

Specification for Welding of Presses and Press Components



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An American National Standard

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American National Standards Institute
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Specification for Welding of Presses and Press Components

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Prepared by the
American Welding Society (AWS) D14 Committee on Machinery and Equipment

Under the Direction of the
AWS Technical Activities Committee

Approved by the
AWS Board of Directors

Abstract

Requirements are presented for the design and fabrication of cyclically loaded press weldments, which includes the weld repair of new and existing components. Filler metals and weld procedure specifications are recommended for the applicable base metals that are limited to those consisting of carbon and low-alloy steels. Allowable unit stresses are provided for weld metal and base metal for various cyclically loaded joint designs. This specification does not address the fabrication or weld repair of pressure containing components such as hydraulic cylinders, air cylinders, or die cushions.



American Welding Society

550 N.W. LeJeune Road, Miami, FL 33126



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E. G. Yevick	<i>Weld-Met International Group</i>

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R. T. Hemzacek	<i>Consultant</i>
B. D. Horn	<i>Consultant</i>
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P. J. Palzkill	<i>Consultant</i>
V. R. Zegers	<i>R E Technical Services, Incorporated</i>

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Advisors to the AWS D14E Subcommittee on Welding of Cranes and Presses

J. G. Nelson	<i>Northrop Grumman</i>
L. Seum	<i>Sheedy Drayage Company</i>
J. L. Warren	<i>CNH America LLC</i>

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Foreword

This foreword is not part of AWS D14.5/D14.5M:2009, *Specification for Welding of Presses and Press Components*, but is included for informational purposes only.

The specification AWS D14.5/D14.5M addresses a recognized need in the press manufacturing and press repair industries to continue the advance of welding and to increase product reliability. The specification provides manufacturers, fabricators, and repair companies with the minimum acceptable requirements for fabrication, modification, and repair of cyclical press components. The requirements for procedure and welder qualification, workmanship, and prequalified weld joints are emphasized.

This third edition has been edited to include both U.S. Customary and SI Units. Other revisions include updated tables and figures. Contributors who prepared this document and worked to provide a high quality, reliable working document represent manufacturers, users, repair companies, and insurance underwriters.

Underlined text in the subclauses, tables, or figures indicates an editorial or technical change from the 1997 edition. A vertical line in the margin indicates a revision from the 1997 edition.

Comments and suggestions for the improvement of this standard are welcome. They should be sent to the Secretary, AWS D14 Committee on Machinery and Equipment, American Welding Society, 550 N.W. LeJeune Road, Miami, FL 33126.

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Specification for Welding of Presses and Press Components

1. General Provisions

1.1 Scope. The purpose of this specification is to establish minimum acceptable requirements for weld joint design and the fabrication by welding of presses and press components, and is not intended to apply to material feed mechanisms and tooling. It shall also apply to the modification or repair by welding of new or existing presses or press components. Its intent is to promote the following:

- (1) High-quality construction and repair of presses;
- (2) Adequate initial and sustained performance of equipment;
- (3) Personnel and equipment safety;
- (4) Clear, concise fabrication practices that will be readily understood by the manufacturer, fabricator, buyer, and user;
- (5) The Manufacturer, Fabricator, and Repair Organization shall have and maintain a welding quality program that will establish that all requirements of this specification will be met. A recommended welding quality program is outlined in Annex D.

This specification establishes the minimum acceptable practice at the time of its publication. It is not intended to restrict new developments or in any way to inhibit advances in the art of welding.

This specification makes use of both U.S. Customary Units and the International System of Units (SI). The measurements may not be exact equivalents; therefore each system shall be used independently of the other without combining in any way. The specification with the designation D14.5 uses U.S. Customary Units. The specification D14.5M uses SI Units. The latter are shown in appropriate columns in tables and figures or within brackets []. Detailed dimensions on figures are in inches. A separate tabular form that relates the U.S. Customary Units with SI Units may be used in tables and figures.

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

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

Informative references (found in nonmandatory language or elements) are shown in Annex G.

AWS Standards¹

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

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

AWS A3.0, *Standard Welding Terms and Definitions*;

AWS A5.1/A5.1M, *Specification for Carbon Steel Electrodes for Shielded Metal Arc Welding*;

AWS A5.5/A5.5M, *Specification for Low-Alloy Steel Electrodes for Shielded Metal Arc Welding*;

AWS A5.01, *Filler Metal Procurement Guidelines*;

AWS A5.17/A5.17M, *Specification for Carbon Steel Electrodes and Fluxes for Submerged Arc Welding*;

AWS A5.18/A5.18M, *Specification for Carbon Steel Filler Metals for Gas Shielded Arc Welding*;

¹ AWS standards are published by the American Welding Society, 550 N.W. LeJeune Road, Miami, FL 33126.

AWS A5.20/A5.20M, *Specification for Carbon Steel Electrodes for Flux Cored Arc Welding*;

AWS A5.23/A5.23M, *Specification for Low Alloy Steel Electrodes and Fluxes for Submerged Arc Welding*;

AWS A5.28/A5.28M, *Specification for Low Alloy Steel Electrodes for Gas Shielded Metal Arc Welding*;

AWS A5.29/A5.29M, *Specification for Low Alloy Steel Electrodes for Flux Cored Arc Welding*;

AWS A5.32/A5.32M, *Specification for Welding Shielding Gases*;

AWS B2.1 *Specification for Welding Procedure and Performance Qualification*;

AWS B4.0, *Standard Methods for Mechanical Testing of Welds*; and

AWS B4.0M, *Standard Methods for Mechanical Testing of Welds*.

