

AWS D1.9/D1.9M:2015
An American National Standard

Structural Welding Code — Titanium



Documents

Document Sharing Hub

AWS D1.9/D1.9M:2015
An American National Standard

Approved by the
American National Standards Institute
August 27, 2015

Structural Welding Code— Titanium

2nd Edition

Supersedes AWS D1.9/D1.9M:2007

Prepared by the
American Welding Society (AWS) D1 Committee on Structural Welding

Under the Direction of the
AWS Technical Activities Committee

Approved by the
AWS Board of Directors

Abstract

This code covers the requirements for design and welding of any type of titanium structure. Titanium pressure vessels and fluid-carrying pipe lines are specifically excluded. Clauses 1 through 5 and Annex A constitute a body of rules for the regulation of welding in titanium construction. A commentary on the code is also included with the document.



ISBN: 978-0-87171-852-5
© 2015 by American Welding Society
All rights reserved
Printed in the United States of America

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

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

Statement on the Use of American Welding Society Standards

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

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

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

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

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

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

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

On occasion, text, tables, or figures are printed incorrectly, constituting errata. Such errata, when discovered, are posted on the AWS Webpage (www.aws.org).

Official interpretations of any of the technical requirements of this standard may only be obtained by sending a request, in writing, to the appropriate technical committee. Such requests should be addressed to the American Welding Society, Attention: Managing Director, Technical Services Division, 8669 NW 36 St, # 130, Miami, FL 33166 (see Annex F). With regard to technical inquiries made concerning AWS standards, oral opinions on AWS standards may be rendered. These opinions are offered solely as a convenience to users of this standard, and they do not constitute professional advice. Such opinions represent only the personal opinions of the particular individuals giving them. These individuals do not speak on behalf of AWS, nor do these oral opinions constitute official or unofficial opinions or interpretations of AWS. In addition, oral opinions are informal and should not be used as a substitute for an official interpretation.

This standard is subject to revision at any time by the AWS D1 Committee on Structural Welding. It must be reviewed every five years, and if not revised, it must be either reaffirmed or withdrawn. Comments (recommendations, additions, or deletions) and any pertinent data that may be of use in improving this standard are required and should be addressed to AWS Headquarters. Such comments will receive careful consideration by the AWS D1 Committee on Structural Welding and the author of the comments will be informed of the Committee's response to the comments. Guests are invited to attend all meetings of the AWS D1 Committee on Structural Welding to express their comments verbally. Procedures for appeal of an adverse decision concerning all such comments are provided in the Rules of Operation of the Technical Activities Committee. A copy of these Rules can be obtained from the American Welding Society, 8669 NW 36 St, # 130, Miami, FL 33166.

This page is intentionally blank.

Personnel

AWS D1 Committee on Structural Welding

A. W. Sindel, Chair	<i>General Electric Power, Steam Power Systems</i>
T. L. Niemann, Vice Chair	<i>Minnesota Department of Transportation</i>
R. D. Medlock, 2nd Vice Chair	<i>High Steel Structures</i>
J. Molin, Secretary	<i>American Welding Society</i>
F. G. Armao	<i>The Lincoln Electric Company</i>
E. L. Bickford	<i>Acute Technologies Services</i>
T. W. Burns	<i>AlcoTec Wire Corporation</i>
H. H. Campbell, III	<i>Pazuzu Engineering</i>
R. D. Campbell	<i>Bechtel</i>
R. B. Corbit	<i>CB&I</i>
M. A. Grieco	<i>Massachusetts Department of Transportation</i>
C. W. Holmes	<i>Modjeski & Masters, Incorporated</i>
J. J. Kenney	<i>Shell International E & P</i>
J. H. Kiefer	<i>ConocoPhillips Company</i>
S. W. Kopp	<i>High Steel Structures</i>
V. Kuruvilla	<i>Genesis Quality Systems</i>
J. Lawmon	<i>American Engineering and Manufacturing</i>
N. S. Lindell	<i>Oregon Iron Works, Incorporated</i>
D. R. Luciani	<i>Canadian Welding Bureau</i>
P. W. Marshall	<i>MHP Systems Engineering</i>
M. J. Mayes	<i>Mayes Testing Engineers, Incorporated</i>
D. L. McQuaid	<i>D. L. McQuaid and Associates, Incorporated</i>
J. Merrill	<i>AMEC E & I</i>
D. K. Miller	<i>The Lincoln Electric Company</i>
J. B. Pearson, Jr.	<i>LTK Engineering Services</i>
D. C. Phillips	<i>Hobart Brothers Company</i>
D. D. Rager	<i>Rager Consulting, Incorporated</i>
T. J. Schlafly	<i>AISC</i>
R. R. Scott	<i>PSI (Retired)</i>
R. E. Shaw	<i>Steel Structures Technology Center, Incorporated</i>
R. W. Stieve	<i>Parsons Corporation</i>
M. M. Tavarani	<i>Massachusetts Department of Transportation</i>
P. Torchio	<i>Williams Enterprises of GA, Incorporated</i>
D. G. Yantz	<i>Canadian Welding Bureau</i>

Advisors to the D1 Committee on Structural Welding

W. G. Alexander	<i>WGAPE</i>
N. J. Altebrando	<i>STV, Incorporated</i>
E. M. Beck	<i>AMEC</i>
B. M. Butler	<i>Walt Disney World Company</i>
R. A. Dennis	<i>Consultant</i>
G. L. Fox	<i>Consultant</i>
H. E. Gilmer	<i>Tampa Tank—Florida Structural Steel</i>
G. J. Hill	<i>G. J. Hill & Associates</i>

Advisors to the D1 Committee on Structural Welding (Continued)

M. L. Hoitomt	<i>Consultant</i>
J. W. Post	<i>J. W. Post & Associates, Incorporated</i>
K. K. Verma	<i>Consultant</i>
B. D. Wright	<i>Advantage Aviation Technologies</i>

AWS D1N Subcommittee on Titanium Structures

J. Lawmon, Chair	<i>American Engineering and Manufacturing</i>
B. Krueger, Vice Chair	<i>Los Alamos National Laboratory</i>
P. Portela, Secretary	<i>American Welding Society</i>
D. R. Bolser	<i>The Boeing Company</i>
N. Cooper	<i>BAE Systems Submarines</i>
M. Davis	<i>BAE Systems—GSD York</i>
T. J. Dorsch	<i>BAE Systems</i>
S. L. Luckowski	<i>ARDEC</i>
W. C. Mohr	<i>Edison Welding Institute</i>
J. C. Monsees	<i>Consultant</i>
R. Rush	<i>Retired</i>
J. R. Schutz	<i>U.S. Army</i>

Advisors to the D1N Subcommittee on Titanium Welding

B. L. Buchholz	<i>AMSTA-RI-SEM</i>
D. Cottle	<i>Consultant</i>
T. A. Higgins	<i>TACOM</i>
D. D. Rager	<i>Rager Consulting, Incorporated</i>
B. Roopchand	<i>ARDEC</i>
A. W. Sindel	<i>General Electric Power, Steam Power Systems</i>

Foreword

This foreword is not part of AWS D1.9/D1.9M:2015, *Structural Welding Code—Titanium*, but is included for informational purposes only.

This second edition of the AWS D1.9/D1.9M, *Structural Welding Code—Titanium* (hereafter referred to as the code), represents the continuing AWS policy to provide standards for structural welding. This code is provided for the fabrication, erection, and manufacturing industries as a set of requirements for structural titanium weldments. This code does not concern itself with such design considerations as the arrangements of parts and the computation of stresses for proportioning the load-carrying members of a structure and their connections. Such considerations, it is assumed, are covered elsewhere in a general specification.

Users of the AWS D1.1/D1.1M, *Structural Welding Code—Steel*, will note similarities in the general format of this code and D1.1. This was done in order to benefit from the long established history of D1.1, adjusted for the specific requirements for titanium. In the early 2000s, interest was expressed in developing a similar consolidated code for the structural welding of titanium. Because of the interest of both the U.S. Department of Defense and the American Welding Society, it was decided to commence the task of developing a structural welding code for titanium.

Underlined text in the clauses, subclauses, tables, figures, or forms indicates a change from the 2007-ADD1 edition. A vertical line in the margin of a table or figure also indicates a change from the 2007-ADD1 edition.

A major difference between the AWS D1.1 and this code, other than the material change from steel to titanium, is that the former allows for prequalified welding procedures, this code does not. This is mainly because of the need to have a method of demonstrating evidence of a fabricator's competency to fabricate one or more of the structural titanium alloys that may be welded under this code. Therefore, all the WPSs used for fabrication of work governed by this code are required to be qualified by testing.

This second edition includes editorial changes to improve clarity and substantive changes to all sections to reflect user feedback including a revised Table 5.1 that was first issued as an addendum in 2011.

Clauses 1 through 5 constitute a body of rules for the regulation of welding on titanium structures. Procedures and standards are outlined for several methods of nondestructive testing. Methods included are visual, radiographic, and penetrant examination.

Comments and suggestions for the improvement of this standard are welcome. They should be sent to the Secretary, AWS D1 Committee on Structural Welding, American Welding Society, 8669 NW 36 St, # 130, Miami, FL 33166.

This page is intentionally blank.

Table of Contents

	Page No.
<i>Personnel</i>	v
<i>Foreword</i>	vii
<i>List of Tables</i>	xii
<i>List of Figures</i>	xiii
1. General Requirements	1
1.1 Scope	1
1.2 Limitations	1
1.3 Terms and Definitions	1
1.4 Responsibilities	2
1.5 Approval	3
1.6 Welding Symbols	3
1.7 <u>Safety</u>	3
1.8 Standard Units of Measurement	4
1.9 Reference Documents	4
2. Design of Welded Connections	5
<i>Part A—General Requirements</i>	5
2.1 General	5
2.2 Drawings and Design Data/Model	5
2.3 Allowable Stresses	5
<i>Part B—Weld Lengths and Areas</i>	6
2.4 Groove Welds	6
2.5 Fillet Welds	6
2.6 Plug and Slot Welds	7
<i>Part C—Structural Details</i>	7
2.7 Filler Plates	7
2.8 <u>Backing and Temporary Welds</u>	7
2.9 Lap Joints	8
2.10 Transitions of Butt Joints	8
2.11 Connections or Splices <u>in Compression Members</u>	8
2.12 Combinations of General Types of Welds	8
2.13 Skewed T-Joints	8
<i>Part D—Cyclically Loaded Structures</i>	9
2.14 <u>Scope of Applicability</u>	9
2.15 Allowable Stresses	9
3. Qualification	19
3.1 Scope	19
<i>Part A—General Requirements</i>	19
3.2 General	19
3.3 Qualification of WPSs	20
3.4 Qualification of Welding Personnel	20
3.5 Common Requirements for WPS and Welding Personnel Performance Qualification	20

<i>Part B—Types of Tests, Test Methods, and Acceptance Criteria</i>	21
3.6 <u>Test Types</u> , Test Methods, and Acceptance <u>Criteria</u>	21
3.7 Visual Examination.....	22
3.8 Radiographic Examination	23
3.9 Macro Examination and Micro Examination	23
3.10 Tension Tests—Groove Welds.....	23
3.11 Bend Tests—Groove Welds—Plate and Pipe	24
3.12 Chemical Analysis	25
<i>Part C—WPS Qualification</i>	26
3.13 General WPS Qualification	26
3.14 Limits of Qualified Positions for WPSs	26
3.15 Limitation of Essential Variables—WPS Qualification	26
3.16 Tests—WPS Qualification.....	27
3.17 Retests.....	27
<i>Part D—Performance Qualification</i>	27
3.18 General Performance Qualification	27
3.19 Limits of Qualified Positions for Performance.....	28
3.20 Test Weldment Types.....	28
3.21 Limitation of Essential Variables—Welder, Welding Operator, and Tack Welder Performance Qualification	29
3.22 Tests—Performance Qualification.....	29
3.23 Retests.....	29
4. Fabrication	61
4.1 Scope.....	61
4.2 <u>Welding</u> Processes	61
4.3 Base Metals.....	61
4.4 Filler Metals.....	61
4.5 Tungsten Electrodes.....	61
4.6 Shielding Gases	62
4.7 Welding and Cutting Equipment	62
4.8 Backing.....	62
4.9 Preheat and Interpass Temperatures	62
4.10 Welding Environment	62
4.11 Compliance with Design.....	62
4.12 Preparation of Base Metal	62
4.13 Assembly	63
4.14 Tack Welds and Temporary Welds.....	64
4.15 <u>Postweld</u> Dimensional Tolerances	64
4.16 Arc Strikes	67
4.17 <u>Postweld Cleaning</u>	67
4.18 Weld Terminations.....	67
4.19 Control of Distortion and Shrinkage.....	67
4.20 Weld Profiles.....	67
4.21 Repairs	68
4.22 Anti-Spatter Compound.....	68
4.23 Peening	68
4.24 Stress- <u>Relief</u>	68
5. Inspection	79
<i>Part A—General Requirements</i>	79
5.1 General.....	79
5.2 Inspection of Materials	80

Page No.

