Non-Keyhole mode only.

Figure A.1(i) – Double-U-Groove Weld Joints



Legend:

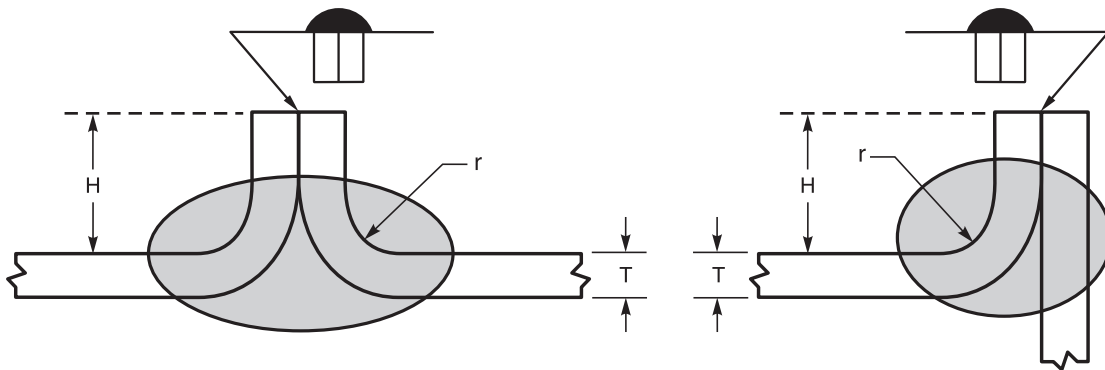
T = Thickness of thinner member.

R = Root opening ≤ 0.010 in [0.25 mm] for $T < 0.100$ in [2.5 mm], ≤ 0.030 in [0.76 mm] for $T \geq 0.100$ in [2.5 mm]

X = Weld Penetration Min. = $1/2 T$ or 0.015 in [0.38 mm], whichever is greater

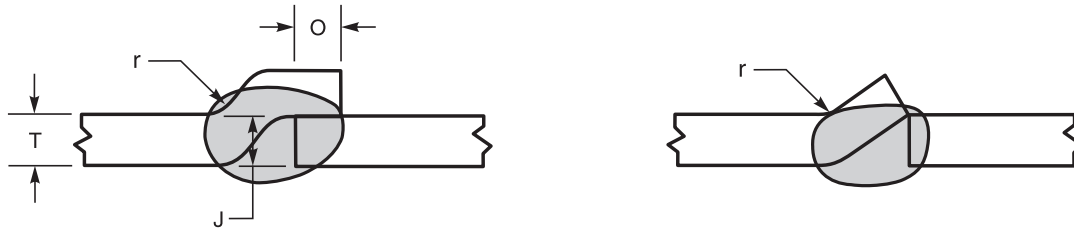
Max. = $2 1/2 T$ or 0.187 in [4.75 mm], whichever is less

Figure A.2—Two- and Three-Piece T-Weld Joints—Melt-through Welds



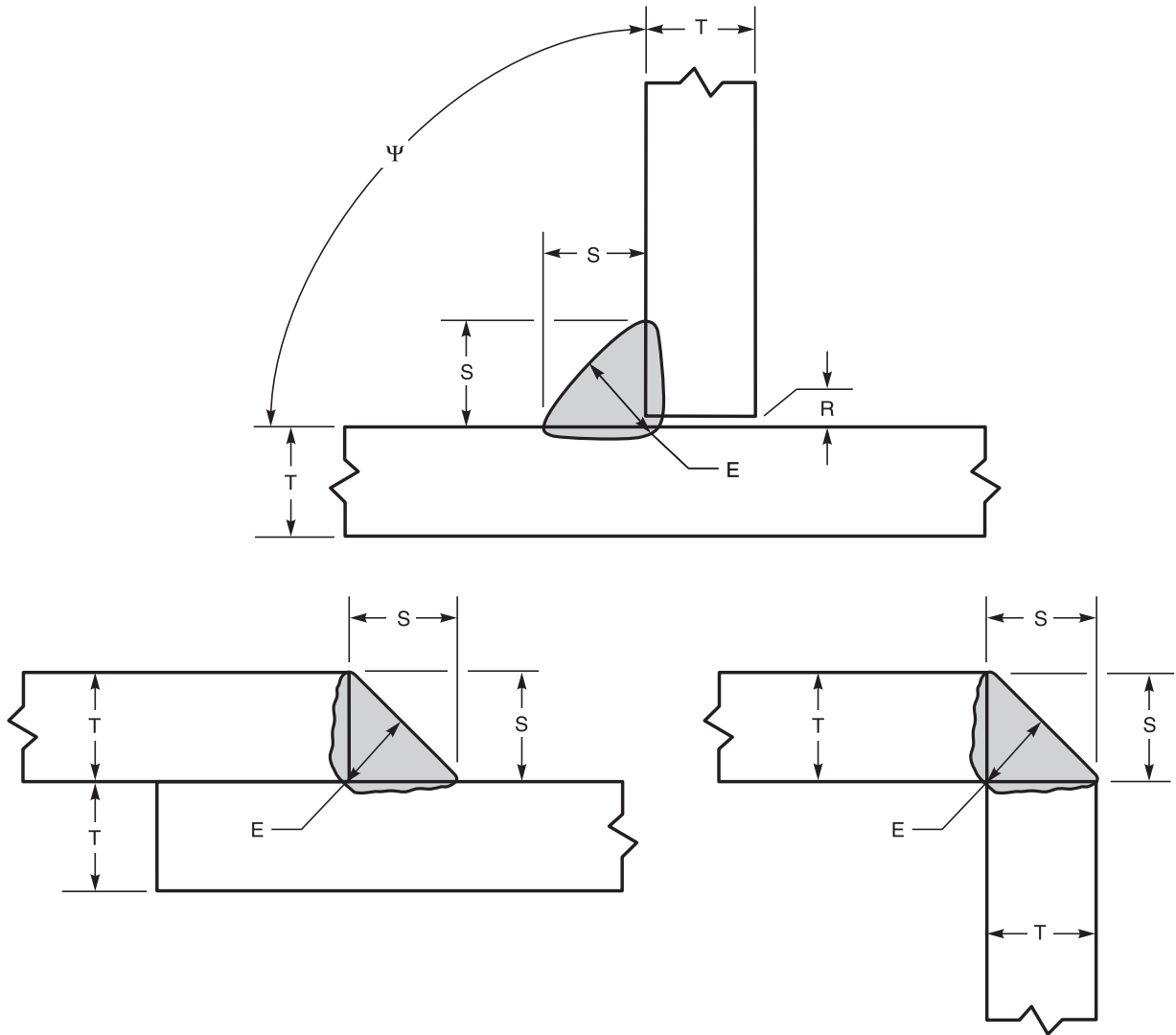
Thickness [T] in[mm]	Bend Radius [r] max (in[mm])	Flange Height [H] (in[mm])
0.016–0.032 [0.41–0.82]	0.04 [1]	0.08–0.12 [2–3]
0.033–0.062 [0.84–1.57]	0.06 [1.5]	0.10–0.16 [2.5–4]
0.063–0.100 [1.6–2.5]	2T	0.12–0.20 [3–5]

Figure A.3 (a)—Flanged Joints



Base Metal	Base Metal Thickness [T] (in [mm])	Bend radius [r] (in [mm])	Joggle [J] (in [mm])	Overlap [O] (in [mm])
Titanium (CP)	0.020–0.040 [0.5–1.0]	0.04 [1] max.	T +0.005 [0.13] –0.000 [0.00]	0.032–0.060 [0.81–1.5]
Stainless Steel	0.020–0.063 [0.5–1.6]	0.04 [1] max.	T +0.005 [0.13] –0.000 [0.00]	0.032–0.090 [0.81–2.29]
Nickel	0.020–0.063 [0.5–1.6]	0.06 [1.5] max.	T +0.005 [0.13] –0.000 [0.00]	0.032–0.090 [0.81–2.29]

Figure A.3(b)—Flanged Edge Joints (Nonstandard)



Legend:

R = Root gap.

T = Thickness of thinnest member.

S = Minimum weld size.

E = Minimum effective throat.

 Ψ = Skew angle. $E_{\min} = 0.707T \times \text{factor}^{(1)}$.

Notes:

1. For corner or lap joints where full throat thickness is required: $S_{\min.} = T_{\min.}$ where T equals thickness of thinner member.
2. For fillet weld size factor see Table A.1.