ASTM Standards²

ASTM A 370, *Test Methods and Definitions for Mechanical Testing of Steel Products*;

ASTM A 435, *Specification for Straight-Beam Ultrasonic Examination of Steel Plates*;

ASTM E 94, *Standard Guide for Radiographic Testing*;

ASTM E 709, *Standard Guide for Magnetic Particle Examination*;

ASTM E 747, *Standard Practice for Design, Manufacture, and Material Grouping Classification of Wire Image Quality Indicators (IQI) Used for Radiology*;

ASTM E 1025, *Standard Practice for Design, Manufacture, and Material Grouping Classification of Hole-Type Image Quality Indicators (IQI) Used for Radiology*; and

ASTM E 1032, *Standard Test Method for Radiographic Examination of Weldments*.

ASNT Specifications³

SNT-TC-1A, *Recommended Practice, Supplement A, Radiography*;

SNT-TC-1A, *Recommended Practice, Supplement B, Magnetic Particle*;

SNT-TC-1A, *Recommended Practice, Supplement C, Ultrasonic Testing Method*; and

SNT-TC-1A, *Recommended Practice, Supplement D, Liquid Penetrant*.

1.3 Definitions. The welding terms used in this code shall be interpreted in conformance with the definitions given in the latest edition of AWS A3.0, *Standard Welding Terms and Definitions*, supplemented by the following definitions:

Engineer. The responsible technical authority.

Fabricator. The person, shop, or agency performing the actual welding. The person may be employed by the Manufacturer's company or the Fabricator may be an independent shop doing work on a subcontract basis.

Inspector. The person designated by the manufacturer, owner, or repair service who shall ascertain that all fabrication by welding is performed in conformance to the requirements of this Specification

Manufacturer. The person, company, or agency responsible for the design and performance of a press or press component.

pipng porosity. Elongated porosity whose major dimension lies in a direction approximately normal to the weld surface. Frequently it is referred to as "pin holes" when the porosity extends to the surface.

press. A machine comprised of mechanical or hydraulic devices for applying forces that are contained within the frame of the machine.

Purchaser or Owner. The person, company, or agency that purchases the press.

Repair Service. The organization that provides repair or modification to a press or press component for the press user.

User. The person, company, or agency that utilizes the press.

1.4 Manufacturer's Responsibility. The Manufacturer's responsibility with respect to this specification shall include the following:

(1) Ensuring that all aspects of design and welding are in conformance to this specification.

(2) Ensuring that welding and nondestructive examination symbols are in conformance with the latest edition of AWS A2.4, *Standard Symbols for Welding, Brazing, and Nondestructive Examination*.

² ASTM standards are published by the American Society for Testing and Materials, 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959.

³ ASNT standards are published by the American Society for Nondestructive Testing, 1711 Arlingate Lane, P.O. Box 28518, Columbus, OH 43228-0518.

(3) Detailing joint preparation and ensuring joint compatibility with applied processes and materials employed.

(4) Selecting processes for all welds.

(5) Establishing written welding procedure specifications (WPSs) qualified in accordance with Clause 7, Qualification, to ensure uniform practice. Each WPS shall list values for each variable for the welding process used (see 7.2), including but not limited to electrode size, welding travel speed, current range for electrode size.

(6) Ensuring the standards of workmanship applied to all welds and welding procedures conform to Clause 6, Workmanship.

(7) Maintaining records of all welder and procedure qualification tests pertaining to welding control.

(8) Ensuring that only personnel qualified in accordance with Clause 7, Qualification, perform welding.

2. Classification of Welded Joints and Materials

2.1 Classification of Welded Joints. Welded joints are divided into the following six classifications based upon the design of the joint and anticipated performance (see Figure 1). Each joint class is also rated for maximum allowable stress levels (see 7.2.4 and Table C.3).

2.1.1 Joint Class I. This class consists of complete groove weld penetration of butt joints, welded from one or both sides. Two-sided welds have the root of the first side chipped, gouged, or ground to sound metal before depositing the second side. Single-sided welds that are made using backing tape, fusible flux backing material, or a nonfusible backing bar, and a back weld to obtain a completely fused root do not require backgouging of the root side of the first weld. Weld surfaces shall have all weld reinforcement ground or machined flush with the direction of removal parallel to the principal stress. Finished joints shall be nondestructively tested according to Table 1 and Clause 8, Inspection, and the results recorded. Use of backing tape, fusible flux backing material, or a nonfusible backing bar requires qualification.

2.1.2 Joint Class II. This class consists of complete joint penetration butt, T-, or corner joint welded from both sides, with the root of the first side chipped, gouged, or ground back to sound metal before depositing the second side. Welds that are made using backing tape, fusible flux backing material, or a nonfusible backing bar, and a back weld to obtain a completely fused root do not require backgouging of the other side of the weld.

Finished joints shall be nondestructively tested according to Table 1 and Clause 8, Inspection, and the results recorded. Use of backing tape, fusible flux backing material, or a nonfusible backing bar requires qualification.

2.1.3 Joint Class III. This class is a complete groove weld penetration of butt, T-, or corner joint, welded from both sides, or from one side using a backing strip that is not removed after welding. The inside corners of double-welded T- and corner joints may be reinforced with a fillet weld. Finished joints shall be nondestructively examined according to Table 1 and Clause 8, Inspection, and the results recorded.

2.1.4 Joint Class IV. This class is a complete groove weld penetration of butt, T-, or corner joint, welded from one side without the use of backing; a partial groove weld penetration of butt, T-, or corner joint welded on both sides; or a lap, T-, or corner joint fillet welded on both sides. The inside corners of groove welded T- and corner joints may be reinforced with a fillet weld. See Table 1 and Clause 8, Inspection, for inspection requirements.

2.1.5 Joint Class V. This class consists of partial groove weld penetration of butt, T-, or corner joints, welded on one side; a fillet-, plug- or slot-welded lap, T-, or corner joint welded on one side. See Table 1 and Clause 8, Inspection, for inspection requirements.