5.3	Inspection of Welding Procedure Specifications and Equipment.....	80
5.4	<u>Inspection</u> of Welder, Welding Operator, and Tack Welder Qualifications	80
5.5	Inspection of Work and Records.....	80
5.6	Obligations of the Contractor	81
5.7	Nondestructive Testing	81
<i>Part B—Visual Inspection</i>		81
5.8	General.....	81
<i>Part C—Penetrant Testing</i>		82
5.9	General.....	82
<i>Part D—Radiographic Inspection</i>		82
5.10	General.....	82
5.11	Radiographic Procedures	82
5.12	Coverage and Acceptability of Welds.....	84
5.13	Examination, Report, and Disposition of Radiographs	85
<i>Part E—Ultrasonic Testing</i>		85
5.14	General.....	85
5.15	Operator Requirements	85
5.16	Procedure	85
<i>Part F—Other Examination Methods</i>		86
5.17	General.....	86
5.18	Radiation Imaging Systems	86
<i>Part G—Acceptance Criteria</i>		86
5.19	General.....	86
5.20	Visual Examination.....	87
5.21	Penetrant Testing	87
5.22	Radiographic Testing	87
5.23	Ultrasonic Testing	87
Annex A (Normative)—Welding of Titanium Armor Structures.....		99
Annex B (Normative)—Reference Documents.....		111
Annex D (Informative)—Sample Welding Forms.....		115
Annex E (Informative)—Metallurgical Sample Preparation.....		125
Annex F (Informative)—Guidelines for the Preparation of Technical Inquiries <u>for the Structural Welding</u> <u>Committee</u>		129
Commentary		131
Foreword.....		133
List of AWS Documents on Structural Welding.....		155

List of Tables

Table	Page No.
2.1 Allowable Stresses in Connections	10
<u>2.2 Fatigue Stress Provisions.....</u>	11
<u>2.3 Equivalent Fillet Weld Size Factors for Skewed T-Joints</u>	12
3.1 WPS Qualification—Type of Weld and Position Limitations.....	30
3.2 Welder, Welding Operator, and Tack Welder Performance Limitations	31
3.3 Limitations of Essential Variables of a WPS	32
3.4 Limitations of Variables for Base Materials.....	36
3.5 <u>WPS Qualification—Number and Type of Test Specimens and Range of Thickness Qualified</u>	37
3.6 <u>Welder, Welding Operator, and Tack Welder Qualification—Number and Type of Test Specimens and Range of Thickness Qualified</u>	39
4.1 Strengths of Welded Titanium Alloys and Products Available for Structural Applications	69
4.2 Recommended Titanium Alloy Filler Metals for Structural Welding of Titanium Alloys	73
5.1 Visual and Penetrant Acceptance Criteria	88
5.2 Radiographic Acceptance Criteria for CJP and PJP Welds.....	90
5.3 <u>Color Acceptance Criteria</u>	91
5.4 Hole-Type IQI Requirements	91
5.5 Wire IQI Requirements	92
5.6 IQI Selection and Placement	92
A.1 Thickness of Test Plates and Requirements for Ballistic Tests	104
A.2 Radiographic Sampling Requirements.....	104

List of Figures

Figure	Page No.
2.1 Maximum Fillet Weld Size Along Edges in Lap Joints	13
2.2 Fillets in Skewed T-Joints	13
2.3 Thin Filler Plates	14
2.4 Thick Filler Plates	14
2.5 Minimum Amount of <u>Overlap</u> and Double Fillet Weld	15
2.6 Thickness.....	16
2.7 Plan Views of Width Transitions	17
2.8 Effective Throats of Groove Welds Combined with Fillet Welds	17
2.9 Cyclic Load Stress Range	18
3.1 Positions of Groove Welds	41
3.2 Positions of Fillet Welds.....	42
3.3 Position of Test Plates for Groove Welds.....	43
3.4 Positions of Groove Welds <u>in Pipe</u>	44
3.5 Positions of Test Plates for Fillet Welds.....	45
3.6 Positions of Test Pipes for Fillet Welds.....	46
3.7 Weld Contact Angle Definition	47
3.8 Root Fusion Requirements for Complete Penetration Groove Weld in T-Joints	47
3.9 Reduced Section Tension Specimens—Plate and Pipe	48
3.10 Alternative Reduced Section Tension Specimen for <u>Pipe or Tubing (3 in [75 mm] Outside Diameter or Less)</u>	49
3.11 Full Section Tension Specimens—Small Diameter, 1 in [25 mm] Outside Diameter or Less, Pipe	49
3.12 Reduced All-Weld Metal Tensile Specimens	50
3.13 Transverse Side Bend Specimens.....	51
3.14 Transverse Face and Root Bend Specimens.....	52
3.15 Longitudinal Face and Root Bend Specimens	53
3.16 Wraparound Guided Bend Jig.....	53
3.17 <u>Relative Location of Test Specimens on Welded Test Plates</u>	54
3.18 <u>Relative Location of Test Specimens for Welded Box Pipe—WPS and Performance Qualifications</u>	55
3.19 Relative Location of Test Specimens <u>for Welded Test Pipe—WPS and Performance Qualification</u>	56
3.20 <u>Relative Location of Test Specimens for Fillet Welded Plates—WPS and Performance Qualification</u>	56
3.21 <u>Relative Location of Test Specimens for Fillet Welded Pipe—WPS and Performance Qualification</u>	57
3.22 <u>Relative Location of Test Specimens for fillet Welded Plate to Pipe—WPS and Performance Qualification</u>	58
3.23 Plug Weld Macroetch Test Plate—WPS, Welder, Welding Operator, and Tack Welder Qualification.....	59
4.1 Acceptable and Unacceptable Weld Profiles.....	74
4.2 Warpage of Flanges: Measurement of the Flange Toe Offset for an “I” or “H” Configuration Section.....	75
4.3 Depth Variation: Relative Location at Which the Beam Depth A-B is Measured for an “I” or “H” <u>Section</u>	76
4.4 Least Panel Dimension “ <u>D</u> ”	77
5.1 Hole Type IQI Design	93
5.2 Wire IQI Design	94
5.3 RT Identification and Hole-Type or Wire IQI Locations on Approximately Equal Thickness Joints 10 in [250 mm] and Greater in Length.....	95

Figure	Page No.
5.4 RT Identification and Hole-Type or Wire IQI Locations on Approximately Equal Thickness Joints Less than 10 in [250 mm] in Length	96
5.5 RT Identification and Hole-Type or Wire IQI Locations on Transitions Joints 10 in [250 mm] and Greater in Length	97
5.6 RT Identification and Hole-Type or Wire IQI Locations on Transition Joints Less than 10 in [250 mm] in Length.....	98
A.1 Specimen for Armor Welder Qualification	105
A.2 Ballistic Test Plate	105
A.3 Single Groove Welds	106
A.4 Double Groove Weld	106
A.5 Examples of Weld Cracks That Can Occur from Projectile Impact and Indication of Measurement of Total Weld Crack for Acceptance Purposes	107
A.6 Welded Armor Data (Sheet 1)	108
A.7 Armor Plate Data (Sheet 2)	109
A.8 Weld Radiographic Report (Sheet 3).....	110
E.1 Well Prepared Grade 2 Titanium Metallographic Specimen.....	128
E.2 Poorly Prepared Grade 2 Titanium Metallographic Specimen	128
C-5.1 Schematic Representation of a Rabbeted Weld Joint	153

Structural Welding Code—Titanium

1. General Requirements

1.1 Scope

The code contains the requirements for designing, fabricating, and inspecting of titanium structures. When the code is stipulated in contract documents, conformance with all provisions of the code shall be required, except for those provisions that the Engineer (see 1.4.1) or contract documents specifically modify or exempt.

Annex A of the code contains requirements for the ballistic testing of structural titanium welds in armor.

The following is a summary of the code clauses:

- (1) **General Requirements.** This clause contains basic information on the scope and limitations of the code.
- (2) **Design of Welded Connections.** This clause contains requirements for the design of welded connections.
- (3) **Qualification.** This clause contains the qualification requirements for Welding Procedure Specifications (WPSs) and welding personnel (welders, welding operators, and tack welders) necessary to perform code work.
- (4) **Fabrication.** This clause contains the requirements for the preparation, assembly, and workmanship of welded titanium structures.
- (5) **Inspection.** This clause contains criteria for the qualifications and responsibilities of inspectors, acceptance criteria for production welds, and procedures for performing visual inspection and nondestructive testing (NDT).

1.2 Limitations

The code is not intended to be used for the following:

- (1) Pressure vessels or pressure piping,
- (2) Base metals other than titanium,
- (3) Aerospace structures.

1.3 Terms and Definitions

The welding terms used in the code shall be interpreted in conformance with the definitions given in AWS A3.0M/A3.0, and the following definitions:

1.3.1 Owner. The individual or company that exercises legal ownership of the product or structural assembly produced to this code.

1.3.2 Engineer. A duly designated individual who acts for and in behalf of the Owner on all matters within the scope of the code.

1.3.3 Contractor. The duly designated person who acts for, and in behalf of, the Contractor on all inspection and quality matters within the scope of the code and of the contract documents.

1.3.4 Original Equipment Manufacturer (OEM). A single Contractor that assumes some or all of the responsibilities assigned by this code to the Engineer.

1.3.5 Inspector. An individual responsible for verification that work is performed in accordance with the inspection and quality requirements of this code. When the inspector category (as defined below) is unspecified, the responsibilities and requirements shall apply equally within the limits of responsibility described in 5.1.1.

1.3.5.1 Contractor's Inspector. An inspector acting for, and in behalf of, the Contractor on all matters within the scope of this code and applicable contract documents.

1.3.5.2 Verification Inspector. The duly designated person who acts for, and in behalf of, the Owner on all inspection and quality matters designated by the Engineer.

1.3.6 Code Terms “Shall,” “Should,” and “May.” “Shall,” “should,” and “may” have the following significance:

1.3.6.1 Shall. Code provisions that use “shall” are mandatory unless specifically modified in contract documents.

1.3.6.2 Should. The word “should” is used to recommend practices that are considered beneficial, but are not requirements.

1.3.6.3 May. The word “may” in a provision allows the use of optional procedures or practices that can be used as an alternative or a supplement to code requirements.

1.3.7 Ballistic Loading. Ballistic loads are the combination of forces transferred to the structure by a ballistic event.

1.3.8 Inspection Classes. The following inspection classifications shall be added to the welding symbol or elsewhere on the drawing. The acceptance criteria for each type of inspection classification are defined in Clause 5.

1.3.8.1 Class A. All cyclically loaded and statically loaded structures requiring inspection criteria greater than those of Class B. This class is not applicable to Annex A ballistically loaded weld joints.

1.3.8.2 Class B. Statically loaded structures. This class is not applicable to Annex A ballistically loaded weld joints.

1.3.8.3 Class C. Ballistically loaded structures. This class of welds applies to joints which have been designed to withstand a ballistic threat in structures that are used in military applications.

Any joint requiring additional inspection requirements shall be identified on the drawings.

1.3.10 Welding Operator. One who operates adaptive control, automatic, mechanized, or robotic welding equipment.

1.4 Responsibilities

1.4.1 Engineer's Responsibilities. The Engineer shall be responsible for the development of the contract documents that govern products or structural assemblies produced under the code. The Engineer may add to, delete from, or otherwise modify, the requirements of the code to meet the particular requirements of a specific structure. All requirements that modify the code shall be incorporated into contract documents.

The Engineer shall specify in contract documents, as necessary, and as applicable, the following:

- (1) Code requirements that are applicable only when specified by the Engineer.
- (2) All additional NDT that is not specifically addressed in the code.
- (3) Verification inspection.
- (4) Weld acceptance criteria other than that specified in Clause 5.
- (5) Level of inspection—Class A, B, or C and the applicability of Annex A.
- (6) All additional requirements that are not specifically addressed in the code.
- (7) For OEM applications, the responsibilities that this code assigns to the Engineer that will be assumed by the Contractor.
- (8) The required weld color when color is to be used as an acceptance criteria.

(9) The acceptance requirements for weld metal composition when weld metal analysis is required.

(10) The requirements for record retention.

(11) Which parts of the structure are subject to cyclic, static, or ballistic loading.

1.4.2 Contractor's Responsibilities. The Contractor shall be responsible for performing work in conformance with the requirements of the code and contract documents.

1.4.3 Inspector's Responsibilities

1.4.3.1 Contractor Inspection. Contractor inspection shall be supplied by the Contractor and shall be performed as necessary to ensure that materials and workmanship meet the requirements of the contract documents.

1.4.3.2 Verification Inspection. The Engineer shall determine if Verification Inspection shall be performed. Responsibilities for Verification Inspection shall be established between the Engineer and the Verification Inspector.

1.5 Approval

All references to the need for approval shall be interpreted to mean approval by the Engineer.

1.6 Welding Symbols

Welding symbols shall be those shown in AWS A2.4, *Standard Symbols for Welding, Brazing, and Nondestructive Examination*. Special conditions shall be fully explained by added notes or details.

1.7 Safety

Safety and health issues and concerns are beyond the scope of this standard; some safety and health information is provided, but such issues are not fully addressed herein.

Safety and health information is available from the following sources:

American Welding Society:

- (1) ANSI Z49.1, *Safety in Welding, Cutting, and Allied Processes*
- (2) AWS Safety and Health Fact Sheets
- (3) Other safety and health information on the AWS website

Material or Equipment Manufacturers:

- (1) Safety Data Sheets supplied by material's manufacturers
- (2) Operating Manuals supplied by equipment manufacturers

Applicable Regulatory Agencies

Work performed in accordance with this standard may involve the use of materials that have been deemed hazardous, and may involve operations or equipment that may cause injury or death. This standard does not purport to address all safety and health risks that may be encountered. The user of this standard should establish an appropriate safety program to address such risks as well as to meet applicable regulatory requirements. ANSI Z49.1 should be considered when developing the safety program.

1.8 Standard Units of Measurement

This standard makes use of both U.S. Customary Units and the International System of Units (SI). The latter are shown with brackets [] or in appropriate columns in tables and figures. The measurements may not be exact equivalents; therefore, each system shall be used independently.

1.9 Reference Documents

Annex B contains a list of all documents referenced in the code.

2. Design of Welded Connections

Part A *General Requirements*

2.1 General

This clause covers the design of welded connections.