Figure A.4—Fillet Weld Details

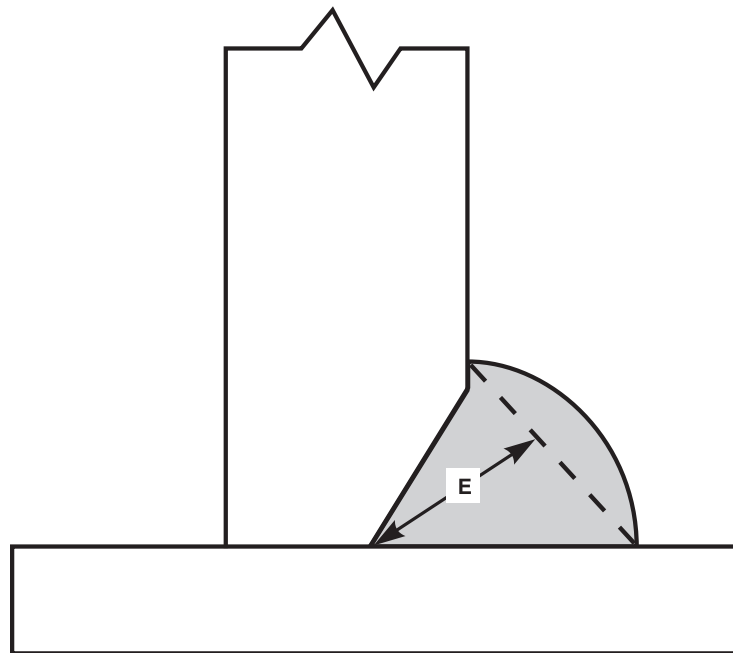
Table A.1
Equivalent Fillet Weld Leg Size
for Skewed T-Joints

Dihedral Angle [Y]	Comparable Fillet Weld Size for Same Strength (in [mm])
60	0.71 [18]
65	0.76 [19.3]
70	0.81 [20.6]
75	0.86 [21.8]
80	0.91 [23.1]
85	0.96 [24.4]
90	1.00 [25.4]
95	1.03 [26.2]
100	1.08 [27.4]
105	1.12 [28.4]
110	1.16 [29.5]
115	1.19 [30.2]
120	1.23 [31.2]
125	1.25 [31.75]
130	1.28 [32.5]
135	1.31 [33.3]

Annex B (Normative)

Effective Throat

This annex is part of AWS D17.1/D17.1M:2010-AMD1, *Specification for Fusion Welding for Aerospace Applications*, and includes mandatory elements for use with this standard.



E = Effective Throat

Note: The effective throat of a weld is the minimum distance from the root of the weld joint to its face less any reinforcement.

Figure B.1 — Effective Throat

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Annex C (Normative)

Bend Testing Criteria

This annex is part of AWS D17.1/D17.1M:2010-AMD1, *Specification for Fusion Welding for Aerospace Applications*, and includes mandatory elements for use with this standard.

C1. Scope. This annex covers the bend testing of groove and fillet welds. It provides the requirements for bend test specimen preparation, test parameters, testing procedures, bend radius requirements, and acceptance criteria. This annex shall be used when bend testing is the method to accept a WPS or welder/operator qualification.

C2. Criteria for Bend Testing. Bend testing may be used as an alternate to radiographic inspection if the following conditions are met:

- a. The members of the test weld differ in thickness by less than 10 % of the thicker member.
- b. For tube welds, the outside diameter is equal to or more than 2 in [60mm] in or the wall thickness is equal to or more than 0.250 in [6.3mm].
- c. Alloy is not included in Table C.1. Alloys listed in Table C.1 shall be metallographic or radiographic inspected in lieu of bend testing.

C3. Bend Testing. Bend testing is required for all fillet welds with a base metal thickness of more than 0.063 in [1.6 mm], except that metallographic examination may be used as an alternate to bend testing. The bend radius requirements are in Tables C.2 and C.2M. Bend testing of groove welds may be used as an alternate to radiographic inspection as described in C2. The bend test requirements for groove welds in tubes are in Table C.3.

Table C.1
Base Metals for Which Bend Testing is Not Applicable

Base Metal Group	Unified Number	Common Description
IA	K91122 K91283 K91313 K91472 K92810	9Ni-4Co steel
		18Ni maraging steel
IB	All	
IIA	S63198 S63199 R30155 R30590 S41800 S42000 S42200	19-9 DL 19-9 DX N155 S590 Greek Ascology 420 422
IIB	All	
IIIB	All	
IV	A03560 A92014 A92219	356 2014 2219
V	All	
VI	R54620 R56210 R56260 R56620 R58640 NA NA	Ti-6Al-2Sn-4Zr-2Mo Ti-6Al-2Cb-1Ta-1Mo Ti-6Al-2Sn-4Zr-6Mo Ti-6Al-6V-2Sn Ti-3Al-8V-6Cr-4Mo-4Zr Ti-6Al-2Sn-2Zr-2Cr-2Mo Ti-15V-3Cr-3Mo-3Sn
VII	All	

Table C.2
Bend Specimen Thickness and Bend Radius (in)

Bend Radius, A in ^b	Bend Specimen Thickness ^a					
	Unified Number (UNS)					
	R54520 R54810 R56320 R56400	A96061 A96063	R50400 R50550 R52400	R50250	A95083 A95086 A95456	Other
	$F = 12^c$	$F = 8$	$F = 5$	$F = 4$	$F = 3$	$F = 2$
	≥ <	≥ <	≥ <	≥ <	≥ <	≥ <
0.070						0.031 0.035
0.079						0.035 0.039
0.088						0.039 0.044
0.099					0.029 0.033	0.044 0.050
0.111					0.033 0.037	0.050 0.056
0.125					0.037 0.042	0.056 0.062
0.140				0.031 0.035	0.042 0.047	0.062 0.070
0.157				0.035 0.039	0.047 0.052	0.070 0.078
0.176			0.031 0.035	0.039 0.044	0.052 0.059	0.078 0.088
0.198			0.035 0.040	0.044 0.049	0.059 0.066	0.088 0.099
0.222			0.040 0.044	0.049 0.055	0.066 0.074	0.099 0.111
0.249			0.044 0.050	0.055 0.062	0.074 0.083	0.111 0.124
0.279		0.031 0.035	0.050 0.056	0.062 0.070	0.083 0.093	0.124 0.140
0.313		0.035 0.039	0.056 0.063	0.070 0.078	0.093 0.104	0.140 0.157
0.351		0.039 0.044	0.063 0.070	0.078 0.088	0.104 0.117	0.157 0.176
0.394	0.029 0.033	0.044 0.049	0.070 0.079	0.088 0.099	0.117 0.131	0.176 0.197
0.442	0.033 0.037	0.049 0.055	0.079 0.088	0.099 0.111	0.131 0.147	0.197 0.221
0.496	0.037 0.041	0.055 0.062	0.088 0.099	0.111 0.124	0.147 0.165	0.221 0.248
0.557	0.041 0.046	0.062 0.070	0.099 0.111	0.124 0.139	0.165 0.186	0.248 0.279
0.625	0.046 0.052	0.070 0.078	0.111 0.125	0.139 0.156	0.186 0.208	0.279 0.312
0.701	0.052 0.058	0.078 0.088	0.125 0.140	0.156 0.175	0.208 0.234	0.312 0.351
0.787	0.058 0.066	0.088 0.098	0.140 0.157	0.175 0.197	0.234 0.262	0.351 0.393
0.883	0.066 0.074	0.098 0.110	0.157 0.177	0.197 0.221	0.262 0.294	
0.991	0.074 0.083	0.110 0.124	0.177 0.198	0.221 0.248	0.294 0.330	
1.111	0.083 0.093	0.124 0.139	0.198 0.222	0.248 0.278	0.330 0.370	
1.247	0.093 0.104	0.139 0.156	0.222 0.249	0.278 0.312	0.370 0.416	
1.399	0.104 0.117	0.156 0.175	0.249 0.280	0.312 0.350		
1.570	0.117 0.131	0.175 0.196	0.280 0.314	0.350 0.392		
1.761	0.131 0.147	0.196 0.220	0.314 0.352			
1.976	0.147 0.165	0.220 0.247	0.352 0.395			
2.218	0.165 0.185	0.247 0.277				
2.488	0.185 0.207	0.277 0.311				
2.872	0.207 0.233	0.311 0.349				
3.132	0.233 0.261	0.349 0.392				
3.515	0.261 0.293					
3.943	0.293 0.329					
4.425	0.329 0.369					
4.965	0.369 0.414					

^a The body of the table contains the bend specimen thickness (T1) in inches.

^b The tolerance on bend radius A is +/-0.001 in or +/-1%, whichever is the larger.