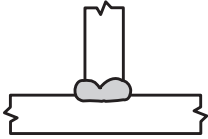
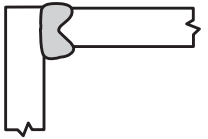
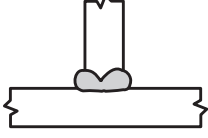
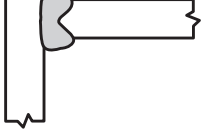
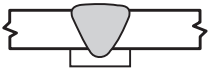
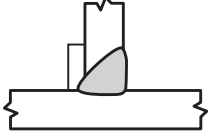
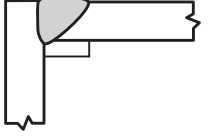
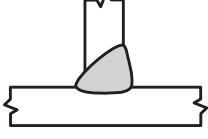
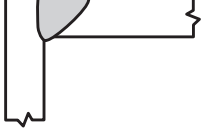
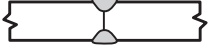
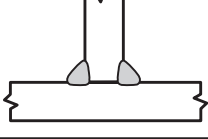
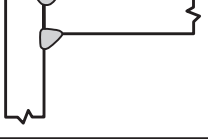
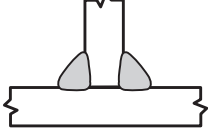
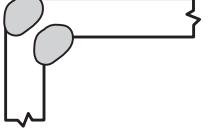
2.1.6 Joint Class VI. This class consists of butt, T-, corner, lap, or edge joints, made without special joint preparation, welded with a fillet, plug, or edge weld; welded joints of secondary importance not subject to dynamic loading; welds of secondary importance in strength. See Table 1 and Clause 8, Inspection, for inspection requirements.

2.1.7 Intermittent Welded Joints. Intermittent partial joint penetration welds in butt, T-, and corner joints and intermittent welded lap joints and plug welds are placed in Joint Class V or VI.

2.1.8 Quality Control Requirements. Table 1 indicates the inspection requirements for weld Joint Classes I through VI. Information furnished to the bidder shall identify the extent of inspection to be performed.

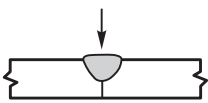
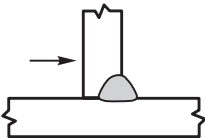
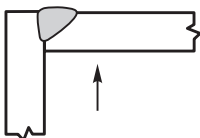
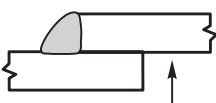
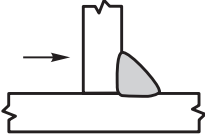
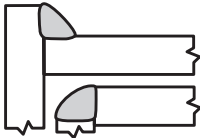
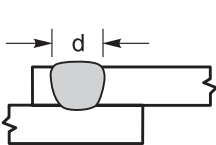
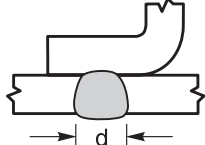
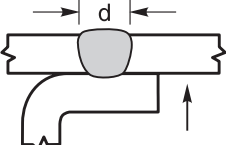
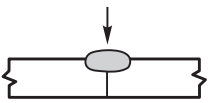
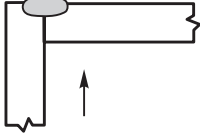
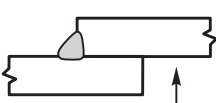
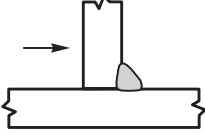
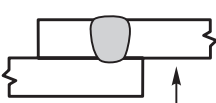
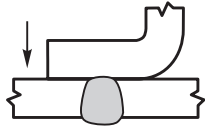
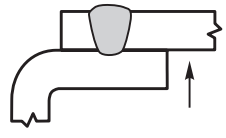
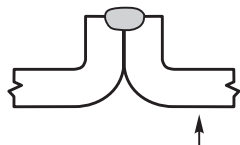
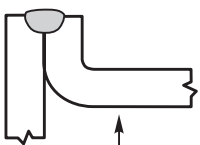
2.2 Classification of Materials

2.2.1 Base Metals. The steels listed in Table 2 are prequalified for welding without further weld qualification. These steels used as base metal in the manufacture of press weldments are divided into five classifications, Material Class I through Material Class V, according to their weldability and minimum preheat and interpass temperature requirements.

JOINT CLASS	CONFIGURATION OF WELDED JOINTS		
I			
II			
III			
			
IV			
			
			

Note: Load applications are not significant within good engineering practices.

Figure 1—Classification of Welded Joints

JOINT CLASS	CONFIGURATION OF WELDED JOINTS		
V			
			
			
			
VI			
			
			

Note: Avoid loading the joint in the arrow direction.

Figure 1 (Continued)—Classification of Welded Joints

Table 1
Weld Quality Control Requirements

Weld Joint Class (see 2.1)	Ultrasonic (8.4) or Radiographic (8.3) Inspection	Magnetic Particle (8.5) or Liquid Penetrant (8.6) Inspection	Visual ^{a,b} Inspection (8.2)	
			Discontinuities Table 13	Dimensions (8.2.7)
I	Yes	Yes	Yes	Yes
II	Yes (10%)	Yes	Yes	Yes
III	—	Yes	Yes	Yes
IV	—	—	Yes	Yes
V	—	—	Yes	Yes
VI	—	—	Yes	Yes

^a 100% inspection is required unless otherwise indicated.

^b Material subject to delayed cracking such as ASTM A 514 and A 517 shall have inspections performed not less than 48 h after the completed weld has cooled down to ambient temperatures.

In addition to the prequalified steels listed in Table 2, steels having a weldability equivalent to the steels listed are to be considered prequalified for welding. Steels having equivalent weldability within a given Material Class are defined as steels which meet all limits for that class as shown in Table 3.

2.2.1.1 Base Metal Limitations. The provisions of this specification are intended for use with steels having a minimum estimated or specified yield strength less than or equal to 110 000 psi [760 MPa]. The steels listed in Table 2 satisfy this requirement.