2.2 Drawings and Design Data/Model

2.2.1 General. The drawing or model shall show information regarding the following:

- (1) Base metal specifications
- (2) Dimensions of the members being joined
- (3) The location, type, size, and extent of all welds

2.2.2 Joint Details. The detail drawings shall clearly indicate, by means of welding symbols, the preparation and tolerances for fit-up of material for the required joints. If joints with backing are to be used, the material, width, thickness, and contour for such backing shall be shown.

2.3 Allowable Stresses

2.3.1 Allowable Stresses. The allowable stresses in welds and connections shall not exceed those given in Table 2.1. It shall be noted that some combinations of weld metal and base metal may introduce additional issues that need to be assessed before the acceptance of the design.

2.3.2 Data and Analysis. Designs shall be supported by experimental data or engineering analysis or both when either:

- (1) Dissimilar titanium grades are joined, or
- (2) The welding filler metal has not been selected in accordance with Table 4.2.

2.3.3 Loading and Fatigue Life. Designs exceeding the loading and fatigue life conditions in Figure 2.9 and alternative or special weld configurations not listed in Table 2.2 are permitted, provided they are supported by experimental data or engineering analysis or both.

Part B

Weld Lengths and Areas

2.4 Groove Welds

2.4.1 Effective Length. The maximum effective weld length of any groove weld, regardless of orientation, shall be the width of the part joined, perpendicular to the direction of tensile or compressive stress. For groove welds transmitting shear stress, the effective length is the length specified.

2.4.2 Complete Joint Penetration (CJP) Groove Welds. The weld size of a complete joint penetration groove weld shall be the thickness of the thinner part joined.

2.4.3 Partial Joint Penetration (PJP) Groove Welds. Weld reinforcement shall not be used when calculating weld size.

2.4.4 Effective Area. The effective area shall be the product of the effective weld length multiplied by the weld size.

2.5 Fillet Welds

2.5.1 Maximum Weld Size. The maximum fillet weld size permitted along edges of material shall be as shown in Figure 2.1 and detailed in the following subclauses:

(1) The thickness of the base metal, for metal less than 1/4 in [6 mm] in thickness.

(2) 1/16 in [1.5 mm] less than the thickness of base metal, for metal 1/4 in [6 mm] or more in thickness, unless the weld size is designated on the drawing to be built out to obtain full throat thickness. The distance between the edge of the base metal and toe of the weld may be less than 1/16 in [1.5 mm], provided the edge is clearly visible and the weld size clearly verifiable.

2.5.1.1 The effective length of a straight fillet weld (not curved) shall be the overall length of the full-size fillet, including end returns. No reduction in effective length need be made for either the start or the crater of the weld if the weld is of full size throughout its length.

2.5.1.2 The effective length of a curved fillet weld shall be measured along the centerline of the effective throat. If the effective length of a fillet weld in a hole or slot leads to an effective area greater than the area found from 2.6.1, then use the greater value.

2.5.1.3 The minimum effective length of a fillet weld shall be at least four times the weld size, or the weld size shall be considered not to exceed one fourth of its effective length.

2.5.1.4 The minimum length of an intermittent fillet weld shall be 1-1/2 in [38 mm] or four times the weld size, whichever is greater.

2.5.2 Effective Area. The effective area of the fillet weld shall be the product of the effective weld length and the effective throat.

2.5.2.1 Stresses in Fillet Welds. Stress in a fillet weld shall be considered as a shear load applied to this area, for any direction of applied load.

2.5.3 Fillets in Holes or Slots. Fillets in holes or slots in lap joints may be used to transfer shear, to prevent buckling or to prevent separation of lapped parts. Fillet welds in holes or slots shall not be considered plug and slot welds.

2.5.4 Fillets in Skewed T-Joints. Fillet welds may be used in skewed T-joints having a dihedral angle of not less than 60° nor more than 120° (see Figure 2.2, details A and B).

2.5.5 Size and Spacing of Holes and Slots. Minimum spacing and dimensions of holes or slots when fillet welds are used shall be in accordance with the requirements of 2.6.

2.6 Plug and Slot Welds

2.6.1 Effective Area. The effective area shall be the nominal area of the hole or slot in the plane of the faying surfaces. Plug and slot welds shall be designed to resist shear loads parallel to their effective area.

2.6.2 Minimum Plug Hole Diameter. The minimum hole diameter for a plug weld in material with thickness (T) of 0.125 in [3 mm] or greater shall be 2.5T.

2.6.3 Minimum Spacing of Plug Welds. The minimum center-to-center spacing of plug welds shall be four times the diameter of the hole.

2.6.4 Slot Length. The length of the slot for a slot weld shall not exceed ten times the thickness of the base metal. The minimum slot length in material with thickness (T) of 0.125 in [3 mm] or greater shall be 2.5T.

2.6.5 Slot Ends. The ends of the slot shall be semicircular or shall have the corners rounded to a radius not less than the thickness of the part containing it, except those ends which intersect an edge of the part.

2.6.6 Minimum Spacing of Slot Welds

2.6.6.1 The minimum spacing of rows of slot welds in a direction transverse to their length shall be four times the width of the slot.

2.6.6.2 The minimum center-to-center spacing in a longitudinal direction on any line shall be two times the length of the slot.

2.6.7 Fill Depth

2.6.7.1 For base metal less than or equal to 5/8 in [16 mm] thick, the depth of fill of plug or slot welds shall be equal to the base metal thickness.

2.6.7.2 For base metal greater than 5/8 in [16 mm] thick, the depth of fill of plug or slot welds shall be at least one-half the thickness of the base metal, but not less than 5/8 in [16 mm].

Part C *Structural Details*

2.7 Filler Plates

Wherever it is necessary to use filler plates in joints required to transfer applied force, the filler plates and the connecting welds shall be in accordance with the requirements of 2.7.1 or 2.7.2, as applicable.

2.7.1 Thin Filler Plates. A filler plate less than 1/4 in [6 mm] thick (see Figure 2.3) shall not be used to transfer loads, but shall be kept flush with the welded edges of the load-carrying part. The weld size of weld 2 (as shown in Figure 2.3) shall equal the required size of weld 1 (see Figure 2.3), i.e., the actual size of weld 2 shall be its effective size plus the thickness (T) of the filler plate.

2.7.2 Thick Filler Plates. Any filler plate 1/4 in [6 mm] or more in thickness (see Figure 2.4) shall extend beyond the edges of the base metal. It shall be welded to the part on which it is fitted, and the joint shall have sufficient strength to transmit the load into the base metal as an eccentric load. The effective area of welds 1, 2, and 3 (as shown in Figure 2.4) joining the base metal to the filler plate shall be sufficient to transmit the load from the base metal and shall be long enough to avoid over stressing the filler plate along planes X-X at the toe of the weld.

2.8 Backing and Temporary Welds

2.8.1 Statically Loaded Structures. In statically loaded structures, backing need not be removed.

2.8.2 Cyclically Loaded Structures. In cyclically loaded structures, backing transverse to the direction of computed stress shall be removed and the joint finished smooth, except that transverse backing that is subject to stress ranges lower than the allowable stress range (see 2.14) need not be removed. Backing parallel to the direction of the computed stress range need not be removed.

2.8.3 Ballistically Loaded Structures. In ballistically loaded structures all backing shall be removed.

2.8.4 Temporary Welds. The use of temporary welds shall be prohibited unless they are detailed on the drawing. The drawing shall define the inspection to be applied after temporary weld removal.

2.9 Lap Joints

2.9.1 Minimum Amount of Overlap. The minimum amount of lap shall be five times the thickness of the thinner part, but not less than 1 in [25 mm] (see Figure 2.5).

2.9.2 Double Fillet Welded. Lap joints shall be double-fillet welded (see Figure 2.5). An exception is permitted: to allow the use of single fillet welded lap joints where deflection of the joint is sufficiently restrained to prevent the joint from opening under load.

2.10 Transitions of Butt Joints

2.10.1 Thickness Transition. Butt joints between axially aligned members of different thicknesses, and subject to cyclic loading as described in Part D, shall be made in such a manner that the slope of the transition does not exceed 1 in 2-1/2 with the surface of either part (see Figure 2.6). The transition shall be accomplished by sloping the weld surface, or by sloping the weld surface and chamfering, or by chamfering the thicker part.

2.10.2 Width Transition. Joints between parts having different widths, and subject to cyclic loading as described in Part D, shall have a smooth transition between offset edges. The transition shall be accomplished by tapering the wider part (see Figure 2.7), radiusing the wider part, sloping the weld metal, or by any combination of these. The slope of the transition shall be no more than 1 in 2-1/2 with the edge of either part. Alternatively, the width shall be transitioned with a 24 in [600 mm] minimum radius that is tangent to the narrower part of the joint (see Figure 2.7).

2.11 Connections or Splices in Compression Members

2.11.1 Where Only Welds Carry Load. Connections or splices in compression members made with fillet, PJP, or plug welds, except as noted in 2.11.2, shall be designed for an average of the sum of the calculated stress and the yield strength of the member, but not less than 75% of the yield strength of the member.

2.11.2 Where Both Bearing Surface and Welds Carry Load. If members subjected to compression only are spliced and full-milled bearing is provided, then the splice material and its welding shall be arranged to hold all parts in alignment and shall be proportioned to carry 50% of the computed stress in the member.

2.12 Combinations of General Types of Welds

If two or more general types of welds (groove, fillet, plug, and slot) are combined in a single connection, their allowable capacity shall be computed with reference to the axis of the group in order to determine the allowable capacity of the combination. Fillet welds reinforcing groove welds shall have a combined effective size (see Figure 2.8) based on the throat of the combination.

2.13 Skewed T-Joints

2.13.1 Qualification. Skewed T-joints which have angles between members less than 80° shall be qualified in accordance with Clause 3 to determine the actual effective throat or effective weld size. These types of joints may use either

fillet welds as permitted by 2.5.4 or groove welds. The groove welds shall be considered PJP groove welds unless the WPS and procedure qualifications show that CJP groove welds can be achieved with the welding methods used.

2.13.2 Leg Size. Table 2.3 is a tabulation showing equivalent leg size factors for the range of dihedral angles between 60° and 120°, assuming no root opening. Root opening(s) shall be added directly to the leg size. The required leg size for fillet welds in skewed joints shall be calculated using the equivalent leg size factor for correct dihedral angle, as shown in the example in Commentary C-2.

2.13.3 Effective Throat. For fillet welds between parts meeting at angles between 80° and 100°, the effective throat (t) shall be the shortest distance from the joint root to the weld face of a 90° diagrammatic weld (see Figure 2.2). For welds in acute angles between 60° and 80° and for welds in obtuse angles greater than 100°, the weld leg size required to provide the specified effective throat shall be calculated to account for geometry.

Part D

Cyclically Loaded Structures

2.14 Scope of Applicability

The requirements of this subclause apply to members and connections subject to cyclic load of frequency and magnitude sufficient to initiate cracking and progressive failure by fatigue. The requirements shall apply when the stress range is expected to exceed 4 ksi [27 MPa] and when the number of loading cycles exceeds the following:

Titanium M Numbers	Cycle Limits
M51	3500
M52	1500
Other M numbers	1000

2.15 Allowable Stresses

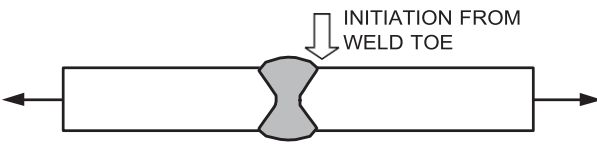
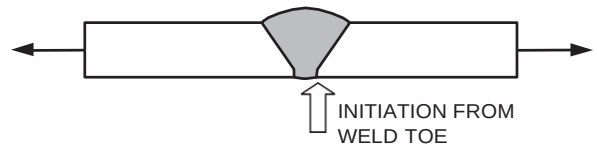
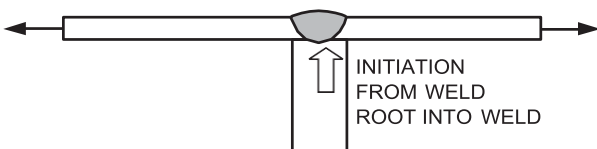
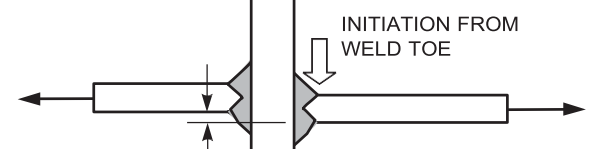
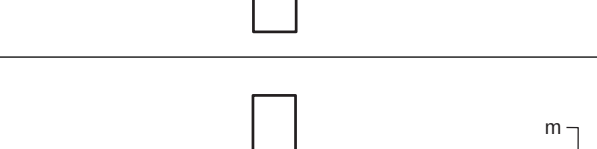
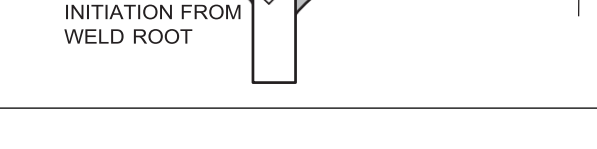
Allowable unit stresses in welds shall not exceed those listed in Table 2.1. In the case of axial stress combined with bending, the maximum combined stress shall be the same as that used for concurrently applied load cases.

The allowable stress range (fatigue) for structures, members and connections subject to cyclic loading shall be as provided in Table 2.2 and Figure 2.9 for the applicable condition and cyclic life. The stress range when using Table 2.2 and Figure 2.9 is the nominal stress range for the section considered, which disregards the local stress concentration of the welded joint, but includes effects of adjacent geometrical shapes and loadings that are not included in the diagrams.