^c F = Bend factor

**Table C.2M
Bend Specimen Thickness and Bend Radius (mm)**

Bend Radius, A mm ^b	Bend Specimen Thickness ^a					
	Unified Number (UNS)					
	R54520 R54810 R56320 R56400	A96061 A96063	R50400 R50550 R52400	R50250	A95083 A95086 A95456	Others
	F = 12 ^c	F = 8	F = 5	F = 4	F = 3	F = 2
	≥ <	≥ <	≥ <	≥ <	≥ <	≥ <
1.78						0.79 0.89
2.01						0.89 0.99
2.24						0.99 1.12
2.51					0.74 0.84	1.12 1.27
2.82					0.84 0.94	1.27 1.42
3.18					0.94 1.07	1.42 1.57
3.56				0.79 0.89	1.07 1.19	1.57 1.78
3.99				0.89 0.99	1.19 1.32	1.78 1.98
4.47			0.79 0.89	0.99 1.12	1.32 1.50	1.98 2.24
5.03			0.89 1.02	1.12 1.24	1.50 1.68	2.24 2.51
5.64			1.02 1.12	1.24 1.40	1.68 1.88	2.51 2.82
6.32			1.12 1.27	1.40 1.57	1.88 2.11	2.82 3.15
7.09		0.79 0.89	1.27 1.42	1.57 1.78	2.11 2.36	3.15 3.56
7.95		0.89 0.99	1.42 1.60	1.78 1.98	2.36 2.64	3.56 3.99
8.92		0.99 1.12	1.60 1.78	1.98 2.24	2.64 2.97	3.99 4.47
10.01	0.74 0.84	1.12 1.24	1.78 2.01	2.24 2.51	2.97 3.33	4.47 5.00
11.23	0.84 0.94	1.24 1.40	2.01 2.24	2.51 2.82	3.33 3.73	5.00 5.61
12.60	0.94 1.04	1.40 1.57	2.24 2.51	2.82 3.15	3.73 4.19	5.61 6.30
14.15	1.04 1.17	1.57 1.78	2.51 2.82	3.15 3.53	4.19 4.72	6.30 7.09
15.88	1.17 1.32	1.78 1.98	2.82 3.18	3.53 3.96	4.72 5.28	7.09 7.92
17.01	1.32 1.47	1.98 2.24	3.18 3.56	3.96 4.45	5.28 5.94	7.92 8.92
20.00	1.47 1.68	2.24 2.49	3.56 3.99	4.45 5.00	5.94 6.65	8.92 9.98
22.43	1.68 1.88	2.49 2.79	3.99 4.50	5.00 5.61	6.65 7.47	
25.17	1.88 2.11	2.79 3.15	4.50 5.03	5.61 6.30	7.47 8.38	
28.22	2.11 2.36	3.15 3.53	5.03 5.64	6.30 7.06	8.38 9.40	
31.67	2.36 2.64	3.53 3.96	5.64 6.32	7.06 7.92	9.40 10.57	
35.53	2.64 2.97	3.96 4.45	6.32 7.11	7.92 8.89		
39.88	2.97 3.33	4.45 4.98	7.11 7.98	8.89 9.96		
44.73	3.33 3.73	4.98 5.59	7.98 8.94			
50.19	3.73 4.19	5.59 6.27	8.94 10.03			
56.34	4.19 4.70	6.27 7.04				
63.20	4.70 5.26	7.04 7.90				
72.95	5.26 5.92	7.90 8.86				
79.96	5.92 6.63	8.86 9.96				
89.28	6.63 7.44					
100.15	7.44 8.36					
112.4	8.36 9.37					
126.11	9.37 10.52					

^a The body of the table contains the bend specimen thickness (T1) in inches.

^b The tolerance on bend radius A is ±0.03 mm or ±1%, whichever is the larger.

^c F = Bend factor

**Table C.3
Bend Specimens for Groove Welds in Tube**

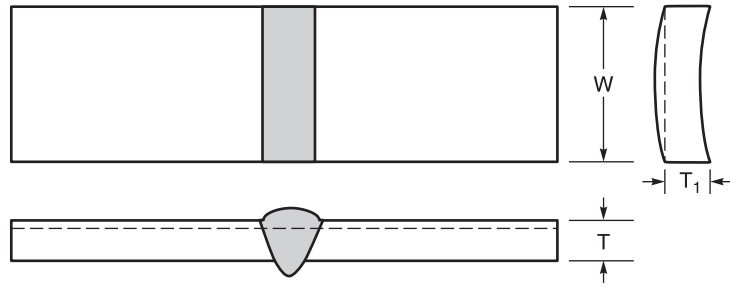
Tube			Bend Test Specimen				
Outside Diameter in [mm]	Wall Thickness <i>T</i> , in [mm]	Base Metal Number	Type Shown in Fig. C.1	Dimensions, in [mm]			
				T1		W	
				Min.	Max.	Min.	Max.
1	2	3	4	5	6	7	8
< 2 [51]	All	All	Radiographic Inspection Required				
2 – 5	< 0.250 [6.3]	All	Radiographic Inspection Required				
[51–127]	≥ 0.250 – 0.375 [6.3 – 9.5]	(Note a) All Others	TB-e and TB-f TB-e and TB-f	0.115 [2.9] (Note b)	0.135 [3.4] (Note b)	0.750 [19] 0.750 [19]	0.800 [20.3] 0.800 [20.3]
	< 0.375 – 0.750 [9.5–19]	(Note a)	TB-e and TB-f or SB-g	0.115 [2.9] 0.115 [2.9]	0.135 [3.4] 0.135 [3.4]	0.750 [19] T	0.800 [20.3] T
		All Others	TB-e and TB-f or SB-g	(Note c) 0.350 [8.9]	(Note c) 0.400 [10.2]	0.750 [19] T	0.800 [20.3] T
	> 0.750 [19]	(Note a) All Others	SB-g SB-g	0.115 [2.9] 0.350 [8.9]	0.135 [3.4] 0.400 [10.2]	T T	T T
> 5 [127]	< 0.250 [6.3]	All	Radiographic Inspection Required				
	≥ 0.250 – 0.375 [6.3–9.5]	(Note a) All Others	TB-e & TB-f TB-e and TB-f	0.115 [2.9] (Note b)	0.135 [3.4] (Note b)	1.50 [38.1] 1.50 [38.1]	1.55 [39.4] 1.55 [39.4]
	> 0.375 – 0.750 [9.5–19]	(Note a)	TB-e and TB-f or SB-g	0.115 [2.9] 0.115 [2.9]	0.135 [3.4] 0.135 [3.4]	1.50 [38.1] T	1.55 [39.4] T
		All Others	TB-e and TB-f or SB-g	(Note c) 0.350 [8.9]	(Note c) 0.400 [10.2]	1.50 [38.1] T	1.55 [39.4] T
	> 0.750 [19]	(Note a) All Others	SB-g SB-g	0.115 [2.9] 0.350 [8.9]	0.135 [3.4] 0.400 [10.2]	(Note d) (Note d)	T T

^a A96061 and A96063 of Base Metal Group IV.

^b The maximum T1 is the thickness resulting from dressing of the curved surface to plane. The minimum T1 is 0.9 times the maximum.

^c The maximum T1 is the thickness resulting from dressing the curved surface to a plane, or 0.400 in [10 mm], whichever is the lesser. In the first case, the minimum T1 is 0.9 times the maximum. In the second case, the minimum T1 is 0.350 in [9 mm].

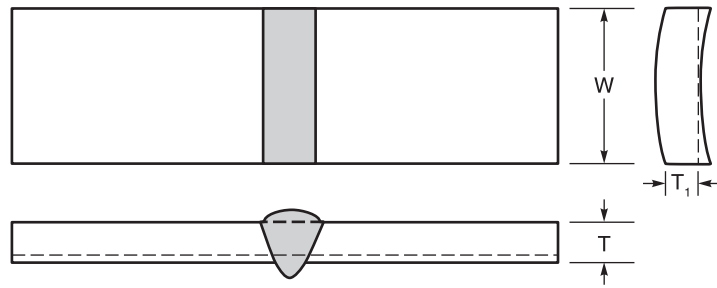
^d For wall thicknesses of >0.750 to 1.50 in [19 to 38 mm], W is equal to T. For wall thicknesses of >1.50 in [38 mm], specimens may be cut into approximately equal strips between 0.75 and 1.50 in [19 to 38 mm] wide for testing, or the specimens may be bent at full width.



TB

NOTE: The thickness of the transverse root bend specimen is measured at the specimen edge.

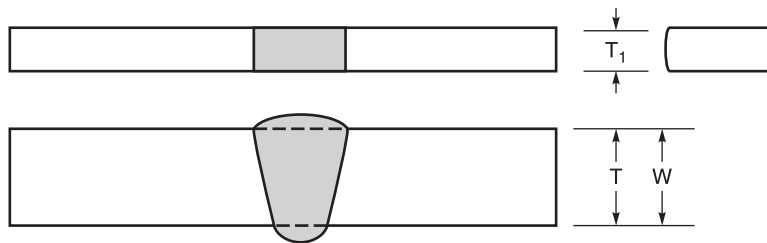
a. TRANSVERSE ROOT BEND



TB

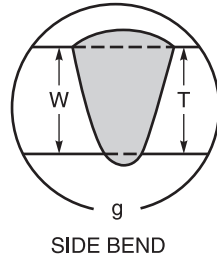
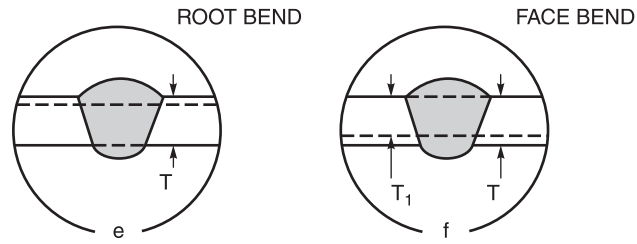
NOTE: The thickness of the transverse root bend specimen is measured at the specimen center.

b. TRANSVERSE FACE BEND



SB

c. SIDE BEND



- NOTES: - Longitudinal corners of all specimens shall be rounded to a radius not to exceed 10 percent of the finished thickness.
- Dashed lines indicate machined surfaces.
- Where the members of the test weld differ in wall thickness, the finished dimensions of the bend specimen shall be based on the thickness of the thicker member.

d. BEND SPECIMEN SECTION DETAILS

Figure C.1 — Bend Specimens in Groove Welded Tube

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Annex D (Informative)

Informative References

This annex is not part of AWS D17.1/D17.1M:2010, *Specification for Fusion Welding for Aerospace Applications*, but is included for informational purposes only.