All groove and fillet weld procedures for weld metal and base metal with a minimum estimated or specified yield strength of 90 000 psi [620 MPa] or higher not listed in Table 2 shall be qualified prior to use by tests provided in 7.3.

2.2.1.2 Material Properties. Table 2 shows either the estimated minimum or the specified tensile and yield strengths for the prequalified steels listed.

Table 3 shows the maximum tensile strength and chemical composition for steels in Material Class I through Material Class V.

For nonprequalified steels, the manufacturer shall establish the minimum tensile and yield strengths for design purposes by reference to published data or from test data. The minimum tensile and yield strengths for design purposes shall be established for a nonprequalified steel with due regard for size effects, thermal or mechanical treatments, and the effect of the welding process on the base material in the heat-affected zone (HAZ).

2.2.2 Other Base Metals. Steels not specifically prequalified in 2.2.1 shall be qualified according to Clause 7, Qualification. When so qualified, these steels may be used in the manufacture or repair of alloy steel fabrications, forgings, and castings.

3. Welding Processes and Consumables

3.1 Processes and Methods

3.1.1 All welding processes and methods recognized by AWS A3.0, *Standard Welding Terms and Definitions*, may be used in the fabrication, construction, and repair of presses and press components. All recognized welding processes and methods used shall conform to Clause 7, Qualification.

3.1.2 Welding processes and methods not recognized by the American Welding Society (AWS) must meet the requirements of, and shall be qualified by, Clause 7, Qualification, if they are to be used in fabrication, construction, and repair of presses and press components.

3.2 Consumables. Consumables include materials such as filler metal, shielding gas, and flux that are used to produce a finished weld joint.

3.2.1 Consumable Qualification. Consumables purchased to the requirements of AWS filler metal specifications need not be tested or qualified for welding. Other consumables shall be considered qualified if the manufacturer's certification states that desired weld metal mechanical properties and chemical compositions are attained.

Table 2
Material Classification of Qualified Steel

Material Class ^a	Steel Specification and Grade			Tensile Strength ksi [MPa]	Yield Strength ksi [MPa]
I	AISI/SAE ^{b, c, d}				
	1005	Sheet, Plate Bar or Casting (Usually Specified by Compression Only—without Mechanical Properties)	Hot Rolled	42 [290]	23.5 [162]
	1006		Hot Rolled	43 [295]	24 [165]
	1008		Hot Rolled	44 [305]	24.5 [170]
	1010		Hot Rolled	47 [325]	26 [180]
	1012		Hot Rolled	48 [330]	26.5 [183]
	1013		Hot Rolled	49 [340]	27 [186]
	1015		Hot Rolled	50 [345]	27.5 [190]
	1016		Hot Rolled	55 [380]	30 [205]
	1017		Hot Rolled	53 [365]	29 [200]
	1018		Hot Rolled	58 [500]	32 [220]
	1020		Hot Rolled	55 [320]	30 [205]
	1021		Hot Rolled	61 [420]	33 [230]
	1025		Hot Rolled	58 [400]	32 [220]
II	ASTM ^e				
	A 27	Grade N-1 Castings Chemistry Only		Not Specified	See 2.2.1.2
		Grade 60-30		60 [415]	30 [205]
		Grade 65-35		65 [450]	35 [240]
	A 36	Shapes, Plate, Bar		58–80 [400–550]	36 [250]
	A 53	Grade B Pipe		60 [415]	35 [240]
	A 106	Grade B Pipe		60 [415]	35 [240]
	A 131	Grade A, B, D, CS, DS Shipbuilding Shapes, Plate, Bars		58–71 [400–490]	34 [235]
	A 139	Grade A Pipe		48 [331]	30 [205]
		Grade B		60 [414]	35 [241]
		Grade C		60 [414]	42 [290]
		Grade D		60 [414]	46 [317]
		Grade E		66 [455]	52 [359]
	A 284	Grade C through 2 in [50 mm] Plate		60 [415]	30 [205]
		Grade D through 2 in [50 mm]		60 [415]	33 [230]
	A 381	Grade Y35 Pipe		60 [414]	35 [240]
	A 500	Grade A Tubing		45 [310]	33 [288]
		Grade B		58 [400]	42 [290]
	A 501	Tubing		58 [400]	36 [250]
	A 515	Grade 55 through 8 in [200 mm] Plate		55–75 [380–515]	30 [205]
	A 516	Grade 55 through 8 in [200 mm] Plate		55–75 [380–515]	30 [205]
	A 524	Grade I through 0.375 in [10 mm] Pipe		60–85 [414–586]	35 [240]
		Grade II Above 0.375 in [10 mm] Wall		55–80 [380–550]	30 [205]
	A 570	Grade 36 Sheet to 0.229 in [6 mm]		53 [380]	36 [250]
	A 573	Grade 58 Plate to 1.5 in [40 mm]		58–71 [400–490]	32 [220]
		Grade 65 Plate to 1.5 in [40 mm]		65–77 [450–530]	35 [240]
	A 662	Grade A Plate to 1.5 in [40 mm]		58–78 [400–540]	40 [275]
		Grade B Plate to 1.5 in [40 mm]		65–85 [400–585]	40 [275]
	A 709	Grade 36 Shapes, Plate, Bar		58–80 [400–550]	36 [250]
	API ^f				
	5L	Grade B Pipe		60 [410]	35 [240]
III	AISI/SAE ^{b, c, d, g}				
	1030	Sheet, Plate, Bar or Casting (Usually Specified by Composition Only—without Mechanical Properties)		68 [470]	37.5 [260]

(Continued)