Table 2.1
Allowable Stresses in Connections (see 2.3 and 2.16)

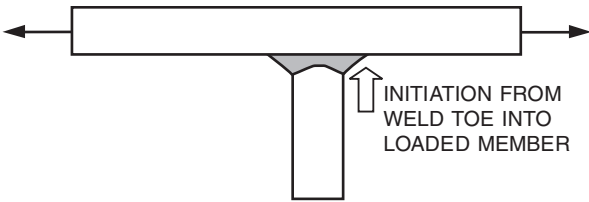
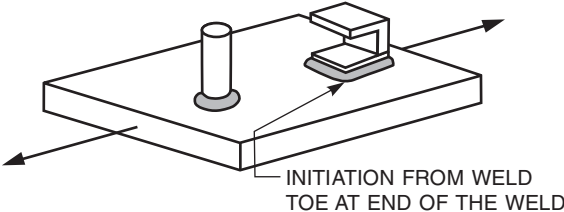
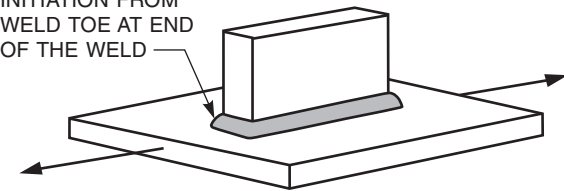
Type of Weld	Stress in Weld		Allowable Connection Stress
Complete joint penetration groove welds	Tension normal to the effective area		90% of <u>the minimum</u> base metal <u>yield strength</u>
	Compression normal to the effective area		90% of <u>the minimum</u> base metal <u>yield strength</u>
	Tension or compression parallel to the axis of the weld		Same as <u>the minimum</u> base metal <u>yield strength</u>
	Shear on the effective area		<u>36% of minimum base metal yield strength except that shear stress on the base metal shall not exceed 40% of the minimum base metal yield strength</u>
Partial joint penetration groove welds	Compression normal to effective area	Joint not designed to bear	60% of minimum base metal <u>yield strength</u>
		Joint designed to bear	Same as <u>the minimum</u> base metal <u>yield strength</u>
	Tension or compression parallel to the axis of the weld		Same as <u>the minimum</u> base metal <u>yield strength</u>
	Shear parallel to axis of weld		<u>36% of minimum base metal yield strength</u>
	Tension normal to effective area		<u>36% of minimum base metal yield strength except tensile stress on the base metal shall not exceed 60% of minimum base metal yield strength</u>
Fillet welds	Shear on effective area		<u>36% of minimum base metal yield strength</u>
	Tension or compression parallel to axis of weld		Same as <u>the minimum</u> base metal <u>yield strength</u>
Plug and slot welds	Shear parallel to faying surfaces (on effective area)		<u>36% of minimum base metal yield strength</u>

Table 2.2
Fatigue Stress Provisions (see 2.3 and 2.15)

Shape of Detail	Description	Category ^a
	Shop CJP weld in flat position, smooth toes 30° angles or less. <u>PT inspection minimum, other additional methods as determined by the Engineer.</u>	100
	CJP weld made in field or out of flat position. <u>PT inspection minimum, other additional methods as determined by the Engineer.</u>	80
	CJP weld made from one side without backing bar, root controlled by <u>PT inspection minimum, other additional methods as determined by the Engineer.</u>	71
	<u>CJP weld made from one side without backing bar, root controlled</u> without NDT.	45
	Connection to attachment through <u>groove weld.</u>	71
	Cruciform or T-joint, complete joint penetration welds, misalignment less than $m = 0.15T$.	71
	Partial joint penetration or fillet welds from both sides, <u>misalignment less than $m = 0.15T$.</u>	63
	Cruciform or T-joint with crack from weld root using weld throat area to determine stress. <u>Misalignment less than $m = 0.15T$.</u>	45

(Continued)

Table 2.2 (Continued)
Fatigue Stress Provisions (see 2.3 and 2.15)

Shape of Detail	Description	Category ^a
	Transverse non-load carrying attachment.	80
	Non-load carrying stud or clip.	80
	Longitudinal gusset of length L along stress direction. L < 12 in [300 mm].	56

^a See Figure 2.9 for additional information.

Table 2.3
Equivalent Fillet Weld Size Factors for Skewed T-Joints (see 2.13)

Dihedral angle Ψ	60°	65°	70°	75°	80°	85°	90°	95°
Comparable fillet weld for same strength	0.71	0.76	0.81	0.86	0.91	0.96	1.0	1.03
Dihedral angle Ψ	100°	105°	110°	115°	120°			
Comparable fillet weld for same length	1.08	1.12	1.16	1.19	1.23			

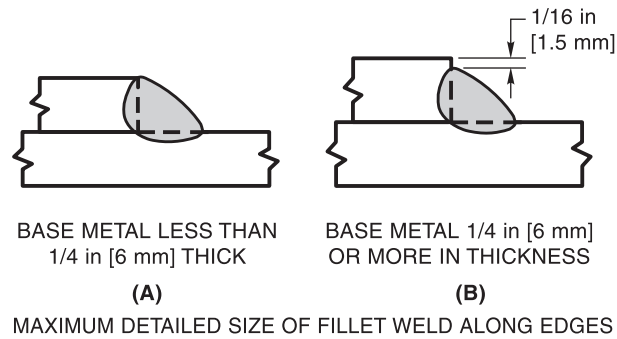
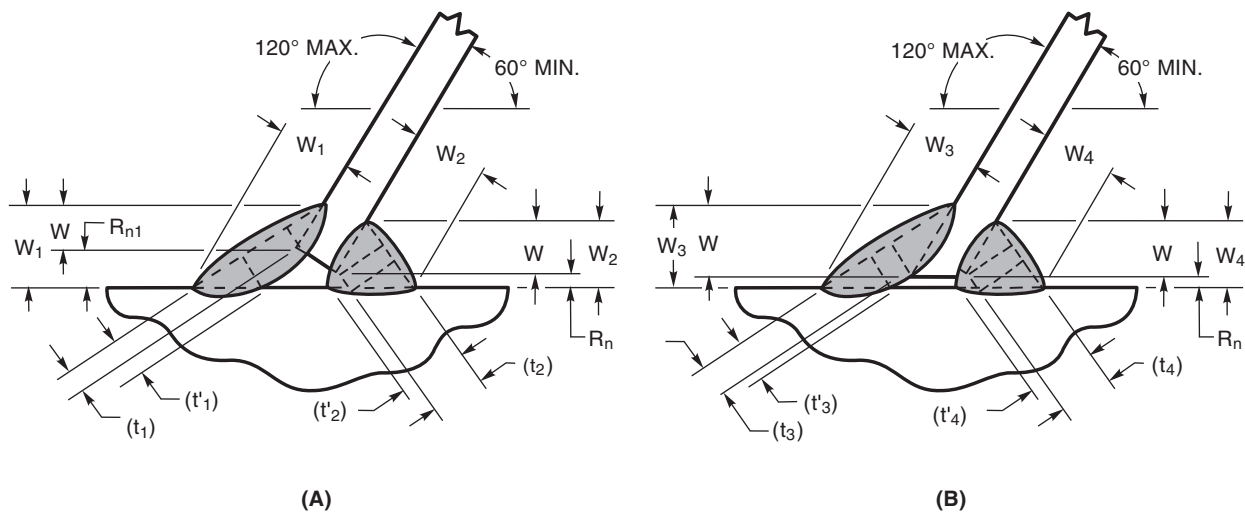


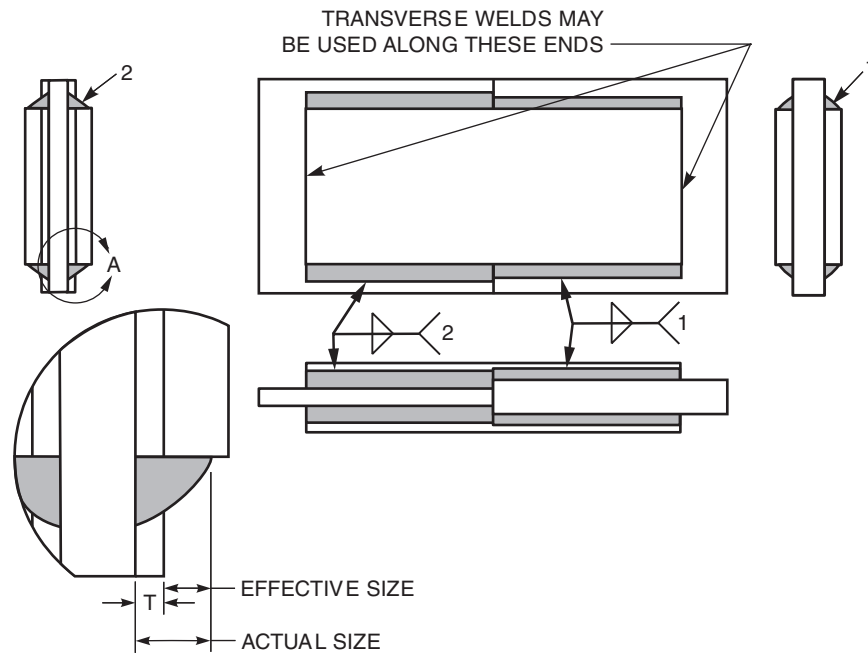
Figure 2.1—Maximum Fillet Weld Size Along Edges in Lap Joints (see 2.5.1)



Notes:

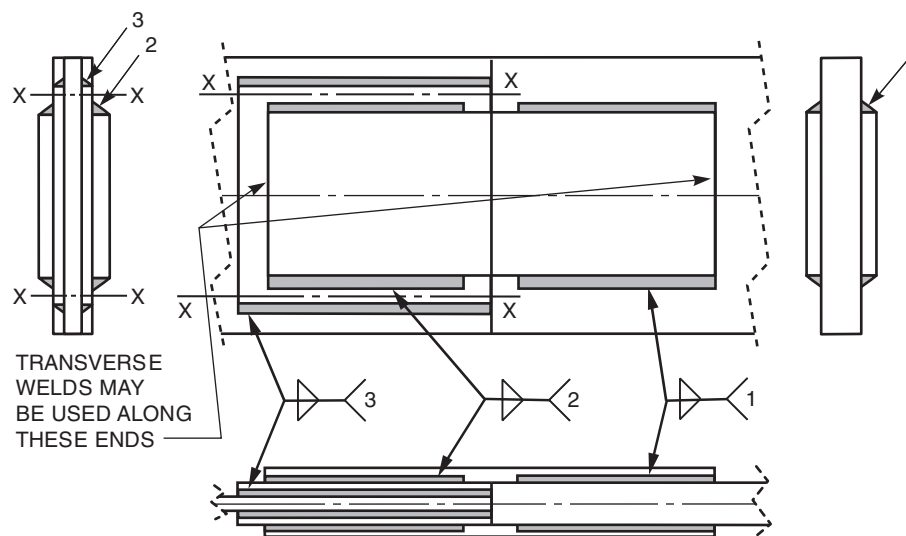
1. $(t_n), (t'_n)$ = Effective throats dependent on magnitude of gap (R_n) (see 2.5.4 and 2.13). Subscript (n) represents 1, 2, 3, or 4.
2. Angles smaller than 60° may be used; however, in such cases, the weld is considered to be a partial joint penetration groove weld.
3. Refer to Commentary C-2.13 for an example.

Figure 2.2—Fillets in Skewed T-Joints (see 2.5.5 and 2.13)



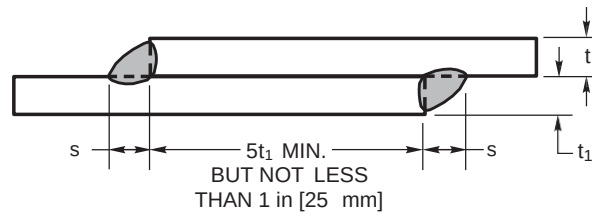
Note: The effective area of weld 2 shall equal that of weld 1, but its size shall be its effective size plus the thickness of the filler plate T .

Figure 2.3—Thin Filler Plates (see 2.7.1)



Note: The effective areas of welds 1, 2, and 3 shall be adequate to transmit the design force, and the length of welds 1 and 2 shall be adequate to avoid overstress of filler plate in shear along planes x-x.

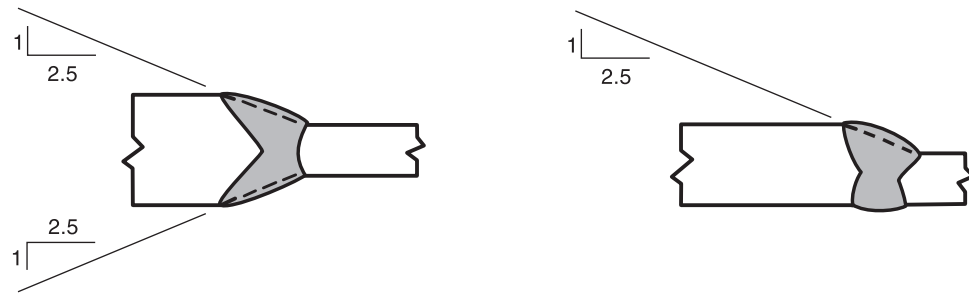
Figure 2.4—Thick Filler Plates (see 2.7.2)



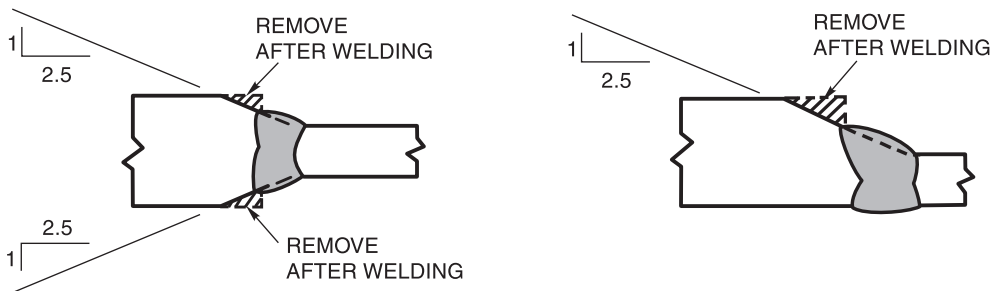
Notes:

1. s = as required.
2. $t \geq t_1$.