AWS B2.1/B2.1M, *Specification for Welding Procedure and Performance Qualification*;
AWS B4.0, *Standard Methods for Mechanical Testing of Welds, U.S. Customary Only*;
AWS B4.0M, *Standard Methods for Mechanical Testing of Welds, Metric Only*;
AWS C7.1M/C7.1, *Recommended Practices for Electron Beam Welding*;
AWS C7.2, *Recommended Practices for Laser Beam Welding, Cutting and Drilling*;
AWS D1.1/D1.1M, *Structural Welding Code — Steel*
AWS D1.2/D1.2M, *Structural Welding Code — Aluminum*
AWS D1.3/D1.3M, *Structural Welding Code — Sheet Steel*
AWS D1.4M/D1.4, *Structural Welding Code — Reinforcing Bar*
AWS D1.5/D1.5M, *Bridge Welding Code*
AWS D1.6/D1.6M, *Structural Welding Code — Stainless Steel*
AWS D3.6M, *Specification for Underwater Welding*
AWS D5.2, *Standard for Welded Steel — Elevated Tanks, Standpipes, and Reservoirs for Water Storage*, (American Waterworks Association (AWWA) Standard D100
AWS D9.1M/D9.1, *Sheet Metal Welding Code*
AWS D14.1/D14.1M, *Industrial and Mill Crane and Other Material Handling Equipment, Specification for Welding*
AWS D14.3/D14.3M, *Specification for Welding Earthmoving, Construction, and Agricultural Equipment*
AWS D14.4/D14.4M, *Specification for Welded Joints in Machinery and Equipment*
AWS D14.5/D14.5M, *Specification for Welding of Presses and Press Components*
AWS D14.6/D14.6M, *Rotating Elements for Equipment, Specification for Welding*
AWS D14.7/D14.7M, *Recommended Practice for Surfacing and Reconditioning of Industrial Mill Rolls*
AWS D14.8M (ISO/TR 17844:2004 IDT), *Standard Methods for the Avoidance of Cold Cracks*
AWS D15.1/D15.1M, *Railroad Welding Specification for Cars and Locomotives*

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Annex E (Informative)

Safe Practices

This annex is not part of AWS D17.1/D17.1M:2010-AMD1, *Specification for Fusion Welding for Aerospace Applications*, but is included for informational purposes only.

This Annex covers many of the basic elements of safety common with arc welding processes. It includes many, but not all, of the safety aspects related to fusion welding operations. Clauses E1 through E6 cover general practices while E7 and E8 cover the requirements for electron or laser beam weld processes or any process involving sophisticated technology. The hazards that may be encountered and the practices that will minimize personal injury and property damage are reviewed here.

E1. Electrical Hazards

Electric shock can kill. However, it can be avoided. Live electrical parts should not be touched. Read and understand the manufacturer's instructions and recommended safe practices. Faulty installation, improper grounding, and incorrect operation and maintenance of electrical equipment are all sources of danger.

All electrical equipment and the workpiece should be grounded. A separate connection is required to ground the workpiece. The work lead should not be mistaken for a ground connection.

To prevent shock, the work area, equipment, and clothing should be kept dry at all times. Dry gloves and rubber soled shoes should be worn. The welder or welding operator should stand or be seated on a dry board or insulated platform.

Cables and connectors should be kept in good condition. Worn, damaged, or bare cables should not be used. In case of electric shock, the power should be turned off immediately. If the rescuer must resort to pulling the victim from the live contact, nonconducting materials should be used.

A physician should be called and CPR continued until breathing has been restored, or until a physician has arrived (see References 7, 8, and 10).

E2. Fumes and Gases

Many welding, cutting, and allied processes produce fumes and gases which may be harmful to one's health. Fumes and solid particles originate from welding consumables, the base metal, and any coatings present on the base metal. Gases are produced during the welding process or may be produced by the effects of process radiation on the surrounding environment. Everyone associated with the welding operation should acquaint themselves with the effects of these fumes and gases.

The possible effects of overexposure to fumes and gases range from irritation of eyes, skin, and respiratory system to more severe complications. Effects may occur immediately or at some later time. Fumes can cause symptoms such as nausea, headaches, dizziness, and metal fume fever.

Sufficient ventilation, exhaust at the arc, or both, should be used to keep fumes and gases from breathing zones and the general work area.

For more detailed information on fumes and gases produced by the various welding processes (see References 1, 4, and 11).

E3. Noise

Excessive noise is a known health hazard. Exposure to excessive noise can cause a loss of hearing. This loss of hearing can be either full or partial, and temporary or permanent. Excessive noise adversely affects hearing capability. In addition, there is evidence that excessive noise affects other bodily functions and behavior.

Personal protective devices such as ear muffs or ear plugs may be employed. Generally, these devices are only accepted when engineering controls are not fully effective (see References 1, 5, and 11).

E4. Burn Protection

Molten metal, sparks, slag, and hot work surfaces are produced by welding, cutting, and allied processes. These can cause burns if precautionary measures are not used.

Workers should wear protective clothing made of fire-resistant material. Pant cuffs or clothing with open pockets or other places on clothing that can catch and retain molten metal or sparks should not be worn. High-top shoes or leather leggings and fire-resistant gloves should be worn. Pant legs should be worn over the outside of high-top boots. Helmets or hand shields that provide protection for the face, neck, and ears, should be worn, as well as head covering to protect the head.

Clothing should be kept free of grease and oil. Combustible materials and propane lighters should not be carried in pockets. If any combustible substance is spilled on clothing, it should be replaced with clean fire-resistant clothing before working with open arcs or flame. Jewelry should not be worn on the hands or arms.

Appropriate eye protection should be used at all times. Goggles or equivalent should also be worn to give added eye protection. Insulated gloves should be worn at all times when in contact with hot items or handling electrical equipment.

For more detailed information on personal protection, see References 2, 3, 7, and 11.

E5. Fire Prevention

Molten metal, sparks, slag, and hot work surfaces are produced by welding, cutting, and allied processes. These can cause fire or explosion if precautionary measures are not used.

Explosions have occurred where welding or cutting has been performed in spaces containing flammable gases, vapors, liquid, or dust. All combustible materials should be removed from the work area. Where possible, move the work to a location well away from combustible materials. If neither action is possible, combustibles should be protected with a cover of fire-resistant material. All combustible materials should be removed or safely protected within a radius of 35 ft [11 m] around the work area. For welding in the field or in situ on aircraft, a fire watch should remain over 30 minutes after work is complete.

Welding or cutting should not be done in atmospheres containing dangerously reactive or flammable gases, vapors, liquid, or dust. Heat should not be applied to a container that has held an unknown substance or a combustible material whose contents when heated can produce flammable or explosive vapors. Adequate ventilation should be provided in work areas to prevent accumulation of flammable gases, vapors, or dusts. Containers should be cleaned and purged before applying heat.

For more detailed information on fire hazards from welding and cutting operations, see References 6, 7, 9, and 11.

E6. Radiation

Welding, cutting, and allied operations may produce radiant energy (radiation) harmful to health. Everyone should acquaint themselves with the effects of this radiant energy.

Radiant energy may be ionizing (such as X-rays) or nonionizing (such as ultraviolet, visible light, or infrared). Radiation can produce a variety of effects such as skin burns and eye damage if excessive exposure occurs.

Some processes such as resistance welding and cold pressure welding ordinarily produce negligible quantities of radiant energy. However, most arc welding and cutting processes (except submerged arc when used properly), laser and torch

welding, cutting, brazing, or soldering can produce quantities of nonionizing radiation such that precautionary measures are necessary.

Protection from possible harmful radiation effects includes the following:

- (1) Welding arcs should not be viewed except through welding lenses (see Reference 2). Transparent welding curtains are not intended as welding lenses, but rather, are intended to protect a passerby from incidental exposure.
- (2) Exposed skin should be protected with adequate gloves and clothing as specified (see Reference 7).
- (3) The casual passerby to welding operations should be protected by the use of screens, curtains, or adequate distance from aisles, walkways, etc.
- (4) Safety glasses with ultraviolet protective side shields have been shown to provide some beneficial protection from ultraviolet radiation produced by welding arcs.

E6.1 Thoriated tungsten electrodes, manufactured using thorium contain radioactive material. Thorium is a radioactive element containing the Alfa (A-Radiation) particle. Although the Alfa particle has no penetrating ability such as the Beta or Gamma Ray contain serious latent body damage could result if these particle where to be ingested into the body. This could result from small particles of the dust coming in contact with the welder's hands and fingers while grinding and shaping the electrodes. The particles could then be ingested into the body when eating or picking at body cavities. Since radiation poison is accumulative, and signs may not be visible until several years later, it is recommended that welders practice safe practices during grinding operations of thoriated electrodes. This could include wiping down the work area where grinding took place after dressing the electrodes and washing their hands after final operation of the task. Special tungsten electrode grinding machines are also available that contain the dust and grinding materials and use of such grinding machines may prove useful.

E7. Electron Beam Welding In addition to the potential safety hazards associated with welding processes in general, there are safety hazards specifically associated with the electron beam welding process. These include the following:

- (1) Electric shock
- (2) X-Radiation
- (3) Fumes and gases
- (4) Visible radiation
- (5) Vacuum

E7.1 Electric Shock. Unlike arc welding processes, voltages used in electron beam welding machines are sufficient to cause fatal injury to personnel. Caution must be exercised during welding operations and maintenance of the electron gun and high voltage power supplies to assure personnel safety.

E7.2 X-Radiation. Whenever the electron beam is on, the system is capable of generating X-rays. If electron beam equipment is improperly shielded or used improperly, X-ray leakage can result in personnel being exposed to a radiation dose sufficient to cause injury.