Table 2 (Continued)
Material Classification of Qualified Steel

Material Class ^a	Steel Specification and Grade			Tensile Strength ksi [MPa]	Yield Strength ksi [MPa]
III (Cont'd)	ASTM ^c				
	A 27	Grade N-2 Castings Heat-Treated		(Not specified)	See 2.2.1.2
		Grade 70-36		70 [485]	36 [250]
		Grade 70-40		70 [485]	40 [275]
	A 106	Grade C Pipe		70 [485]	40 [275]
	A 131	Grades AH32, DH32, EH32,	Shipbuilding Shapes, Plate, Bars	68–85 [470–585]	46 [315]
		AH36, DH36, EH36		71–90 [490–620]	51[360]
	A 284	Grade C 2 in–4 in [100 mm–200 mm] Plate		60 [415]	30 [205]
		Grade D 2 in–4 in [100 mm–200 mm] Plate		60 [415]	33 [230]
	A 500	Grade C Round Tubing		62 [427]	46 [317]
		Grade C Shaped Tubing		62 [427]	50 [345]
	A 515	Grade 60 through 2 in [50 mm] Plate		60–80 [415–550]	32 [220]
		Grade 65 through 2 in [50 mm] Plate		65–85 [450–585]	35 [240]
	A 516	Grade 60 through 2 in [50 mm] Plate		60–80 [415–550]	32 [220]
		Grade 65 through 2 in [50 mm] Plate		65–85 [450–585]	35 [240]
	A 537	Class 1, through 2.5 in [65 mm] Plate		70–90 [485–620]	50 [345]
	A 572 HSLA Cb-V Steels	Grade 42 to 2 in [50 mm]	Shapes, Plate, Sheet, and Bar	60 [415]	42 [290]
		Grade 50 0.5 in to 5 in [13 mm to 125 mm]		65 [450]	50 [345]
		Grade 50 0.5 in to 2 in [13 mm to 50 mm]		65 [450]	50 [345]
	A 588	Grades A, B, C, and K 4 in [100 mm] and Under	Shapes, Plate, and Bar	70 [485]	50 [345]
	A 606	Type 2 & 4 Sheet to 0.180 in [5 mm] Weathering Steel	As-Rolled Cut Lengths	70 [485]	50 [345]
		All Other Coils & Cut Lengths		65 [450]	45 [310]
	A 607	Type 1 Class 2 Sheet to 0.180 in [5 mm] HSLA Nonweathering	Grade 45	60 [410]	45 [310]
			Grade 50	65 [450]	50 [340]
	A 618	HSLA Structural Tubing	Grade II	70 [485]	50 [345]
		Wall to 3/4 in [19 mm]	Grade II	67 [460]	46 [315]
		Wall to 3/4 in to 1.5 in [19 mm to 38 mm]	Grade III	65 [450]	50 [345]
	A 633 HSLA Normalized Structural	Plate to 4 in [100 mm]	Grade A	63–83 [430–570]	42 [290]
		through 2.5 in [65 mm]	Grades C & D	70–90 [485–620]	50 [345]
		2.5 in–4 in [65 mm–100 mm]	Grades C & D	65–85 [450–590]	46 [315]
	A 662	Grade B PV Plate Mod and Low Temperature Applications		65–85 [450–590]	40 [275]
	A 709	Nonweathering Grade 50	Structural Shapes, Plate, Bars–Bridges	65 [450]	50 [345]
		Weathering Grade 50W		70 [485]	50 [345]
	API ^f				
	5LX	Grade 42 High-Strength Pipe		60 [410]	42 [290]
IV	ASTM ^c				
	A 284	Grade C, 4 in–12 in [100 mm–300 mm] Plate		60 [415]	30 [205]
		Grade D, 4 in–8 in [100 mm–200 mm] Plate		60 [415]	33 [230]
	A 515	Grade 60, Over 2 in [50 mm] Plate		60–80 [415–550]	32 [220]
		Grade 65, Over 2 in [50 mm] Plate		65–85 [450–585]	35 [240]
	A 516	Grade 60, Over 2 in [50 mm] Plate		60–80 [415–550]	32 [220]
		Grade 65, Over 2 in [50 mm] Plate		65–85 [450–585]	35 [240]
	A 537	Class 2, through 2.5 in [65 mm] Plate		80–100 [550–690]	60 [415]
	A 572	Grade 60 to 1.25 in [32 mm]	Shapes, Plate, Sheet, and Bar	75 [520]	60 [415]
Grade 65 to 1.25 in [32 mm]		80 [550]		65 [450]	

(Continued)

Table 2 (Continued)
Material Classification of Qualified Steel

Material Class ^a	Steel Specification and Grade			Tensile Strength ksi [MPa]	Yield Strength ksi [MPa]
IV (Cont'd)	A 607 HSLA Nonweathering	Grade 60	Type 1 Class 2 Sheet to 0.180 in [5 mm]	75 [520]	60 [410]
		Grade 65		80 [550]	65 [450]
	A633 HSLA	Grade E, through 4 in [100 mm]	Normalized Structural Plate	80–100 [550–690]	60 [415]
		Grade E, 4 in to –6 in [100 mm to –150 mm]		80–100 [550–690]	55 [380]
V	ASTM ^c				
	A 514 HSLA	to 2.5 in [65 mm]	Q & T Plate	110–130 [760–895]	100 [690]
		>2.5 in to 6 in [65 mm–150 mm]		100–130 [690–895]	90 [620]
	A 517 HSLA	to 2.5 in [65 mm]		110–130 [760–895]	100 [690]
		>2.5 in to –6 in [65 mm–150 mm]		100–130 [690–895]	90 [620]
	A 709 HSLA	to 2.5 in [65 mm]	Q & T Plate Grades 100 & 100 W	110–130 [760–895]	100 [690]
		2.5 in–4 in [65 mm–150 mm]		100–130 [690–895]	90 [620]

^a Materials Class I steels are the most weldable, and Material Class V steel the most difficult to weld of the steels listed.

^b All tensile and yield strength values for AISI/SAE steels are *estimated minimum values*.