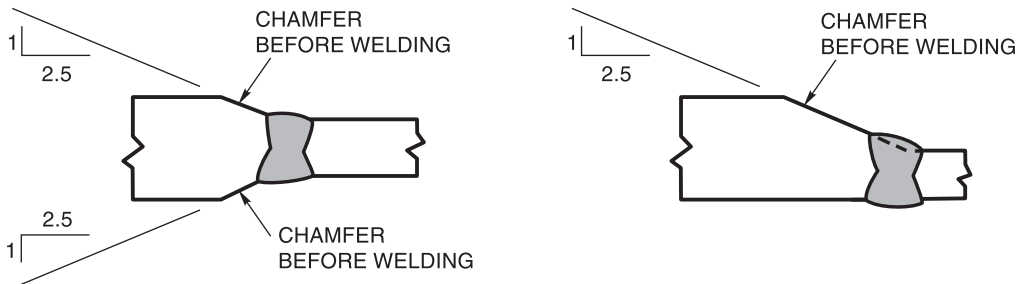
Figure 2.5—Minimum Amount of Overlap and Double Fillet Weld (see 2.9.1 and 2.9.2)



(A) TRANSITION BY SLOPING WELD SURFACE



(B) TRANSITION BY SLOPING WELD SURFACE AND CHAMFERING



(C) TRANSITION BY CHAMFERING THICKER PART

Notes:

1. Groove may be of any permitted or qualified type and detail.
2. Transition slopes shown are the maximum permitted.

Figure 2.6—Thickness (see 2.10.1)

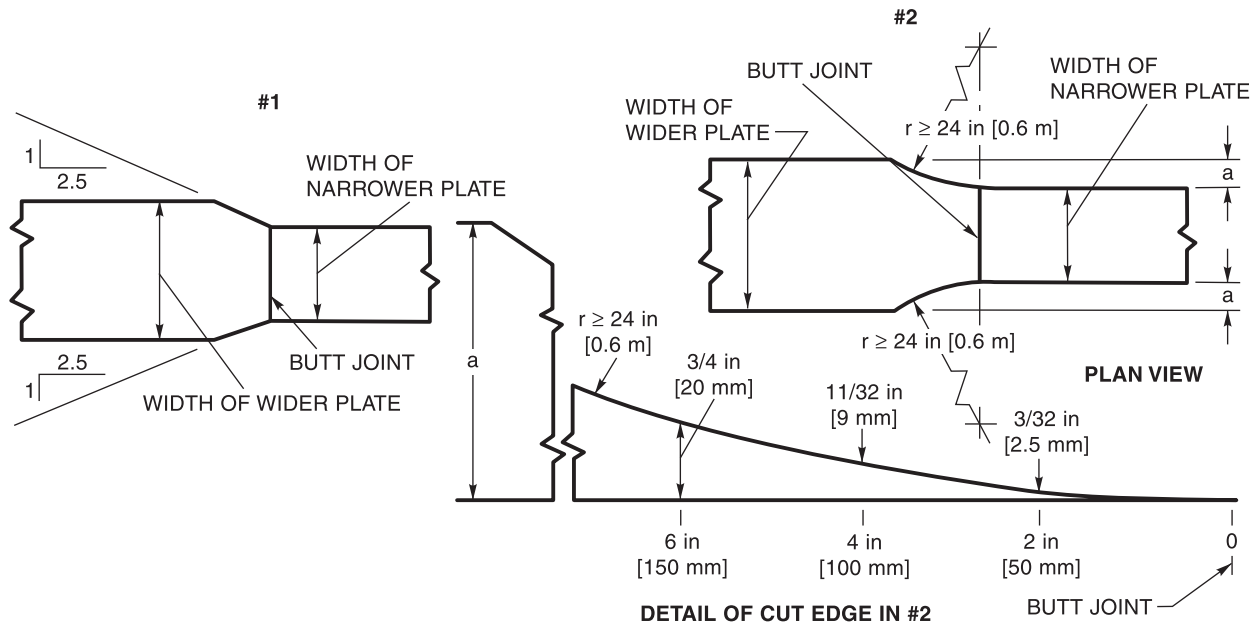
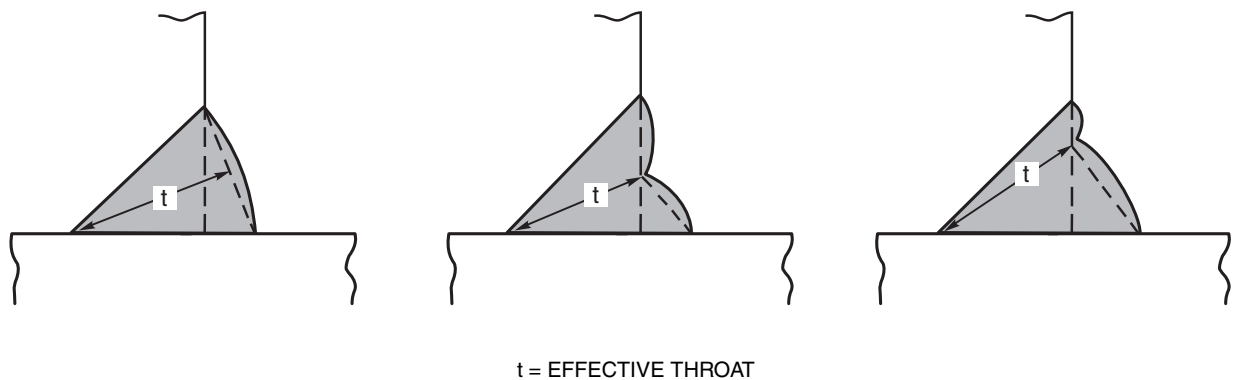
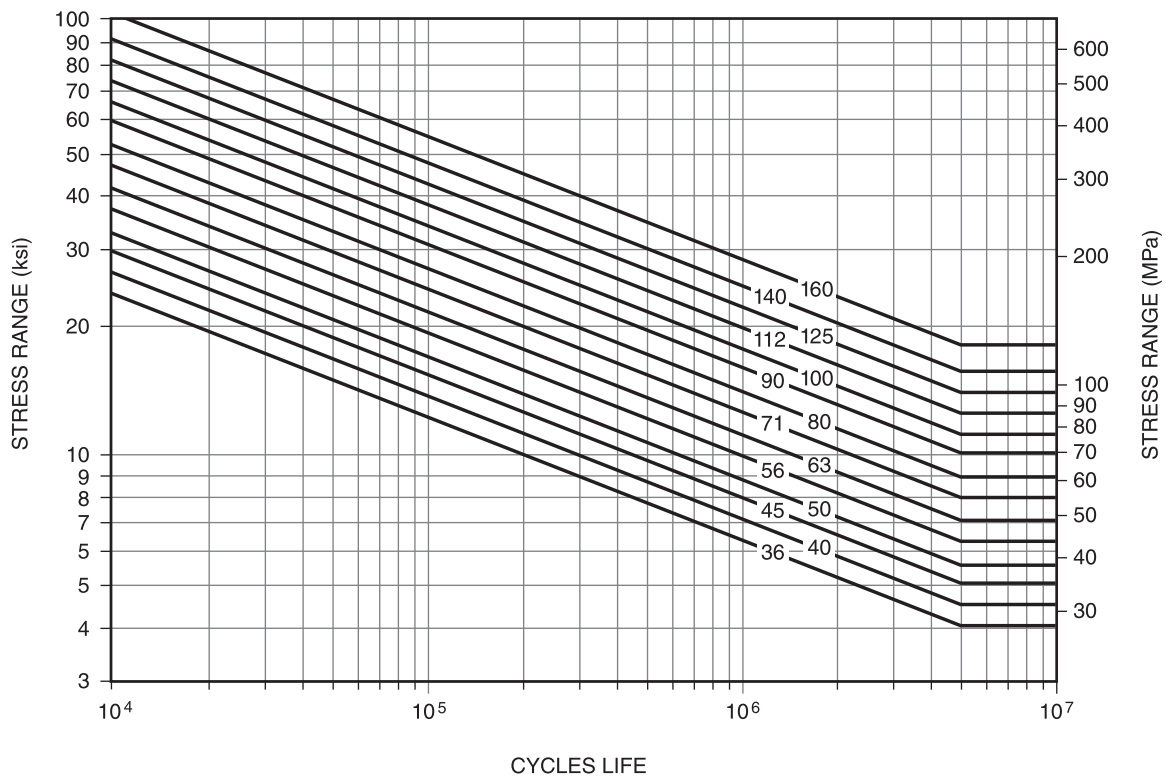


Figure 2.7—Plan Views of Width Transitions (see 2.10.2)



Note: The effective throat is the minimum distance from the weld face, minus any convexity, to the weld root. In the case of a fillet weld combined with a groove weld, the weld root of the groove weld should be used.

Figure 2.8—Effective Throats of Groove Welds Combined with Fillet Welds (see 2.12)



Notes:

1. Additional information regarding the use of this table may be found in the commentary for Clause 2.
2. The numbers shown on each line indicate the fatigue category.

Figure 2.9—Cyclic Load Stress Range (see 2.3 and 2.15)

3. Qualification

3.1 Scope

3.1.1 The requirements for the qualification and testing of welding procedure specifications (WPSs) and welding personnel using the GMAW (gas metal arc welding), GTAW (gas tungsten arc welding), PAW (plasma arc welding), LBW (laser beam welding), or EBW (electron beam welding) process are described in Parts A, B, C, and D of this clause. Annex A contains additional requirements specific to ballistic qualification. Other welding processes may be qualified using the provisions of this code, with the Engineer's approval.

(1) **Part A—General Requirements.** This part covers the general requirements for the qualification of a WPS and for the qualification of welding personnel.

(2) **Part B—Types of Tests, Test Methods and Acceptance Criteria.** This part details the type of destructive test methods, nondestructive test methods, or both, including acceptance criteria, to be used to assess both WPS and welding personnel performance qualification.

(3) **Part C—WPS Qualification.** This part covers the detail test requirements for the qualification of a WPS.

(4) **Part D—Performance Qualification.** This part covers the detail test requirements for performance qualification tests required by the code to determine the ability of welding personnel to produce sound welds.

Part A General Requirements

3.2 General

The qualification requirements of this code are intended to demonstrate understanding of the special needs and tools required by a fabricator to work with structural titanium alloys and to assure that the fabrication procedures used in production consistently meet a recognized quality standard. To accomplish this objective, each Contractor shall, prior to the start of production, perform the following which shall be documented to become part of an auditable trail:

(1) Qualify and record the essential variables and test results needed to compile a Procedure Qualification Record (PQR) to be used to define WPSs in accordance with Clause 3, Part C.

(2) Prepare written WPSs in accordance with [3.13](#).

(3) Qualify the welders, welding operators, and tack welders in accordance with Clause 3, Part D.

(4) Certify and maintain records of all tests and procedures on forms as shown in [Annex D](#) or similar, and make available such records to those authorized to examine them.

(5) Provide all welders, welding operators, tack welders and quality control personnel with access to the relevant WPSs.

3.3 Qualification of WPSs

3.3.1 The following WPSs shall be acceptable:

- (1) WPSs that have been qualified and documented in accordance with Clause 3, Part C.
- (2) WPSs that have been previously qualified and documented that meet the requirements of Clause 3, Part C.
- (3) WPSs that have been previously qualified to the requirements of other codes or standards that are documented and approved by the Engineer.

3.4 Qualification of Welding Personnel

3.4.1 Qualification Requirements. Welding personnel shall be qualified by one of the following:

- (1) Qualification in accordance with Clause 3, Part D.
- (2) Previous and properly documented qualifications that meet the requirements of Clause 3, Part D.
- (3) Previous and properly documented qualifications that meet the requirements of other codes or standards, when approved by the Engineer.

3.4.2 Period of Effectiveness. The welder's, welding operator's, or tack welder's qualification shall remain in effect for 5 years. Welders, welding operators, and tack welders shall be requalified every five years in accordance with 3.4.1 or by providing evidence of volumetric and visual inspection of welds made in the last five years that meet the requirements of this code. The qualification shall lapse immediately if either of the following occur:

- (1) The welder, welding operator, or tack welder is not engaged in a welding process for which he is qualified for a period exceeding 6 months.
- (2) There is some specific reason to question the individual's ability.

3.5 Common Requirements for WPS and Welding Personnel Performance Qualification

3.5.1 Records. Records, which form part of a body of supporting evidence applicable to the contract, shall be retained, as defined by the contract.

3.5.2 Position of Test Welds. Each WPS, welder, welding operator, and tack welder shall be qualified by welding the test assembly in the manner stated below and as shown in Figures 3.1 through 3.6 for the positions for which the test assembly is to be qualified.