E7.3 Fumes and Gas. Toxic fumes and gases that may be generated in sufficient quantities to be harmful include ozone (O₃), various oxides of nitrogen (NO and NO₂, in particular) and metallic fumes from the workpiece being welded. Particulate matter deposited during welding on fixtures and the walls of the workpiece enclosure may become airborne when disturbed. Personnel should not be allowed to enter the workpiece enclosure after welding until the concentrations of airborne contaminants have been reduced to safe levels.

E7.4 Visible Radiation. Direct viewing of visible radiation during welding operations can be harmful to eyesight.

Radiation intensity increases with increasing metal temperature. Filters must be used to provide adequate eye protection.

E7.5 Vacuum. Because all electron beam machines require a high vacuum for beam generation and some level of vacuum surrounding the workpiece, users must observe the safety precautions associated with conventional vacuum systems.

For more detailed information on the safety requirements for electron beam welding (see Reference 12).

E8. Laser Beam Welding

In addition to the potential safety hazards associated with welding processes, there are safety hazards specifically associated with the laser beam welding process. These include the following:

- (1) Electrical hazards
- (2) Radiation
- (3) Fumes and gases

E8.1 Electrical Hazards. Unlike arc welding processes, voltages used in laser beam welding machines are sufficient to cause fatal injury to personnel. Caution must be exercised during welding operations and maintenance of the equipment to assure personnel safety.

E8.2 Radiation. There are two potential dangers associated with laser radiation; eye and skin damage. Extent of damage can be affected by the type of laser, the power level used, material being welded, and the shielding gases.

Eye damage can include damage to the cornea, the retina, or both. Skin damage is typically burns which can be deep and cause permanent damage.

Filters must be used to provide adequate eye protection.

E8.3 Fumes and Gases. Toxic fumes and gases that may be generated in sufficient quantities to be harmful include ozone (O₃), metal particles and oxide particles and other toxic gases.

For more detailed information on the safety requirements for laser beam welding, see Reference 13.

E9. References

1. American Conference of Governmental Industry Hygienists (ACGIH). *Threshold Limit Values for Chemical Substances and Physical Agents in the Workroom Environment*. Cincinnati, OH: American Conference of Governmental Industry Hygienists.
2. American National Standards Institute (ANSI). *Practice for Occupational and Educational Eye and Face Protection*, ANSI Z87.1. New York: American National Standards Institute.
3. ——. *Standard Specification for Performance Requirements for Foot Protection*, ASTM F2413. West Conshohocken, PA: ASTM International.
4. American Welding Society (AWS). *Fumes and Gases in the Welding Environment*, AWS report. Miami, FL: American Welding Society.
5. ——. *Method for Sound Level Measurement of Manual Arc Welding and Cutting Processes*, AWS F6.1. Miami, FL: American Welding Society.
6. ——. *Recommended Safe Practices for the Preparation for Welding and Cutting Containers That Have Held Hazardous Substances*, AWS F4.1. Miami, FL: American Welding Society.
7. ——. *Safety in Welding, Cutting, and Allied Processes*, ANSI Z49.1. Miami, FL: American Welding Society.
8. ——. *Safety Practices*. (Reprint from *Welding Handbook*, Volume 1, Eighth Edition) Miami, FL: American Welding Society.
9. National Fire Protection Association (NFPA). *Cutting and Welding Processes*, NFPA Standard 51B. Quincy, MA: National Fire Protection Association.
10. ——. *National Electrical Code*, NFPA No. 70. Quincy, MA: National Fire Protection Association.
11. Occupational Safety and Health Administration (OSHA). *Code of Federal Regulations*, General Industry Standards. Washington, DC: U.S. Government Printing Office.
12. American Welding Society. *Recommended Practices for Electron Beam Welding*. AWS C7.1. Miami, FL: American Welding Society.
13. American Welding Society. *Recommended Practices for Laser Beam Welding, Cutting, and Drilling*, AWS C7.2. Miami, FL: American Welding Society.

Annex F (Informative)

Guidelines for the Preparation of Technical Inquiries

This annex is not part of AWS D17.1/D17.1M:2010-AMD1, *Specification for Fusion Welding for Aerospace Applications*, but is included for informational purposes only.

F1. Introduction

The American Welding Society (AWS) Board of Directors has adopted a policy whereby all official interpretations of AWS standards are handled in a formal manner. Under this policy, all interpretations are made by the committee that is responsible for the standard. Official communication concerning an interpretation is directed through the AWS staff member who works with that committee. The policy requires that all requests for an interpretation be submitted in writing. Such requests will be handled as expeditiously as possible, but due to the complexity of the work and the procedures that must be followed, some interpretations may require considerable time.

F2. Procedure

All inquiries shall be directed to:

Managing Director
 Technical Services Division
 American Welding Society
 550 N.W. LeJeune Road
 Miami, FL 33126

All inquiries shall contain the name, address, and affiliation of the inquirer, and they shall provide enough information for the committee to understand the point of concern in the inquiry. When the point is not clearly defined, the inquiry will be returned for clarification. For efficient handling, all inquiries should be typewritten and in the format specified below.

F2.1 Scope. Each inquiry shall address one single provision of the standard unless the point of the inquiry involves two or more interrelated provisions. The provision(s) shall be identified in the scope of the inquiry along with the edition of the standard that contains the provision(s) the inquirer is addressing.

F2.2 Purpose of the Inquiry. The purpose of the inquiry shall be stated in this portion of the inquiry. The purpose can be to obtain an interpretation of a standard's requirement or to request the revision of a particular provision in the standard.

F2.3 Content of the Inquiry. The inquiry should be concise, yet complete, to enable the committee to understand the point of the inquiry. Sketches should be used whenever appropriate, and all paragraphs, figures, and tables (or annex) that bear on the inquiry shall be cited. If the point of the inquiry is to obtain a revision of the standard, the inquiry shall provide technical justification for that revision.

F2.4 Proposed Reply. The inquirer should, as a proposed reply, state an interpretation of the provision that is the point of the inquiry or provide the wording for a proposed revision, if this is what the inquirer seeks.

F3. Interpretation of Provisions of the Standard

Interpretations of provisions of the standard are made by the relevant AWS technical committee. The secretary of the committee refers all inquiries to the chair of the particular subcommittee that has jurisdiction over the portion of the

standard addressed by the inquiry. The subcommittee reviews the inquiry and the proposed reply to determine what the response to the inquiry should be. Following the subcommittee's development of the response, the inquiry and the response are presented to the entire committee for review and approval. Upon approval by the committee, the interpretation is an official interpretation of the Society, and the secretary transmits the response to the inquirer and to the *Welding Journal* for publication.

F4. Publication of Interpretations

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

F5. Telephone Inquiries

Telephone inquiries to AWS Headquarters concerning AWS standards should be limited to questions of a general nature or to matters directly related to the use of the standard. The *AWS Board Policy Manual* requires that all AWS staff members respond to a telephone request for an official interpretation of any AWS standard with the information that such an interpretation can be obtained only through a written request. Headquarters staff cannot provide consulting services. However, the staff can refer a caller to any of those consultants whose names are on file at AWS Headquarters.

F6. AWS Technical Committee

The activities of AWS technical committees regarding interpretations are limited strictly to the interpretation of provisions of standards prepared by the committees or to consideration of revisions to existing provisions on the basis of new data or technology. Neither AWS staff nor the committees are in a position to offer interpretive or consulting services on (1) specific engineering problems, (2) requirements of standards applied to fabrications outside the scope of the document, or (3) points not specifically covered by the standard. In such cases, the inquirer should seek assistance from a competent engineer experienced in the particular field of interest.

Annex G (Informative) Commentary

This annex is not part of AWS D17.1/D17.1M:2010-AMD1, *Specification for Fusion Welding for Aerospace Applications*, but is included for informational purposes only.

Foreword

This foreword is not part of AWS D17.1/D17.1M:2010-AMD1, *Specification for Fusion Welding for Aerospace Applications*, but is included for informational purposes only.

Note: All references to numbered paragraphs, tables and figures, unless otherwise indicated, refer to subclauses, tables or figures in AWS D17.1/D17.1M:2010, *Specification for Fusion Welding for Aerospace Applications*. Reference to subclauses, tables, or figures in this commentary is prefixed with the letter G. Hence, Figure 5.2 is in AWS D17.1/D17.1M, while Figure G5.2 is in this commentary.

This commentary on AWS D17.1/D17.1M:2010 has been prepared to generate better understanding in the application of this specification in aircraft and aerospace welding.

Since the specification cannot contain background information or discuss the committee's intent, it is the function of this commentary to fill this need.

Suggestions for application, as well as clarification of specification requirements, are offered with specific emphasis on requirements that differ from the requirements given in MIL-STD-1595, or MIL-STD-2219.

It should be recognized that the fundamental premise of this specification is to provide general stipulations and to leave sufficient latitude for the exercise of engineering judgment. Due to the diverse nature of the Aerospace industry, it is not possible to establish a single set of specification controls that are applicable to all design applications. This specification represents the collective experience of the committee and while some provisions may seem overly conservative for some applications, they may be too liberal in others. All provisions are based on sound engineering practice. The Engineering Authority assumes responsibility for applying this specification in a given design situation and modifying the requirements to achieve the desired performance at reasonable cost without taking undue risk.