^c Hardness is not to exceed 160 Brinell for the AISI/SAE steels listed under Material Class I. These same AISI/SAE steels should be placed in a higher Weldability Class (see Table 3) when hardness exceeds 160 Brinell (ultimate strength greater than 80 000 psi).

^d See 2.2.1.2 for tensile-yield property determination for AISI/SAE steels.

^e All Tensile and yield strength values listed for ASTM steels are specified by the ASTM standard.

^f API = American Petroleum Institute.

^g Hardness is not to exceed 180 Brinell for the AISI/SAE steel listed under Material Class III. This same AISI/SAE steel should be placed in a higher Material Class (see Table 3) when hardness exceeds 180 Brinell (ultimate strength greater than 90 000 psi [630 MPa]).

Table 3
Allowed Chemical Composition Limits for Steels Prequalified for Welding

Material Class	Material Class I	Material Class II	Material Class III	Material Class IV	Material Class V
Maximum Ultimate Tensile Strength, ksi [MPa]	80 [550]	85 [585]	90 [620]	100 [690]	135 [930]
Carbon equivalent ^a , <u>max.</u>	0.38	0.48	0.63	0.54	0.74
Carbon %, <u>max.</u>	0.23	0.30	0.24	0.26	0.22
Manganese %, <u>max.</u>	0.90	1.35	1.35	1.65	1.50
Phosphorus %, <u>max.</u>	0.04	0.04	0.04	0.035	0.035
Sulfur %, <u>max.</u>	0.05	0.05	0.05	0.05	0.05
Silicon %, <u>max.</u>	0.60	0.60	0.90	0.30	0.90
Nickel %, <u>max.</u>	Note b	Note b	1.25	0.25 ^b	1.50
Chromium %, <u>max.</u>			1.00	0.20 ^b	2.00
Molybdenum %, <u>max.</u>			0.25	0.06 ^b	0.65
Vanadium % ^c , <u>max.</u>			0.10 ^d	0.15	0.08
Titanium %, <u>max.</u>			0.07	0.07	0.10
Zirconium %, <u>max.</u>			0.15	0.15	0.15
Niobium % (Columbium %), <u>max.</u>			0.04 ^d	Note b	Note b
Copper %, <u>max.</u>			1.00	0.35 ^b	0.50
Boron %, <u>max.</u>				0.0005 ^b	0.006

^a Carbon equivalent = $C + Mn/6 + Mo/4 + Cr/5 + Ni/15 + V/5$.

^b Residual quantities only, maximum values are Ni = 0.25, Cr = 0.20, Cu = 0.35, Mo = 0.06, B = 0.0005; Cb is not specified.

^c **Caution:** The filler metal or the base metal should not exceed 0.05% vanadium if the welds are to be thermally stress relieved because of the decrease in fracture toughness.

^d Maximum for niobium (columbium) + vanadium = 0.10.

3.2.2 Mechanical Property Determination. The mechanical properties of as-deposited weld metal specified in the appropriate standards shall be obtained from all-weld-metal tension specimens. (Refer to AWS B4.0 or B4.0M, *Standard Methods for Mechanical Testing of Welds*.)

3.2.3 Practices in Consumable Use. The practices recommended by the consumable manufacturer shall be followed.

3.2.3.1 Filler Metal. Electrodes having low-hydrogen coatings conforming to AWS A5.1/A5.1M, *Specification for Carbon Steel Electrodes for Shielded Metal Arc Welding*, or AWS A5.5/A5.5M, *Specification for Low-Alloy Steel Electrodes for Shielded Metal Arc Welding*, shall be supplied in hermetically sealed containers. If not provided in hermetically sealed containers, consumables shall be dried in accordance with Annex A or manufacturer's recommendations.

3.2.3.2 Fluxes. Fluxes used for submerged arc welding (SAW) shall be dry and free of contamination from dirt, mill scale, or other foreign material.

All flux shall be supplied in packages capable of being stored under normal conditions for at least six months without such storage affecting its welding characteristics or weld properties.

3.2.3.3 Recrushed Slag. Flux containing recrushed slag may be used, provided it has its own marking, using the supplier's name and trade designation. In addition, each dry batch or dry blend (lot) of flux containing recrushed slag, as defined in AWS A5.01, *Filler Metal Procurement Guidelines*, shall be tested in accordance with Schedule I of AWS A5.01 and classified by the supplier per AWS A5.17/A5.17M, *Specification for Carbon Steel Electrodes and Fluxes for Submerged Arc Welding*, or A5.23/A5.23M, *Specification for Low Alloy Steel Electrodes and Fluxes for Submerged Arc Welding*, as applicable.

3.2.3.4 Gases. A gas or gas mixture used for shielding shall conform to the requirements of AWS A5.32/A5.23M, *Specification for Welding Shielding Gases*. When requested, the gas manufacturer shall furnish certification that the gas or gas mixture is suitable for the intended application and will meet the dew point requirement.

3.3 Practices in Consumable Storage. Consumables shall be protected and stored so that their characteristics or welding properties are not adversely affected. Consumable manufacturer's specific recommendations shall be applied. Annex A contains general practices for storage and the use of SMAW, FCAW, GMAW, and SAW

consumables employed for application within the scope of this specification.

3.3.1 Filler Metal. Electrodes and hermetically sealed containers of low-hydrogen electrodes shall be properly labeled and identified and shall be stored in a dry, organized storeroom. Opened containers of low-hydrogen electrodes shall be stored in ovens according to Annex A.

3.3.2 Fluxes. Fluxes shall be stored in a dry storeroom, well protected from weather effects, preferably in their original containers. The proper identification and labeling shall be maintained. Fluxes shall be dried, if required, before use, according to Annex A. All fluxes that have become fused, oily, or dirty shall be discarded.