3.5.2.1 Groove Welds—Plate (with and without backing). Groove welds in plate shall be welded in one or more of the positions outlined below as required by Table 3.1:

- (1) *Position 1G (Flat).* The test plates shall be placed in an approximately horizontal plane and the weld metal deposited from the upper side [see Figure 3.3(A)].
- (2) *Position 2G (Horizontal).* The test plates shall be placed in an approximately vertical plane with the groove approximately horizontal [see Figure 3.3(B)].
- (3) *Position 3G (Vertical).* The test plates shall be placed in an approximately vertical plane with the groove approximately vertical [see Figure 3.3(C)].
- (4) *Position 4G (Overhead).* The test plates shall be placed overhead in an approximately horizontal plane, and the weld metal deposited from the underside [see Figure 3.3(D)].

3.5.2.2 Groove Welds—Pipe (with and without backing). The term pipe, as used herein, shall include all square or round tubular shapes. Groove welds in pipe shall be welded in one or more of the positions outlined below as required by Table 3.1:

(1) *Position 1G (Pipe Horizontal-Rotated)*. The test pipe shall be placed with its axis approximately horizontal and the groove approximately vertical. The pipe shall be rotated during welding so the weld metal is deposited in the flat position [see Figure 3.4(A)].

(2) *Position 2G (Pipe Vertical-Fixed)*. The test pipe shall be placed with its axis approximately vertical and the groove approximately horizontal. The pipe shall not be rotated during welding [see Figure 3.4(B)].

(3) *Position 5G (Pipe Horizontal-Fixed)*. The test pipe shall be placed with its axis approximately horizontal and the groove approximately vertical. The pipes shall not be rotated during welding [see Figure 3.4(C)].

(4) *Position 6G (Pipe Inclined-Fixed)*. The test pipe shall be inclined at approximately 45°. The pipe shall not be rotated during welding [see Figure 3.4(D)].

3.5.2.3 Fillet Welds—Plate. Fillet welds in plate shall be welded in one or more of the positions outlined below as required by Table 3.1:

(1) *Position 1F (Flat)*. The test plates shall be so placed that each fillet weld is deposited with its axis approximately horizontal and its throat approximately vertical [see Figure 3.5(A)].

(2) *Position 2F (Horizontal)*. The test plates shall be so placed that each fillet weld is deposited on the upper side of a horizontal surface and against a vertical surface [see Figure 3.5(B)].

(3) *Position 3F (Vertical)*. The test plates shall be placed in approximately vertical planes, and each fillet weld deposited on vertical surfaces [see Figure 3.5(C)].

(4) *Position 4F (Overhead)*. The test plates shall be so placed that each fillet weld is deposited on the underside of a horizontal surface and against a vertical surface [see Figure 3.5(D)].

3.5.2.4 Fillet Welds—Pipe. The term pipe, as used herein, shall include all square or round tubular shapes. Fillet welds in pipe shall be welded in one or more of the positions outlined below as required by Table 3.1:

(1) *Position 1F (Pipe Inclined-Rotated)*. The test pipe shall be placed with its axis at approximately 45° and rotated during welding so that the filler metal is deposited in the flat position [see Figure 3.6(A)].

(2) *Position 2F (Pipe Vertical-Fixed)*. The test pipe shall be placed with its axis approximately vertical. The filler metal shall be placed on the outer surface of the pipe at its juncture with the upper side of the abutting plate or pipe. The assembly shall not be rotated during welding [see Figure 3.6(B)].

(3) *Position 2F-Rotated (Pipe Horizontal-Rotated)*. The test pipe shall be placed with its axis approximately horizontal and rotated during welding so that filler metal is deposited in the horizontal position [see Figure 3.6(C)].

(4) *Position 4F (Overhead-Fixed)*. The test pipe shall be placed with its axis approximately vertical. The filler metal shall be placed against the outer surface of the pipe at its juncture with the abutting plate or pipe. The assembly shall not be rotated during welding [see Figure 3.6(D)].

(5) *Position 5F (Pipe Horizontal-Fixed)*. The test pipe shall be placed with its axis approximately horizontal and with the welding joint vertical. The assembly shall not be rotated during welding [see Figure 3.6(E)].

Part B

Types of Tests, Test Methods, and Acceptance Criteria

3.6 Test Types, Test Methods, and Acceptance Criteria

When required by Table 3.5 and/or Table 3.6, the tests, test methods, and acceptance criteria described in Part B are intended to determine the mechanical properties and soundness of welds made in accordance with the WPS or the soundness of welds made by a welder, welding operator, or tack welder.

The provisions of AWS B4.0 or AWS B4.0M, *Standard Methods for Mechanical Testing of Welds*, may be used for the testing of welds made for WPS or welding personnel qualification. However, in instances where the provisions of AWS B4.0 or B4.0M and AWS D1.9 are in conflict, AWS D1.9 shall take precedence.

3.7 Visual Examination

Visual inspection of the weld surfaces shall be performed in accordance with 3.7.1. The acceptance criteria are given in 3.7.2.

3.7.1 Surface Examination Methods (Visual)

3.7.1.1 The weld face and weld root shall be visually examined. Sectioning of the weldment is permitted to allow complete macro examination.

3.7.2 Surface Examination and Acceptance Criteria (Visual)

3.7.2.1 Groove Welds on Plate or Pipe. The visual examination of the test weldment shall satisfy the following acceptance criteria:

- (1) The face and root surfaces shall be free of cracks.
- (2) All craters shall be filled to the full cross section of the weld, except as permitted in 3.7.2.1(4).
- (3) The toes of the weld shall blend smoothly with the base metal such that the contact angle as defined in Figure 3.7 is less than 90°.
- (4) Underfill shall not exceed 10% of the design weld thickness or 1/32 in [0.8 mm], whichever is less, provided the underfill condition does not exceed 10% of the weld length.
- (5) The root surface shall show (a) complete fusion and joint penetration for complete joint penetration groove welds, or (b) fusion and joint penetration to a depth equal to or greater than the weld size specified for partial joint penetration groove welds.
- (6) The maximum root reinforcement on single-sided groove welds in plate and pipe shall not exceed the lesser of 1/8 in [3 mm] or 25% of the thickness of the thinnest member being welded except as noted in Figure 3.8 for complete joint penetration groove welds in T joints.
- (7) Root concavity shall not be allowed for WPS or welder or welding operator qualification with the exception of the weld restart region which may be locally concave by 1/32 in [0.8 mm] with a maximum diameter of concavity of 3/8 in [10 mm]. No more than three areas of concavity (associated with the restart region) are allowed in any linear 14 in [350 mm] of the test coupon.
- (8) For complete joint penetration groove welds, the weld size shall be no less than the thickness of the thinner member being joined except as allowed by 3.7.2.1(4).
- (9) Color shall be used as an acceptance criteria when specified in the contract document. When color is invoked as an acceptance criterion, cleaning (e.g., wire brushing, polishing) or additional welding that is used to remove coloration shall be cause for rejection.
- (10) The face reinforcement shall not exceed the lesser of 3/16 in [5 mm] or 50% of the thickness of the thinnest member being welded.
- (11) Undercut shall not exceed the lesser of 1/32 in [0.8 mm] or 25% of the thickness of the thinnest member being welded.

3.7.2.2 Fillet Welds on Plate or Pipe. The visual examination of the test weldment shall satisfy the following acceptance criteria:

- (1) The surface of the weld shall be free from cracks.
- (2) All craters shall be filled to the full cross section of the weld except as permitted in 3.7.2.2(4).

(3) The weld toe shall blend smoothly with the base metal such that the contact angle as defined in Figure 3.7 is less than 90°.

(4) The weld size shall meet the requirements of the WPS except that an undersize which does not exceed 10% or 1/32 in [0.8 mm], whichever is less, for a length that is not more than 10% of the weld length, is allowed.

(5) Color shall be used as an acceptance criteria when specified in the contract document. When color is invoked as an acceptance criterion, cleaning (e.g., wire brushing, polishing) or additional welding that is used to remove coloration shall be cause for rejection.

(6) Undercut shall not exceed the lesser of 1/32 in [0.8 mm] or 1/4 of the thickness of the thinnest member being welded.

3.8 Radiographic Examination

3.8.1 Radiographic Examination Procedure. All welds shall be examined for 100% of their length (excluding weld tabs). Radiographic examination shall be performed in accordance with the requirements of Clause 5.

3.8.2 Acceptance Criteria. Acceptability shall be based on Table 5.2.

3.9 Macro Examination and Micro Examination

Macro examination of the weld shall be performed in accordance with 3.9.1 to determine whether the sample weldments pass the acceptance criteria detailed in 3.9.2. Guidance on macro and micro sample preparation is provided in Annex E.

3.9.1 Macro Examination. The weld shall be cross-sectioned, polished, and examined at 5X magnification.

3.9.2 Macro Examination Acceptance Criteria. The cross section shall meet the following acceptance criteria:

- (1) The weld metal and heat-affected zones (HAZs) shall be free of cracks.
- (2) The joint shall be completely penetrated unless the weld is designed to be partially penetrated.
- (3) The weld shall be completely fused.
- (4) The required weld size shall be met.

3.9.3 Micro Examination. If the specimen prepared for 3.9.1 is to be micro examined, it shall be etched to give a clear definition of the weld and heat-affected zones and examined at no greater than 100X. Guidance on micro examination is provided in Commentary C-3.9.3.

3.10 Tension Tests—Groove Welds

3.10.1 Specimens. Weld metal tension test specimens shall be in accordance with one of the types illustrated in Figure 3.9, 3.10, or 3.11. All weld metal test specimens shall be in accordance with one of the types illustrated in Figure 3.12.

For partial joint penetration groove welds in plate and pipe, the unfused material on the root side of the joint shall be removed by machining to the thickness of the weld size.

3.10.1.1 Reduced Section Weld Metal Test Specimens—Plate. Reduced section specimens from plate, conforming to the requirements given in Figure 3.9, shall be used for tension tests on all thicknesses of plate.

- (1) A single specimen of full plate thickness shall be used for thicknesses up to and including 0.75 in [19 mm].
- (2) For plate thicknesses greater than 0.75 in [19 mm], single or multiple specimens may be used.

(3) When multiple specimens are necessary because of the limitations of the testing equipment, the entire thickness shall be mechanically cut into the minimum number of approximately equal thickness specimens that can be tested in the available equipment. Each specimen shall be tested, and collectively shall represent a single required tension test.

3.10.1.2 Reduced Section Weld Metal Test Specimens—Pipe. Reduced section specimens conforming to the requirements given in either Figure 3.9 or 3.10 shall be used for tension tests on all thicknesses.

(1) A single specimen of the full thickness shall be used for pipe whose wall thickness is less than or equal to 0.75 in [19 mm].

(2) For pipe wall thicknesses greater than 0.75 in [19 mm], single or multiple specimens may be used.

(3) When multiple specimens are necessary because of the limitations of the testing equipment, the entire thickness shall be mechanically cut into the minimum number of approximately equal thickness specimens that can be tested in the available equipment. Each specimen shall be tested, and collectively shall represent a single required tension test.

3.10.1.3 Full-Section Weld Metal Test Specimens—Pipe. For pipe having a nominal outside diameter of 1.0 in [25 mm] or less, full-section specimens conforming to the requirements given in Figure 3.11 shall be used for tension tests.

3.10.1.4 Reduced Section All-Weld Metal Tension Test Specimen—Plate. Reduced section, all-weld metal tension test specimens conforming to the requirements given in Figure 3.12 shall be used for tension tests of all plate thicknesses. The gauge length shall contain only weld metal.

(1) A single specimen shall be used for plate thicknesses up to and including 1 in [25 mm].

(2) For plate thicknesses greater than 1 in [25 mm], single or multiple specimens may be used.

(3) If the thickness of the weld is thicker than can be demonstrated by a single all-weld-metal sample, then multiple samples shall be used. Each specimen shall be tested, and collectively shall represent a single required tension test.

3.10.2 Tension Test Procedure. The test specimen shall be tested in conformance with AWS B4.0, Standard Methods for Mechanical Testing of Welds.

3.10.3 Acceptance Criteria—Transverse Weld Metal Tension Tests—Plate and Pipe

3.10.3.1 The ultimate tensile strength shall be no less than the minimum values stated for the applicable grade of base metal in the fully annealed condition, as shown in Table 4.1. When multiple specimens are used, as allowed in 3.10.1.1 and 3.10.1.2, each specimen shall meet the requirement.

3.10.3.2 If base metals of different tensile strengths are used, the specified minimum tensile strength of the lower strength base metal, as shown in Table 4.1, applies.

3.10.4 Acceptance Criteria—All Weld Metal Tension Tests—Plate

3.10.4.1 The ultimate tensile strength shall not be less than 90% of the value for the applicable grade of base metal stated in Table 4.1. When multiple specimens are used, as allowed in 3.10.1.4, each specimen shall meet the same requirements.

3.11 Bend Tests—Groove Welds—Plate and Pipe

3.11.1 Specimens. Bend specimens are of five types, depending on whether the axis of the weld is transverse or parallel to the longitudinal axis of the specimen and which surface (side, face, or root) is on the convex (outer) side of the bent specimen. Longitudinal bend specimens may be used in lieu of transverse bend specimens for testing combinations of base and filler materials which differ markedly in tensile properties. Bend test specimens shall be in accordance with one of the types shown in Figure 3.13, 3.14, or 3.15. The cut surfaces shall be designated as the sides of the specimen. The original surfaces of the specimen shall be called the face and root surfaces, the face surface having the greater width of weld.

For partial joint penetration groove welds in plate and pipe, the excess material on the root side of the joint shall be removed by machining to the plane at the bottom of the weld.

A supporting PQR for a complete joint penetration groove weld of the same welding position in which the partial joint penetration groove weld is made is acceptable for qualification, providing all essential variables remain within their limits of qualification.

3.11.1.1 Transverse Side Bend Specimen. The weld is transverse to the longitudinal axis of the specimen which is bent so that the side surface with the larger discontinuity, if any, becomes the convex surface of the bent specimen. Transverse side bend specimens shall be in accordance with the dimensions shown in Figure 3.13.