The committee, therefore, believes that a commentary is the most suitable means to provide clarification as well as proper interpretation of the many specification requirements. Obviously, the size of the commentary imposes restrictions on the extent of coverage on a given requirement.

This commentary is not intended to provide a historical background of the development of this specification, nor is it intended to provide a detailed resume of the studies and research data reviewed by the committee in formulating the provisions of this specification.

This specification does not treat the selection of materials or the sizing of the weld joints. Such considerations are assumed to be covered elsewhere; that is the statement of work, corporate design manuals, etc.

The committee has endeavored to produce a useful document suitable in language, form and coverage for welding in the Aerospace and Aircraft industry. The specification provides a means for establishing welding standards for use in the design and construction by the customer or the Engineering Authority. The specification includes provisions for the regulation of welding that are necessary for public safety.

The committee recommends that the customer or the Engineering Authority be guided by this commentary in application of the specification to the welded structure. The commentary is not intended to supplement code requirements, but only to provide a useful document for interpretation and application of the specification; none of its provisions are binding.

It is the intention of the Committee on Welding in the Aircraft and Aerospace Industries to revise the commentary on a regular basis so that commentary on changes to the specification can be promptly supplied to the user. In this manner, the commentary will always be current with the edition of the specification for fusion welding Aerospace structures with which it is bound.

Changes in the commentary will be indicated by a single vertical line that appears in the margin immediately adjacent to the paragraph, tables or figures.

G1. Scope and General Requirements

G1.1 Scope

This specification provides general welding requirements applicable to aerospace welded structures. It replaces MIL-STD-2219, *Fusion Welding for Aerospace Applications*, and MIL-STD-1595, *Qualification of Aircraft Missile and Aerospace Fusion Welders*, and is intended to complement any specification for the design and construction of aerospace and aircraft structures. When using this specification, customers and the Engineering Authority should recognize that not all provisions may be applicable or suitable to their particular structure.

Because of the diversity of the mission and systems criteria for aerospace structures, the specification committee allows modification of the provisions when deemed necessary by the Engineering Authority and when supported by engineering data. All modification of specification provisions should be clearly referenced in the contractual agreement between the customer and the Engineering Authority.

G1.1.1. In the United States, nonmilitary flight structures, including engines, used for commercial and general aviation are subject to the requirements set forth in the Code of Federal Regulations (CFR), Title 14. The Parts of the CFR most directly applicable to D17.1/D17.1M are Parts 23, 25, 27, 29, 33, and 43.

G1.1.2 Contract requirements in the aerospace industry may not distinguish between welding intended for flight hardware (engines, structures, and flight systems) and welding for support functions (nonflight systems, tooling, ground support equipment, and related nonconventional facilities). For this reason it was necessary to create Clause 9.

G1.2 Classification. Aircraft and aerospace structures are classified according to structural integrity requirements, and welds in these structures commonly are subject to the same classifications. However, when design analysis can demonstrate that the weld(s), or a portion of the weld(s) in the structure is/are not subject to the same structural integrity requirements, or loads as the rest of the structure, these welds may carry different classifications.

MIL-STD-2219 (Dec. 1988) provided the following nonmandatory clarification for the use of weld classifications A, B, and C:

Class A: Critical applications. Welds the single failure of which would cause loss of system, loss of major component, loss of control, unintentional release of critical stores or inability to release armament stores or endangering personnel.

Class B: Semicritical application. Welds where a failure would reduce overall efficiency of the system, preclude the intended function or use of the equipment; but loss of the system or endangering of personnel would not be experienced.

Class C: Noncritical application. Welds where a failure would not affect the efficiency of the system or endanger personnel.

In general, much of the weld design data for Class A and Class B welds used in the aircraft and aerospace industry was derived from statistical analysis of data derived from test welds, and Effects of Defects Studies. The extent of the testing may not be consistent from material/filler metal combination to material/metal combination or gage to gage. Early industry databases generated in the 1950s and 1960s established acceptance standards that were related to workmanship standards and did not reflect the fracture toughness characteristics of the various material/filler metal combinations. Consequently, there may be a degree of conservatism in the application of acceptance standards to welds in certain

materials, while in others the standards may be too liberal. When selecting the appropriate weld classification, and the extent of inspection, the Engineering Authority should consider not only the structural integrity requirements, but the ability to inspect, repair or replace during the design life of the structures.

This specification recognizes that there are other factors that may enter into the selection of weld classifications and consequently uses weld classifications to identify the level for inspection and the acceptance criteria. The reason for this approach is that two identical welds may be exposed to different environments, have different degrees of accessibility for maintenance inspection during its design life, and be subject to different loading conditions (i.e., static versus dynamic). It is incumbent on the Engineering Authority to establish the weld classification that is both cost effective and assures the structural integrity of the weldment for any given application.

When a detailed design analysis of the structure shows that the loading or criticality of the weld varies along its length, it is permissible to zone the weld and apply different inspection requirements and different acceptance standards to the individual zones.

G2. Design of Welded Connections

G2.1 Scope. The ability of a weld to achieve its purpose or mission starts with the design process. Neither fabrication prowess nor inspections will make up for a poor or inadequate design. The design process, in a large part, will establish the fabrication and life costs of the weldment. Weld joint selection and joint location play a major role in a weld's manufacturability and inspectability. Aside from ensuring that the weld will have adequate structural integrity, it is imperative that the design process also consider the fabrication and inspection techniques necessary to complete the weld. The weld joint must be accessible for both welding and inspection.

G2.2 Weldment Design Data. The first step in the design process should be to ensure that there is adequate data which reflect the performance of the weld zone under the anticipated loading. This weld zone includes the weld metal and the adjacent parent metal, or heat-affected zone (HAZ). All of the components of the weld zone, not just the weld metal, make up the weld joint. The weld joint performance and strength will be affected by subsequent processing, such as heat treatment, forming, or peening, to name a few. Consideration of weld discontinuities is a part of sound design analysis. It is important to remember that fusion welding is an in-situ casting process and the presence of weld metal discontinuities is possible.

The presence or absence of weld reinforcement, or the use of weld lands, determines which is the most critical area of the structure: the weld, the HAZ, or parent metal. Weld lands may be used where the joint strength, or other properties, are less than the parent metal.

Shrinkage and the resulting residual stress are normal occurrences in fusion welding. The residual stress present will affect the performance of the weld joint. Under some loading conditions this effect will be deleterious. Steps may be necessary to either reduce the residual stress in the weld joint with a postwelding treatment or to compensate for its effects by modifying the weld joint design. In the case of shrinkage, preweld joint details may need added material to allow the weldment to meet postwelding dimensional requirements.

G2.3 General Drawing Requirements

G2.3.1 Drawing Information. There should be sufficient unambiguous information concerning the size, extent, type, location, and inspection requirements for the welds on the engineering drawing to allow the fabricator to produce the welds. The engineering drawing is often the sole mechanism by which the Engineering Authority communicates the weldment requirements to the fabricator and the inspector. There are some cases where the standard symbols of AWS A2.4 do not adequately describe the required weld and inspections. In these cases the Engineering Authority must add enough additional information, often in the form of weld details, to the engineering drawing to provide reasonable assurance that the fabricator will know what type of weld to produce and how to inspect it.

G2.3.2 Groove Welds. Full penetration groove welds are the default requirement. Full penetration welds do not have the built in discontinuity in the weld joint that is always present in a partial penetration weld. Thus, the internal examination of full penetration groove welds for discontinuities is more straightforward than that for partial penetration groove welds. The effective area of a groove weld coupled with the weld metal strength indicates the load-carrying capacity of the weld metal. Weld reinforcement is not considered when calculating the effective area of a groove weld for loading analysis because reinforcement is of little benefit to the load-carrying capacity of the weld joint.

G2.3.3 Fillet Welds. Typical practice in welding is to specify the fillet weld size as a minimum with the maximum size controlled by the governing fabrication specification. However, the drawing should state a specific maximum weld size allowed when there are issues with mechanical interference at a higher assembly level. The effective area of a fillet weld coupled with the strength of the weld filler metal in shear determines the strength of the fillet joint. Some weld filler metals in fillet joints have shear strength values that differ according to the direction of the applied shear stress. The principal shear stress directions are parallel or perpendicular (longitudinal or transverse) to the length of the fillet weld.

In this specification the minimum distance from the design joint root to the face of the triangle representative of the fillet weld cross section at the minimum allowable size is the effective throat. The definition here is consistent with that in AWS D1.1/D1.1M but differs from AWS A3.0M/A3.0. This calculation of the minimum effective throat requires a large amount of additional weld metal. Because fillet welds are triangular in cross section (often a right triangle) increasing the effective throat requires a large amount of additional weld metal. For example, in a 90-degree equal leg fillet weld with no root gap, increasing the weld leg size from 1/8 to 3/16 in [3.2 to 4.8 mm] will increase the effective throat by a factor of 1.5 while the volume of weld metal increases by a factor of 2.25.

G2.3.4 Essential Information. The eight listed categories provide the minimum drawing information that should be sufficient to address most situations. It is incumbent upon the Engineering Authority to add necessary additional requirements to the engineering documentation when warranted. If the documentation does address all the essential line items without providing sufficient unambiguous information covering the fabrication and inspection requirements, the Engineering Authority has failed in its job.