3.3.3 Gases. The storage and labeling of welding gas containers shall follow the recommendations of the gas supplier and comply with local and federal codes.

4. Weld Joint Design

4.1 Introduction. This clause describes various weld joints used to fabricate presses and press components. Weld joints shall be designed for the intended service using the geometries listed in this clause. Other geometries shall be qualified per Clause 7, Qualification. Complete information regarding location, type, size, and extent of all welds and welded joints shall be shown on the drawings.

4.2 Weld Joint Nomenclature. Weld joint nomenclature shall be in conformance with the latest edition of AWS A3.0, *Standard Welding Terms and Definitions*.

4.3 Weld Joint Qualification

4.3.1 Joints that conform to the details shown in the figures of Annex B, and which are welded in conformance to the requirements of Clause 7, Qualification, Method A, are designated as prequalified. They may be used without performing a welding procedure qualification as prescribed in Clause 7, Qualification, Method B or C.

4.3.2 Joint details that depart from those prescribed in the figures of Annex B, or which are not welded in conformance to the requirements of Clause 7, Qualification, Method A, shall be qualified in conformance to Clause 7, Qualification, Method B or C.

4.3.3 Dimensions of groove welds specified on design or detail drawings may deviate from the dimensions shown in the figures of Annex B only within the following limits:

4.3.3.1 The specified thickness of base metal is the maximum nominal thickness that may be used.

4.3.3.2 The root face of the joints shall be as dimensioned in the figures of Annex B. The root face may be detailed to exceed this dimension or the specified dimension by not more than 1/16 in [2 mm] except for SAW, in which case the root face as shown is maximum. The root face may not be detailed less than the specified dimension for any other process.

4.3.3.3 The root opening of the joint is the minimum. It may be detailed to exceed the dimension shown by not more than 1/16 in [2 mm] except for SAW, in which case the root opening of closed joints shall be detailed as zero (no deviation). The root opening of open joints with backing is minimum. It may be detailed to exceed the dimension shown by not more than 1/16 in [2 mm].

4.3.3.4 The groove angle is the minimum. It may be detailed to exceed the dimension shown by not more than 10°.

4.3.3.5 The radius of J-grooves and U-grooves is the minimum. It may be detailed to exceed the dimension shown by not more than 1/8 in [3 mm]. U-grooves may be prepared prior to or after fitting.

4.3.3.6 Double-groove welds may have grooves of unequal depth, but the depth of the smaller groove shall not be less than one-fourth of the thickness of the thinner part joined for complete penetration welds or as noted in Table 4.

4.4 Groove Welds

4.4.1 The effective area is the effective weld length multiplied by the weld size.

4.4.2 The effective weld length for any groove weld, square or skewed, is the width of the part joined, perpendicular to the direction of stress.

4.4.3 The effective weld size of a complete joint penetration groove weld is the thickness of the thinner piece of base metal joined. No increase is permitted for weld reinforcement or overlaying fillet.

4.4.4 The effective weld size of a partial joint penetration bevel-groove weld with less than a 60° included angle, where back chipping or gouging is not done, is determined by subtracting 1/8 in [3 mm] from the groove depth.

4.4.5 Root openings should be limited to the dimensions noted in the sketches of prequalified joint details shown in the figures of Annex B.

4.4.6 The effective throat of a partial joint penetration groove weld is the joint penetration obtained by sectioning a weld, or as noted in 4.4.4.

4.4.7 A complete joint penetration groove weld is defined as one that has been made from both sides, or from one side, having complete joint penetration and fusion of weld and base metals through the thickness of the joint.

4.4.8 Complete joint penetration groove welds made without use of a backing strip shall have the root gouged to sound metal before welding is started from the second side.

4.4.9 Groove welds without backing strips, welded from one side, and groove welds welded from both sides, but without backgouging, are considered partial joint

Table 4
Minimum Weld Size for Fillet and Partial Joint Penetration Groove Welds

Base-Metal Thickness of Thicker Part Joined		Minimum Weld Size ^a	
in	mm	in	mm
1/8 to ≤3/16	3 to ≤5	1/16 ^{b,c}	2
>3/16 to ≤1/4	>5 to ≤6	1/8 ^b	3
>1/4 to ≤1/2	>6 to ≤13	3/16	5
>1/2 to ≤3/4	>13 to ≤20	1/4	6
>3/4 to ≤1-1/2	>20 to ≤40	5/16	8
>1-1/2 to ≤2-1/4	>40 to ≤55	3/8	10
>2-1/4 to ≤6	>55 to ≤150	1/2	13
>6	>150	5/8	16

^a Except the weld size need not exceed the thickness of the thinner part.

^b Minimum size for dynamically loaded components is 3/16 in [5 mm].

^c Applicable to PJP groove welds only.

penetration groove welds unless qualification testing proves complete fusion of base metal and filler metal throughout the thickness of the joint.

4.4.10 A partial joint penetration groove weld is defined as one welded from one or both sides and having joint penetration that is less than complete.

4.4.11 For a combined partial joint penetration groove weld and fillet weld, the effective weld area is the effective weld length multiplied by the effective throat. The effective throat is the shortest distance from the joint root to the weld face of the diagrammatic weld. When the groove angle, α , is less than 60° , refer to the figures of Annex B to determine when to reduce the groove weld size, E, and therefore the effective throat of the combined joint, by 1/8 in [3 mm].

4.4.12 Double-groove welds may have grooves of unequal depth, provided that the weld deposit on each side of the joint conforms to the limitations of Table 4.

4.4.13 The minimum weld size of partial joint penetration square-, bevel-, and V-groove welds shall be as shown in Table 4.

4.5 Fillet Welds

4.5.1 No allowance for penetration into the plate surfaces at the root of a fillet weld is made when computing the effective throat except as follows: Only when sectioned test pieces show that the welding procedure gives penetration 3/32 in [2.5 mm] beyond the root of the joint may the effective throat be considered to extend from the joint root to the face of the weld (see Figure 2).