3.11.1.2 Transverse Face Bend Specimen. Transverse face bend test specimens shall be in accordance with the dimensions shown in Figure 3.14. They shall be bent so that the face surface becomes the convex surface of the bent specimen. Pipe less than or equal to 4 in [100 mm] in outside diameter shall have face bend specimens prepared as described in 3.11.1.4.

3.11.1.3 Transverse Root Bend Specimen. Transverse root bend test specimens shall be in accordance with the dimensions shown in Figure 3.14. They shall be bent so that the root surface becomes the convex surface of the bent specimen. Pipe less than or equal to 4 in [100 mm] in outside diameter shall have root bend specimens prepared as described in 3.11.1.4. In specimens taken from partial joint penetration groove welds, the weld specimen shall be cut and tested coincident with the plane at the bottom of the weld.

3.11.1.4 Subsize Transverse Face and Root Bend Specimen. For pipe 4 in [100 mm] or less in outside diameter, the width of the specimen may be 3/4 in [19 mm], measured around the outside surface. Alternatively, for pipe less than 2-3/8 in [60 mm] in outside diameter, the width of the specimen may be that obtained by cutting the pipe into quarter sections, less the allowance for cutting. The other dimensions shall be as shown in Figure 3.14.

3.11.1.5 Longitudinal Face Bend Specimen. The weld is parallel to the longitudinal axis of the specimen which is bent so that the face surface becomes the convex surface of the bent specimen. Longitudinal face bend test specimens shall be in accordance with the dimensions shown in Figure 3.15.

3.11.1.6 Longitudinal Root Bend Specimen. The weld is parallel to the longitudinal axis of the specimen which is bent so that the root surface becomes the convex surface of the bent specimen. Longitudinal root bend test specimens shall be in accordance with the dimensions shown in Figure 3.15. In specimens taken from partial joint penetration groove welds, the weld size shall be measured from the bottom of the weld preparation to the material surface, and the weld assembly shall be cut to and tested coincident with the plane at the bottom of the weld.

3.11.2 Test Procedures—Bend Tests—Plate and Pipe

3.11.2.1 Bend Test Fixture. A wraparound fixture (Figure 3.16) shall be used. The face surface of the specimen is turned toward the outer roller for face bend tests, the root surface for root bend tests, and the side with the larger discontinuity, if any, for side bend tests. The specimen shall be wrapped around the center roller by a 180° movement of the outer roller.

3.11.3 Acceptance Criteria—Bend Tests—Pipe and Plate

3.11.3.1 The weld and heat-affected zone of a transverse weld bend specimen shall be completely within the bent portion of the specimen after bending.

3.11.3.2 The convex surface of the bend test specimen shall be visually examined for surface discontinuities. For acceptance, the surface shall not contain any discontinuities exceeding the following dimensions:

- (1) 1/8 in [3 mm] measured in any direction on the surface.
- (2) 3/8 in [10 mm] the sum of the greatest dimensions of all discontinuities exceeding 1/32 in [0.8 mm], but less than or equal to 1/8 in [3mm].
- (3) 1/4 in [6 mm]—the maximum corner crack, except where that corner crack results from inclusions or other fusion type discontinuity, then the 1/8 in [3 mm] maximum shall apply.

Specimens with corner cracks exceeding 1/4 in [6 mm] with no evidence of a fusion type discontinuity shall be discarded. A replacement test specimen from the original weldment shall be tested.

3.12 Chemical Analysis

When the weld metal is required by contract documents to be analyzed, the following steps shall be undertaken: The chemical analysis of weld metal shall be conducted using a sample extracted as detailed in 3.12.2. Chemical analysis for hydrogen shall be in accordance with ASTM E1447. Chemical analysis for oxygen and nitrogen shall be in accordance with ASTM E1409. Chemical analysis for titanium alloys shall be in accordance with ASTM E2371.

3.12.1 Analysis Procedure. The weld metal and base metal shall be analyzed for the following elements: carbon, oxygen, hydrogen, nitrogen, aluminum, vanadium, iron, and titanium. The composition may be obtained from the manufacturer's certificates or from a chemical analysis.

3.12.2 Weld Metal Sample Removal. When the contract documents require the weld metal to be analyzed, the following steps shall be undertaken:

- (1) A length of weld shall be cut from the joint.
- (2) The end faces of the section shall be polished and etched to determine the likely base/weld metal interface.
- (3) The base metal shall be removed from the weld deposit by any nonthermal cutting process.

3.12.3 Acceptance Criteria—Chemical Analysis. The acceptance criteria for chemical analysis shall be stated in the contract. The Engineer shall use the unique filler metal and base metal chemical compositions for the weld being analyzed as a basis for establishing acceptance limits.

Part C

WPS Qualification

3.13 General WPS Qualification

WPS qualification shall be conducted by the Contractor performing the production welding. The WPS qualification tests required in Part C are devised to determine the mechanical properties and soundness of the welds made with a specific WPS. Results of these tests are used to establish WPS welding parameters that define the limitations of essential variables applicable to production welding under this code.

3.13.1 Procedure Qualification Record. The specific values of conditions involved in qualifying a WPS shall be recorded on a form called the Procedure Qualification Record (PQR). The essential variables for the specific welding process shall be recorded on this form. Suggested forms for these records are given in Annex D.

3.13.2 WPS. The WPS shall list the group numbers of the base metals to be joined, the filler metal(s) to be used, the range of preheat and postweld heat treatments, thicknesses, and other variables associated with the welding process as defined in the PQR.

Suggested forms for these records are given in Annex D.

3.13.3 Combination of WPSs. More than one WPS may be used in a single production joint, provided each WPS is qualified either separately or in combination with the other WPS(s) within the position and thickness limits specified in Table 3.1 and Table 3.5, respectively.

3.14 Limits of Qualified Positions for WPSs

To reduce the number of WPS qualifications that may be required, qualification in certain welding positions also qualifies for other welding positions as shown in Table 3.1.

3.15 Limitation of Essential Variables—WPS Qualification

Changes greater than the limitations set in Table 3.3 shall be considered essential changes in a WPS and shall require qualification of the altered WPS.

3.16 Tests—WPS Qualification

3.16.1 Number and Type of Examinations. The number and type of examinations shall be determined in accordance with Table 3.5. Test methods and acceptance criteria for each test shall be in accordance with Clause 3, Part B. Additional testing may be added at the discretion of the Engineer or Contractor.

3.16.2 Test Specimens for WPS Qualification. Sample weldments of sufficient size to obtain the length/number of test specimens required by Table 3.5, as applicable, shall be prepared in accordance with the WPS. When it is impractical to obtain all the required specimens from one weldment, multiple weldments shall be used.

3.16.2.1 Test Specimens—Groove Welds—Plate. The location of test specimens shall be in accordance with Figure 3.17.

3.16.2.2 Test Specimens—Groove Welds—Hollow Section or Pipe. The location of test specimens shall be in accordance with Figure 3.18 or 3.19, as applicable.

3.16.2.3 Partial Joint Penetration Groove Welds—Plate or Pipe. A test weld shall be made in accordance with the WPS to be used in production. But, if the WPS was qualified for a complete joint penetration groove weld and will now be used to weld a partial joint penetration groove weld, then three macroetch cross section test specimens shall be prepared and visually examined.

3.16.2.4 Test Specimens—Fillet Welds—Plate, Hollow Section, or Pipe. The location of test specimens shall be in accordance with Figure 3.20, 3.21, or 3.22 for fillet welded plate, fillet welded pipe, and fillet welded plate to pipe, respectively. The mechanical properties of fillet welds shall be determined by the mechanical testing of a groove weld procedure qualification in accordance with 3.16.2.1 and 3.16.2.2. This groove weld qualification is only required for changes to the material thickness range and weld process essential variables as determined by reference to Table 3.3.

3.16.2.5 Test Specimens—Plug and Slot Welds. The location of the test specimens shall be in accordance with Figure 3.23 for plug and slot welds. The mechanical properties of fillet welds shall be determined by the mechanical testing of a groove weld procedure qualification in accordance with 3.16.2.1 and 3.16.2.2. This complementary groove weld qualification is only required for changes to the material thickness range and weld process essential variables as determined by reference to Table 3.3.

3.17 Retests

If a destructive test specimen fails to meet the acceptance criteria, then two retests may be performed with identical specimens cut from the same test weldment, or from an additional weldment made in accordance with the WPS being qualified. Both retest specimens are required to meet the acceptance criteria in order to qualify the WPS.

Part D *Performance Qualification*

3.18 General Performance Qualification

The tests described in Part D are devised to determine whether or not a welder, welding operator, or tack welder can produce sound welds in accordance with a qualified WPS. These qualification tests are not intended as a guide for selecting the WPS to be used for welding during construction. The test welds shall be made in accordance with the requirements of a qualified WPS.

3.18.1 Identification of Welders, Welding Operators, and Tack Welders. Each qualified welder, welding operator, and tack welder shall be assigned an identifying number, letter or symbol by the contractor, which shall be used to identify the work of that person.

3.18.2 Records of Tests. The essential variables (as defined in 3.21) of the performance qualification test and the test results obtained by each welder, welding operator, or tack welder shall be recorded on a welder, welding operator, or tack welder qualification test record, respectively. A suggested form for these records is given in Annex D.

3.18.3 Welder and Welding Operator Qualification through WPS Qualification. A welder, welding operator, or tack welder who completes a test weldment that meets the criteria for WPS qualification in Clause 3, Part C, shall be considered qualified to weld joints within the positions and essential variables described in 3.19 and 3.21.

3.19 Limits of Qualified Positions for Performance

The welding positions qualified by a given test weld position are shown in Table 3.2.

3.19.1 Position of Test Weld. A Contractor who does production welding in a special orientation may make the tests for performance qualification in this specific orientation. Such qualifications are valid only for the positions actually tested, except that an angular deviation of $\pm 15^\circ$ is permitted in the inclination of the weld axis and the rotation of the weld face, as defined in Figure 3.1 or 3.2.

3.20 Test Weldment Types

The test weld type and product form to be used for performance qualification shall be determined in accordance with the paragraphs below.

3.20.1 Groove Weld Qualification Test

3.20.1.1 Plate. Each half of the test plate assembly shall have minimum dimensions as indicated in Figure 3.17 with the groove preparation along the long edge. The welded joint (from one or more test assemblies) shall be of sufficient length to allow the removal of all of the required test specimens. The locations of destructive test specimens and stop and restart locations shall be in accordance with Figure 3.17.

3.20.1.2 Pipe. Each pipe of the test assembly shall have a minimum length of 8 in [200 mm]. The welded joint (from one or more test assemblies) shall be of sufficient length to allow the removal of all of the required test specimens. The locations of destructive test specimens shall be in accordance with Figure 3.18 or 3.19, as applicable.

3.20.2 Fillet Weld Qualification Test

3.20.2.1 Plate. One plate shall have minimum dimensions of 6 in $\times$ 12 in [150 mm $\times$ 300 mm]. The other plate shall have minimum dimensions of 3 in $\times$ 12 in [75 mm $\times$ 300 mm] with the square face along the 12 in [300 mm] dimension. The welded joint (from one or more test assemblies) shall be of sufficient length to allow the removal of all of the required test specimens. The locations of the destructive test specimens and stop/start locations shall be in accordance with Figure 3.20.

3.20.2.2 Pipe. Each pipe of the test assembly shall have a minimum length of 3 in [75 mm]. The welded joint (from one or more test assemblies) shall be of sufficient length to allow the removal of all of the required test specimens. The locations of the destructive test specimens and stop/start locations shall be in accordance with Figure 3.21.

3.20.2.3 Plate to Pipe/Hollow Section. The plate section of the test assembly shall be at least 2 in [50 mm] larger than the outside dimensions of the pipe/hollow section. The welded joint (from one or more test assemblies) shall be of sufficient length to allow the removal of all of the required test specimens. The location of the destructive test specimens and stop/start locations shall be in accordance with the relative positions of Figure 3.22.

3.20.3 Tack Weld Qualification

3.20.3.1 Tack Weld—Groove. The test assembly required for a production groove joint with a root opening shall be in accordance with the requirements of 3.20.1.1 or 3.20.1.2. In the case of production groove joints without a root opening, the test assembly shall be in accordance with the requirements of 3.20.2.1 or 3.20.2.2.

3.20.3.2 Tack Weld—Fillet. The test assembly for fillet tack welds shall be in accordance with the requirements of 3.20.2.1, 3.20.2.2, or 3.20.2.3.

3.21 Limitation of Essential Variables—Welder, Welding Operator, and Tack Welder Performance Qualification

3.21.1 Qualification using any titanium alloy permitted by this code shall be considered as qualification to weld or tack weld any other titanium alloy permitted by this code with the process used for the qualification.

3.21.2 A welder shall be qualified for each welding process used.

3.21.3 A change in the position defined in 3.19 or outside the limitations of Table 3.2 shall require requalification.

3.21.4 A change from one thickness and diameter group shown in Table 3.6 to another shall require requalification.

3.21.5 When the test plate is in the 3G or 3F vertical position, or the test pipe is in the 5G or 6G position, a change in the direction of vertical welding shall require requalification.

3.21.6 The omission of either backing or backing gas in complete joint penetration groove welds welded from one side shall require requalification.

3.22 Tests—Performance Qualification

3.22.1 Required Tests. The number and type of nondestructive and destructive examinations shall be determined in accordance with Table 3.6. Test methods and acceptance criteria shall be as directed by Clause 3, Part B.

3.23 Retests

3.23.1 The performance test may be stopped whenever it becomes apparent to the testing authority that the welder, welding operator, or tack welder does not have the skill to produce welds that meet the acceptance criteria.