G2.3.5 Inspection Requirements. It is important to establish both the appropriate inspections and acceptance criteria for each weld joint or separate regions within the weld joint, based upon the service loading conditions. The weld joint classifications A, B, and C provide generally suitable levels of inspection and acceptance criteria. The Engineering Authority may tailor the inspection and acceptance criteria for each weld to better suit the application and the loading conditions.

Inspections and acceptance criteria applied generically to a weldment may lead to under-inspection of some welds and over-inspection of others. Consideration must also be given to the practicality of meeting the acceptance criteria chosen. Choosing acceptance criteria beyond the capability of the welding process may lead to numerous inspection rejections, increasing costs. The weld joint configuration must also allow for the appropriate inspections to take place. Every inspection technique has its own weld joint access requirements and detection limitations. Designs and/or the inspection process(es) selected may require reevaluation if the acceptance criteria are beyond the detection capability of the inspection process(es).

G3. Welding Performance and Procedure Qualification

The fundamental purpose of the welding performance and procedure qualification clause of this specification is to provide basic requirements applicable to most situations. When necessary it allows latitude for the use of Engineering Authority's judgment. These commentary provisions are not binding.

G3.1 thru G3.3 MIL-STD-1595A and MIL-STD-2219 were used as the basis for this document. Changes were made where considered appropriate by the D17K Subcommittee on Fusion Welding for Aerospace Applications.

G3.4 Welding Procedure Qualification (Procedure). All welds require a written procedure and suggest using AWS B2.1 format. As stated in 5.4.2 of D17.1/D17.1M:2010, "Procedures for Class A and B welds shall be qualified. Qualification of weld settings for manual welds is not required unless specified by the Engineering Authority. Class C welds do not require procedure qualification."

This document, as stated above, has not waived the need for qualification of Class A and Class B welds. However, the requirement for settings on manual welds is not practical. The welder is unable to view amperage or voltage meter readings, or to accurately estimate travel speed. Aerospace and Aircraft welder qualification /certification requirements often exceed structural welding qualification requirements. Consequently, the more practical and experienced personnel on D17K have abandoned the old paradigm of specifying weld settings on manual operations. Other methods have been defined and used to capture and maintain the necessary control. One method, when welding with GTAW, is to specify the tungsten electrode size, electrode tip preparation geometry, and shielding gas. This results in a more practical and measurable method for controlling the amperage rather than to specify a specific amperage level. A certified welder is trained to recognize weld puddle behavior.

By qualifying the essential variables in a written weld procedure such as: type of gas, AC or DC current, polarity, tungsten geometry, base metal alloy (and heat treat), filler diameter type and size, torch size, cup size, lead/lag angle, appropriate fixturing, joint backup gas or other, shielding trailers, gas flow, and most important “specifics” for successful welding of the given component. The basic rule is if the welder can control a welding variable during the welding process (Hood Down), such as those listed above, they are to be qualified on the weld procedure specification/weld schedule. Welding variables that cannot be controlled by the welder with the welding hood down need not be listed on the weld procedure.

G4. Fabrication

G4.1 Scope. The fundamental purpose of the Fabrication Clause of this specification is to provide basic requirements applicable to most situations. When necessary, it allows latitude for use of the engineering judgment. These commentary provisions are not binding.

G4.2 Welding Consumables. Due to the criticality of many aerospace weldments, the identification, storage, and the use of all welding consumables (including wires, rods, inserts, fluxes, gases, etc.) require proper controls. It is important to store fluxes and covered electrode in dry environment or sealed containers. Proper identification and storage of consumable will have positive contribution to the quality of the product.

G4.3 Welding Equipment. A certain minimum amount of maintenance, possibly including periodic calibrations, must be conducted to prevent equipment-related weld defects. Calibration should also be performed when there is reason to question the capability of the machine to produce acceptable welds.

G4.4 Weld Settings. Weld settings from the qualified WPS must be used during the production welding. For manual weld, qualified WPS may or may not contain weld settings. After a major repair of welding equipment, it is important to prepare and test reproducibility test weld to ensure proper operation of the equipment. Reproducibility test weld should also be used to determine and remedy continual quality problems in the weld shop.

G4.5 Preweld Cleaning and Other Preparation. Before welding the joint surfaces should be properly cleaned, (chemically and/or mechanically) and then protected from contamination. This preparation procedure should be documented and consistently followed.

G4.6 Preweld Joint Preparation and Fit-Up. Proper joint preparations and adhering to fit-up gap requirements will reduce or eliminate problems associated with weld penetration, distortion, and mismatch.

G4.7 Preheating and Interpass Temperature Control. Although Table 6.3 provides recommended preheat and interpass temperatures for certain materials, it is the fabricator’s responsibility to establish these temperatures. The fabricator, at minimum, should consider material’s chemistry composition, metallurgical properties, and part’s integrity requirement during the establishment of the preheat and the interpass temperature controls. Preheat and interpass temperature listed on the qualified WPS must be used and maintained during production welding.

G4.8 Tack Welds. Essential variables, including filler material, should be specified in the WPS. Experience has proved the need to either fully consume the tack weld in the next weld pass or remove the tack welds before next weld pass.

G4.9 Weld Start and Run-Off Tabs. The tab material must be that listed in the WPS. The tab should be fabricated from the same material as that of the base metal being welded. A tab material from the base metal being welded may only be used if it is beneficial to the welding process.

G4.10 Weld Shielding for GTAW, GMAW, and PAW. The weld and heat-affected zone should be shielded during the welding process to prevent defects caused by oxidation. Reactive base metal, such as titanium and its alloys, requires special attention in shielding. In such materials, deposited and solidified weld metal immediately behind and certain distance beyond the progressing weld pool must also be shielded to preclude contamination. The consumable, such as shielding gases, fluxes, etc., should always be listed in the WPS.

G4.11 Tungsten Electrodes. AWS A5.12, *Specification for Tungsten and Tungsten-Alloy Electrodes for Arc Welding and Cutting*, is the industry standard for tungsten electrodes used in GTAW and PAW.

G4.12 Filler Materials. Filler materials, when used in the welding process, must be as required by the Engineering Authority. Tables 6.4, 6.5, and 6.6 provide filler materials normally used in welding aerospace base materials. Unless Engineering Authority allows use of the table in selection of the filler material, they shall only be used as guidance by the

fabricator. The fabricator is responsible to verify the correct application of any filler material through the WPS/PQR cycle.

G4.13 Interpass Cleaning. Interpass cleaning in multipass weld is important in obtaining weld with an acceptable quality. This will remove contaminants, such as oxides and slag, deposited on the weld bead or joint surface during previous weld pass. Interpass cleaning should be performed using mechanical methods. Chemical or liquid solutions used during cleaning may be entrapped in crevices that can contribute to the poor quality of the weld and may cause corrosion during service. Cleaning of titanium weldments is not allowed until after a visual inspection and acceptable surface discoloration condition. This requirement is important in preventing premature service failure of the titanium weldments.

G4.14 Welding and Weldments. Welding must begin only after ensuring that welding equipment settings are as shown in the WPS.

Arc strikes outside of the weld joint are often detrimental to the service life of a weldment, and therefore it should be rejected.

All in-process correction must be performed after cleaning the area to be corrected. Certain materials when welded in the heat-treated condition, such as 6061-T6, it is important to control and document the in-process correction process. It is fabricator's responsibility to look at the engineering drawing and other contract document for the limitation on the in-process correction. The in-process correction is only allowed once at a location. When properly tested during the establishment of a qualified WPS, the number of in-process correction attempts can be increased and listed on the WPS. The fabricator should seek out Engineering Authority's opinion on the in-process correction.

Welds made with an automatic, mechanized, robotic process, or without use of filler material must not be in-process corrected by using a process that requires a filler material. Such weld must be in-process corrected as directed by the engineering drawing or other contract document. WPS and PQR qualification process should include in-process correction methodology, as well as, allowed number of the in-process correction attempts at the same location.

Weld reinforcement should not be removed unless required by the drawing. Any weld removal method shall neither thin the base metal nor reduce the reinforcement height below the adjacent base metal. Unless otherwise specified by the Engineering Authority, the weld reinforcement should never be completely removed for any reason.

Figure 7.2 dictates maximum mismatch at the completed weld joint. Excessive mismatch can drastically reduce the load-carrying capacity of a weld joint.

Angular distortion and peaking should be kept to less than 5 degrees with weld sequencing and tooling.

G4.15 Postweld Cleaning. Postweld cleaning efforts shall not reduce the weld or the base metal below drawing requirements. Titanium weldments must be visually inspected before any postweld cleaning.

G4.16 Postweld Processing. All postweld processing must be specified on the drawing or the WPS. This operation may be before or after any acceptance inspection. Fabricator shall be responsible for ensuring that the in-process correction occurs before this operation.

G4.17 Weld Identification Requirements. All weldments shall have traceability to their welder. A structurally critical weld, defined such by the Engineering Authority, requires traceability and processing history be documented and maintained through the life of the product. Fabricator is responsible for maintaining all traceability and processing documentation for a period defined by the Engineering Authority or a contract document.

G4.18 Acceptance Inspection. The fabricator is responsible for ensuring submittal of the welded part to the appropriate inspection department or its designate for an acceptance inspection per Clause 7. This inspection may be performed by an inspection facility other than that of the fabricator. However, this will require fabricator to ensure that the inspection facility and its personnel are properly qualified to perform the inspection.