3.23.2 If a welder, welding operator, or tack welder fails to meet the acceptance criteria of any test, a retest may be allowed under the following conditions:

3.23.2.1 An immediate retest may be made consisting of two test specimens of each type and position which failed. All retest specimens shall meet all the specified requirements.

3.23.2.2 A complete performance qualification retest may be made at a later date for any failed qualification tests, provided there is evidence that the welder, welding operator, or tack welder has had additional training or practice.

Table 3.1
WPS Qualification—Type of Weld and Position Limitations (see 3.13.3 and 3.14)

Qualification Test		Type of Weld and Position of Welding Qualified ^a			
		Plate		Tube	
Weld	Plate or Pipe Positions ^a	Groove	Fillet	Groove	Fillet
Plate Groove	1G	1G,	1F	1G ^b	1F ^b
	2G	1G, 2G	1F, 2F	1G ^b , 2G ^b	1F ^b , 2F ^b
	3G	1G, 3G	1F, 3F	1G ^b , 2G ^b	1F ^b , 2F ^b
	4G	1G, 4G	1F, 4F	1G ^b	1F ^b , 4F ^b
Plate Fillet ^c	1F	—	1F	—	—
	2F	—	1F, 2F	—	—
	3F	—	1F, 3F	—	—
	4F	—	1F, 4F	—	—
Pipe Groove	1G	1G	1F	1G	1F
	2G	1G, 2G	1F, 2F	1G, 2G	1F, 2F
	5G	1G, 3G, 4G	1F, 3F, 4F	1G, 5G	1F, 4F, 5F
	6G	1G, 2G, 3G, 4G	1F, 2F, 3F, 4F	1G, 2G, 5G, 6G	1F, 2F, 4F, 5F
Pipe Fillet ^c	1F	—	1F	—	1F
	2F, 2FR	—	1F, 2F	—	1F, 2F
	4F	—	1F, 2F, 4F	—	1F, 2F, 4F
	5F	—	1F, 2F, 3F, 4F	—	1F, 2F, 4F, 5F

^a See Figures 3.3, 3.4, 3.5, and 3.6.

^b Qualifies for welding pipe equal to or greater than 24 in [610 mm] in diameter.

^c Fillet weld procedure qualification shall also require a groove weld qualification, as detailed in 3.16.2.4 and 3.16.2.5, which may be in any position or thickness for that process.

Table 3.2
Welder, Welding Operator, and Tack Welder Performance Limitations
(see 3.19 and 3.21.3)

Qualification Test		Type of Weld and Position Qualified ^a			
		Plate		Pipe	
Weld	Plate or Pipe Positions	Groove	Fillet ^b	Groove	Fillet ^b
Plate Groove	1G	1G	<u>1F</u>	1G (Rolled) ^c	<u>1F (Rolled)^c</u>
	2G	1G, 2G	<u>1F, 2F</u>	1G (Rolled), ^c 2G ^c	<u>1F (Rolled),^c 2F^c, 2F (Rolled)^c</u>
	3G	1G, 3G	<u>1F, 3F</u>	<u>1G (Rolled)^c</u>	<u>1F (Rolled)^c</u>
	4G	1G, 4G	<u>1F, 4F</u>	<u>1G (Rolled)^c</u>	<u>1F (Rolled),^c 2F^c, 2F (Rolled),^c 4F^c</u>
	3G and 4G	1G, 2G, 3G, 4G	<u>1F, 2F, 3F, 4F</u>	<u>1G (Rolled),^c 2G^c, 5G^c</u>	<u>1F (Rolled),^c 2F^c, 2F (Rolled),^c 4F^c, 5F^c</u>
Plate Fillet	1F	—	1F	—	<u>1F (Rolled)^c</u>
	2F	—	1F, 2F	—	<u>1F (Rolled),^c 2F^c, 2F (Rolled)^c</u>
	3F	—	<u>1F, 3F</u>	—	<u>1F (Rolled)^c</u>
	4F	—	<u>1F, 4F</u>	—	<u>1F (Rolled),^c 2F^c, 2F (Rolled),^c 4F^c</u>
Pipe-Groove Complete Joint Penetration	<u>1G (Rolled)</u>	1G	<u>1F</u>	<u>1G (Rolled)</u>	<u>1F (Rolled)</u>
	2G	1G, 2G	<u>1F, 2F</u>	<u>1G (Rolled), 2G</u>	<u>1F (Rolled), 2F, 2F (Rolled)</u>
	5G	1G, 2G, 3G, 4G	<u>1F, 2F, 3F, 4F</u>	<u>1G (Rolled), 2G, 5G</u>	<u>1F (Rolled), 2F, 2F (Rolled), 4F, 5F</u>
	6G	<u>1G, 2G, 3G, 4G</u>	<u>1F, 2F, 3F, 4F</u>	<u>1G (Rolled), 2G, 5G, 6G</u>	<u>1F (Rolled), 2F, 2F (Rolled), 4F, 5F</u>
	<u>6G^d</u>	<u>1G, 2G, 3G, 4G</u>	<u>1F, 2F, 3F, 4F</u>	<u>1G (Rolled), 2G, 5G, 6G, 6G^d</u>	<u>1F (Rolled), 2F, 2F (Rolled), 4F, 5F</u>
Pipe Fillet	<u>1F (Rolled)</u>	—	1F	—	<u>1F (Rolled)</u>
	2F	—	1F, 2F	—	<u>1F (Rolled), 2F, 2F (Rolled)</u>
	<u>2F (Rolled)</u>	—	1F, 2F	—	<u>1F (Rolled), 2F, 2F (Rolled)</u>
	4F	—	1F, 2F, 4F	—	<u>1F (Rolled), 2F, 2F (Rolled), 4F</u>
	5F	—	<u>1F, 2F, 3F, 4F</u>	—	<u>1F (Rolled), 2F, 2F (Rolled), 4F, 5F</u>

^a See Figures 3.3, 3.4, 3.5 and 3.6.

^b Welders requiring qualification for fillet welding shall also possess a groove weld qualification in any position and thickness.

^c Pipe equal to or greater than 24 in [610 mm].

^d The pipe has been welded with a restriction ring.

Table 3.3
Limitations of Essential Variables of a WPS^a (see 3.15)

Essential Variable (Changes outside these limits require requalification)	GMAW	GTAW (Manual)	GTAW (Mechanized or Automatic)	PAW (Manual)	PAW (Mechanized or Automatic)	EBW	LBW
Welding Process							
1) A change in the welding process, e.g., from GMAW to GTAW	X	X	X	X	X	X	X
Base Metal Alloy							
2) A change from one material M number to another, except as detailed in Table 3.4 ^b	X	X	X	X	X	X	X
Base Metal Thickness							
3) A change in thickness beyond the limitations of the qualified range, as shown in Table 3.5	X	X	X	X	X	X	X
Filler Metal							
4) A change from one filler metal grade to another ^c	X	X	X	X	X	X	X
5) The addition or deletion of filler metal		X	X	X	X	X	X
6) A change in the method by which filler metal is added ^f		X	X	X	X	X	X
Electrode/Filler Metal							
7) An increase or decrease in the nominal filler metal diameter	X	by >0.035 in [<u>>0.9</u> mm]	by >0.02 in [<u>>0.5</u> mm]	by >0.035 in [<u>>0.9</u> mm]	by >0.02 in [<u>>0.5</u> mm]	by >0.02 in [<u>>0.5</u> mm]	by >0.02 in [<u>>0.5</u> mm]
8) An increase or decrease in the nominal filler metal volume feed rate ^e			>20%		>20%	>20%	>20%
9) The addition or deletion of resistance heating of the filler wire			X		X	X	X
Travel Speed							
10) An increase or decrease in the specified travel speed	>15%	>15%	>15%	>15%	>15%	X	X
Electrical Parameters							
11) An increase or decrease in the specified amperage	>15%	>20%	>20%	>20%	>20%	X	X
12) An increase or decrease in the specified voltage	>15%	>15%	>15%	>15%	>15%	>2%	X
13) A change in the beam or beam focus current						>5%	
14) A change in the beam pulsing frequency or duration						X	

(Continued)

Table 3.3 (Continued)
Limitations of Essential Variables of a WPS^a (see 3.15)

Essential Variable (Changes outside these limits require requalification)	GMAW	GTAW (Manual)	GTAW (Mechanized or Automatic)	PAW (Manual)	PAW (Mechanized or Automatic)	EBW	LBW
15) A change in the filament type, size, or shape						X	
Shielding							
16) A change in shielding gas from a single gas to any other single gas or to a mixture of gases	X	X	X	X	X	X	X
17) A change in the specified nominal percentage composition of a gas mixture	X	X	X	X	X		X
18) A change in shielding gas concept ^g	X	X	X	X	X		X
19) An increase in the total flow rate	>50%	>50%	>30%	>50%	>30%		>30%
20) A decrease in the total flow rate	>20%	>20%	>10%	>20%	>10%		>10%
21) A change of shielding environment from vacuum to inert gas							X
22) An increase in vacuum pressure						X	
23) The deletion of, or a change in composition of, or a decrease exceeding 10% in the trailing gas flow rate	X	X	X	X	X	X	X
24) The addition, deletion, or a flow rate change exceeding 5% for any gas used in the process, or a change in the orientation of the plasma removing gas jet relative to the workpiece (e.g., coaxial transverse to the beam)							X
25) A change in plasma orifice diameter				X	X		
26) A change in the plasma electrode tip geometry				X	X		
27) A change in plasma gas flow rate				X	>10%		
28) A change in plasma gas composition				X	X		
29) A change in secondary (shield) gas flow rate				>10%	>10%		
30) A change in secondary (shield) gas composition				X	X		
31) A change in electrode "set back"				X	X		

(Continued)

Table 3.3 (Continued)
Limitations of Essential Variables of a WPS^a (see 3.15)

Essential Variable (Changes outside these limits require requalification)	GMAW	GTAW (Manual)	GTAW (Mechanized or Automatic)	PAW (Manual)	PAW (Mechanized or Automatic)	EBW	LBW
32) A change in the plasma torch type				X	X		
Welding Power Source							
33) A change from non pulsed to pulsed type and vice versa	X	X	X	X	X		
34) A change in AC to DC or vice versa	X	X	X	X	X		
35) A change in the type of AC "wave form"	X	X	X	X	X		
36) A change from DCEP to DCEN and vice versa	X	X	X	X	X		
Number of Weld Passes							
37) For a specified groove area, a change >25% in the number of passes specified ^b	X	X	X	X	X		
Technique							
38) A change from stringer-bead technique to a weave-bead technique	X	X	X	X	X		
39) A change from multiple pass per side to single pass per side <u>or vice versa</u>						X	X
40) A change exceeding $\pm 5\%$ in gun to workpiece distance, or axis of beam angle related work						X	
41) A change exceeding $\pm 20\%$ in oscillation length or width from that qualified, or the addition of a cosmetic <u>weld</u> pass						X	
42) A change from single-sided welds to double-sided or vice versa						X	X
Welding Position							
43) A change in position in which welding is done exceeding the limitations of Table 3.1	X	X	X	X	X	X	X
Direction of Welding							
44) A change from push to pull and vice versa	X		X		X	X	X
45) A change in torch angle	>10°	>15°	>5°	>15°	>5°	>5°	>5°
46) Vertical welding: For any pass from upward to downward or vice versa	X	X	X	X	X	X	X

(Continued)

Table 3.3 (Continued)
Limitations of Essential Variables of a WPS^a (see 3.15)

Essential Variable (Changes outside these limits require requalification)	GMAW	GTAW (Manual)	GTAW (Mechanized or Automatic)	PAW (Manual)	PAW (Mechanized or Automatic)	EBW	LBW
Groove Type							
47) A change in the type of groove	X	X	X	X	X	X	X
48) A change in the M number of the backing	X	X	X	X	X	X	X
Fit-Up Tolerances							
49) Changes involving the following:							
50) A decrease in the groove angle by	>5%	>5%	>5%	>5%	>5%		
51) A change in the root opening (when backing is not used) by	>1/16 in [1.5 mm]	>1/32 in [0.8 mm]	>1/32 in [0.8 mm]	>1/32 in [0.8 mm]	>1/32 in [0.8 mm]		
52) An increase in the root face (when not back machined) by	>1/16 in [1.5 mm]	>1/32 in [0.8 mm]	>1/32 in [0.8 mm]	>1/32 in [0.8 mm]	>1/32 in [0.8 mm]		
53) An increase in fit-up gap beyond that used in the qualification test						X	X
Cleaning							
A change in the type of cleaning used (for example mechanical, chemical)							
54) For initial joint preparation	X	X	X	X	X	X	X
55) For interpass cleaning of weld beads	X	X	X	X	X	X	X
Antispatter							
56) <u>The addition of an antispatter compound and/or change of chemical cleaning method used</u>	<u>X</u>	<u>X</u>	<u>X</u>	<u>X</u>	<u>X</u>	<u>X</u>	<u>X</u>
Backing							
57) A change from permanent backing to temporary backing or no backing (i.e., other than inert gas backing)	X	X	X	X	X	X	X
58) <u>A change from permanent backing to an inert gas backing</u>	<u>X</u>	<u>X</u>	<u>X</u>	<u>X</u>	<u>X</u>		
59) <u>A change from an inert gas backing to a permanent backing</u>	<u>X</u>	<u>X</u>	<u>X</u>	<u>X</u>	<u>X</u>		
60) <u>A change from an inert gas backing to temporary backing</u>	<u>X</u>	<u>X</u>	<u>X</u>	<u>X</u>	<u>X</u>		
Back-Machining							
61) <u>Deletion</u> , but not inclusion of	X	X	X	X	X	X	X

(Continued)