G4.19 Rework. Rework is any action to bring the as-welded condition weld (without any postweld processing except the inspection process) into a complete conformance with the engineering drawing and specification after an acceptance inspection. All operations involved in the rework activity require documentation. Rework should be performed within the guidelines provided by the Engineering Authority. WPS and PQR qualification process should include rework methodology, as well as allowed number of rework attempts on a part.

G4.20 Repair. This activity takes place on the rejected part dispositioned by the Engineering Authority for a repair. Usually the Engineering Authority disposes a rejected part for a repair when it deems possible to correct and bring the weld or the part within the specified acceptance, integrity, and/or functional requirement. All operations involved in this

activity are a part of the disposition from the Engineering Authority. The fabricator and the welder must follow provided directions and guidelines.

Some examples of the disposition to repair a rejected part include, but are not limited to:

- (a) welding from the root side to correct incomplete penetration,
- (b) welding on a heat-treated part,
- (c) additional weld on the part to bring the part within the dimensional or the configuration requirement of the drawing,
- (d) welding to correct an unintentional gouge or a nick,
- (e) weld was made using filler metal other than that specified by the Engineering Authority

G4.21 Record Requirements. All fabricators, at minimum, should prepare and maintain records of the consumables, equipment calibrations, in-process corrections (as necessary), qualified welding procedures and associated test data, inspection and its result, rework, and repair. The record, at minimum, should be maintained for a period defined by the Engineering Authority or a contract document.

G5. Inspection

G5.1 Penetrant Inspection (PT). Per the requirements of ASTM E 1417 only Type I Fluorescent penetrants are authorized for use on aerospace applications. ASTM E 1417 makes no mention of restricting the use of any of the four basic methods of dye penetrant; however, the Department of Defense NDT Manual TO 33-B1.1 restricts the use of Method-A “Water Wash” Penetrant Systems unless specifically authorized by their Engineering Authority.

G5.2 Magnetic Particle Inspection. ASTM E 1444 makes no mention of restricting the use of the nonfluorescent or dry powder methods for magnetic particle inspection on aerospace systems; however, the Department of Defense NDT Manual TO 33-B1.1 restricts the use of both dry powder and nonfluorescent inspection vehicles on DOD aircraft systems unless specifically authorized by their Engineering Authority.

G5.3 Proof Testing (PRT). Proof Testing is controversial. In the past proof testing was used on vessels and mechanical components. It consisted of loading the part to 50 or 100% greater than the design load. It was felt that if the part passed this test and if it was never loaded above its designed load that it would never fail in service. It is now thought that proof testing could cause internal damage that might reduce service life. Also, proof testing cannot provide assurance if the part is subjected to corrosion, fatigue, low-temperature impact and so on. Consider proof testing but only in light of the above. Its use is declining.

G6. Repair of Existing Structures

G6.1 Scope. The purpose behind the Clause on repair welding is to establish a consistent systems approach for in-service weld repairs to aviation flight hardware. This will include all primary and secondary structures, and component repairs. This systems approach will follow the general format of the main and subclauses of D17.1/D17.1M for application of a welding repair. In general, there are weld repairs to in-service components performed everyday at repair stations or other FAA approved facilities and this Clause of the welding specification may or may not apply to those repairs. The decision to apply this Clause resides with the Engineering Authority and the governmental regulating agency, as permitted by the Code of Federal Regulations (Title 14, Parts 43 and 145). The final authority for all approvals for weld repair procedures resides solely with the governmental regulating agency.

What distinguishes the weld repair procedure of Clause 8 and previously approved weld procedures for other repairs is the *application* of the weld. This is summarily defined as: *When the weld repair becomes an integral part of flight hardware maintenance, where the failure of the weld becomes the failure of the component or flight hardware, Clause 7 will apply.*

Generally, an overhaul manual approved by the governmental regulating agency will contain established weld repair procedures that are acknowledged and approved by the FAA for use by Repair Stations or the OEMs as permitted, without additional qualification or re-qualification of which are used for generic or common weld repairs. That distinction is limited for weld repairs to flight hardware on structures which have limited or unsatisfactory weldability, such as,

Aluminum Alloy 7075-T73. As corrosion and fatigue begin to affect the base metal in critical areas, the Engineering Authority will need to investigate and develop economical means to repair welding. This will prompt the welding industry to develop new uses for current and future technologies.

G6.2 Design Design/stress analyses performed to satisfy requirements of specification could vary from performing qualitative engineering assessment of loading up to a detailed finite element analysis of repaired area.

G6.3 Welding Procedures. Originally, most weld procedures may not have been a qualified or adequately documented weld procedure. Where welds become an integral method of fabrication, the need and requirement for developing and documenting the weld procedure becomes an important aspect of weld repairs.

This clause of the specification prohibits the weld repair application unless sufficient testing has been performed. The testing of the weld repair procedure must satisfactorily apply to the specific application. This will include weld repair procedures that may have been previously qualified for another application or base metal/weld metal combination. If sufficient data exists to support another similar application, the Engineering Authority may approve the weld repair procedure for additional uses.

The actual application of the weld repair procedure must be the controlling factor when using previously qualified weld procedures.

G6.4 Welder and Welding Operator Qualification. A welder is certified using a qualified weld procedure. The qualified weld procedure permits a certified welder to use the weld procedure for applications as the procedure was qualified to fabricate. Therefore, when a “special” weld procedure is developed and approved by the appropriate government authority, only welders who have demonstrated their proficiency using the “special” weld procedure may be permitted to make the weld repair. This approach is consistent with other welding industries and demonstrates the significance of the “special” weld procedure. When developing a weld repair procedure on parts that are not or were not normally weld repaired, there may have been techniques developed to satisfactorily utilize the weld repair procedure. These techniques, not originally established or recorded, become essential elements or attributes and may require that properly qualified and trained welders are utilizing the weld repair procedure. The techniques developed for such a repair may be within the capability of the general welder population in which the welders can be assigned. However, weld repair procedures that have identified techniques or skills in which a limited number of welders are capable to perform, then only those welders properly qualified and trained should be utilized.

G6.5 Weld Repair Inspection. In most cases, the currently specified inspection methods are adequate for weld repairs. When the inspection is not normally used for the item because of limitations of the method, the Engineering Authority may authorize alternative inspection methods if the current method is not sufficient. Approval from the appropriate government agency is required. Each weld repair in areas not normally inspected should have adequate Engineering oversight, ensuring the adequacy of the repair inspection.

G6.7 Repair Documentation. The use of welding to repair items that are not normally welded, is a very possible situation and the need to document the location of the weld repair is critical to track and monitor the repair in the event of failure. Weld repairs performed per this Clause have inherent liability issues and documentation of the repair is important to provide a long-term record of the suggested welding variables listed in this Clause. The variables listed are not all inclusive and may be changed by adding or deleting some of the welding variables depending on the welding procedure development. The documentation provides feedback, to the extent the weld repair was utilized and any corresponding corrective action taken is properly documented.

G7. Nonflight Hardware

This specification recognizes fundamental differences between welding flight and nonflight structures (which are often overlooked in contracts), and allows for their unique requirements to be covered by a single master specification.

G7.1 Scope. The typical aerospace hardware considered herein support the operations of manufacturing, transporting, receiving, handling, assembly, inspection, test, checkout, and service of aircraft, missile and space vehicles and payloads, and the launching of small or ballistic missiles, space vehicles, and payloads.

G7.2 Exceptions and Additional Requirements. This clause is intended to establish uniform practices for the design, qualification, fabrication, and inspection of nonflight hardware. This goal is accomplished by combining the requirements

of consensus industrial welding codes with supplementary requirements as necessary. Supplementary requirements were added in areas where the pertinent industrial code either contained no requirements or contained requirements insufficient for aerospace applications. This approach is consistent with the intended use of the referenced codes which typically establish minimum requirements. For example, even though AWS D1.1/D1.1M, *Structural Welding Code — Steel*, contains requirements for NDE methods and acceptance criteria, NDE is not required unless specifically requested in the contract agreement (such a request would be separate from the general AWS D1.1/D1.1M callout, and would have to contain details on the desired methods and extent of examination). A normative annex in AWS D1.1/D1.1M contains examples of how to write a specification that invokes some of the optional provisions of that code. ASME B31.3, *Code for Pressure Piping — Process Piping*, states that “*The owner is also responsible for imposing requirements supplementary to those of the code if necessary to assure safe piping for the proposed installation.*” Some additional examples of the supplementary requirements are the following:

- (1) data requirements for engineering drawings;
- (2) requirements for material certifications;
- (3) requirements for structural welding of nontraditional structural alloys;
- (4) provisions for verification of WPS and welder qualifications;
- (5) fabrication techniques, including preheating and postweld heating requirements;
- (6) requirements for visual inspection and NDE (including personnel qualification, methods, extent, and acceptance criteria).

Excluded from the requirements of Clause 9 are pressure vessels for nonflight applications which should be fabricated in accordance with the ASME *Boiler and Pressure Vessel Code (BPVC)*. Supplementary requirements are not added to the ASME BPVC due to the fact that the BPVC directly links weld design factors (e.g., joint efficiencies and allowable stresses) to the type and extent of NDE performed, and also establishes extensive requirements for such subjects as weld categories, weld types, service restrictions, and fabrication details (including detailed requirements for postweld heat treatment). Furthermore, the ASME BPVC states that engineering judgment used in the application of the BPVC “. . . must never be used to overrule mandatory requirements or specific provisions of the Code.”

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