4.5.2 The effective area of fillet welds is the effective weld length multiplied by the effective throat. Stress in a fillet weld shall be considered as applied to this effective area for any direction of applied load.

4.5.2.1 The effective length of a fillet weld is the overall length of the full size fillet including end returns.

4.5.2.2 The effective length of a curved fillet weld is the length of the line generated by the center point of the effective throat. For a fillet weld in a hole or slot, if the weld area computed from this length is greater than the area found in 4.6 below, then this latter area shall be used as the effective area of the fillet weld.

4.5.2.3 The effective throat is the minimum distance from the fillet weld face, minus any convexity, and the weld root.

4.5.3 The details of fillet welds made by shielded metal arc welding (SMAW), submerged arc welding (SAW), gas metal arc welding (GMAW), or flux cored arc welding (FCAW) which may be used without joint welding procedure qualification are shown in Figure 2.

4.5.4 Minimum required fillet weld sizes are shown in Table 4.

4.5.5 The maximum size fillet weld that may be used along edges of material shall be as follows:

4.5.5.1 Along edges of material less than 1/4 in [6 mm] thick, the maximum size may be equal to the thickness of the material.

4.5.5.2 Along edges of material 1/4 in [6 mm] or more in thickness, the maximum size shall be 1/16 in [2 mm] less than the thickness of the material, unless the drawings specify that the weld is to be built out to obtain full throat thickness as illustrated in Figure 2(A) or 2(B).

4.5.6 The minimum effective length of a fillet weld shall be 1-1/2 in [40 mm].

4.5.7 Fillet welds which support a tensile force that is not parallel to the axis of the weld, or are proportioned to withstand repeated stress, shall not terminate at corners of parts or members; such welds shall be returned continuously, full size around the corner for a length equal to twice the weld size, where such return can be made in the same plane. End returns shall be indicated on design and detail drawings.

4.5.8 Fillet welds in holes or slots may be used to transmit shear in lap joints or to prevent the buckling or separation of lapped parts. Fillet welds in a hole or slot may overlap. Fillet welds in holes or wide slots are not to be considered as plug or slot welds (see 4.6).

4.5.9 Seal welding shall be accomplished by a continuous weld combining the functions of sealing and strength, changing section only as the required strength or the requirements of 4.5.4 may necessitate.

4.5.10 Fillet welds may be used in skew joints that have an acute angle of not less than 60° . Permitted forms of such joints are detailed in Figure 2(C) and 2(D).

4.5.11 For intermittent fillet welds, the following requirements shall be met:

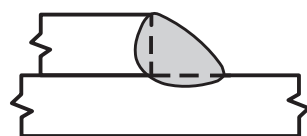
4.5.11.1 Minimum effective length of each weld shall be 1-1/2 in [40 mm].

4.5.11.2 At least 25% of the joint shall be welded.

4.5.11.3 Maximum clear spacing, end-to-end, of welds shall be 12 times the thickness of the thinner part, but not more than 6 in [150 mm].

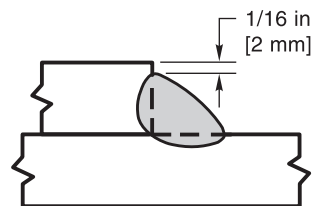
4.5.11.4 If intermittent fillet welds are used, there shall be welds located at each end of the joint.

4.5.11.5 Intermittent fillet welds may be used to carry loads, provided the requirements of Clause 5, Design Stresses, and Annex C are satisfied. When calculating



BASE METAL LESS THAN
1/4 in [6 mm] THICK

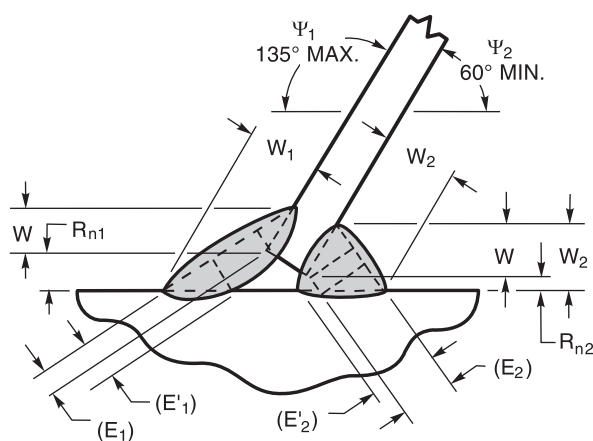
(A)



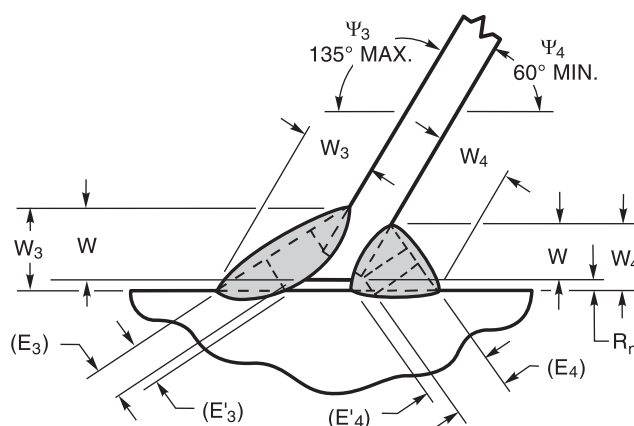
BASE METAL 1/4 in [6 mm]
OR MORE IN THICKNESS

(B)

MAXIMUM DETAILED SIZE OF FILLET WELD ALONG EDGES



(C)



(D)

SKEWED T-JOINTS

Notes:

1. E_n & E'_n = effective throats dependent on magnitude of gap (R_n). Subscript (n) represents 1, 2, 3, or 4.
2. The parts to be joined by fillet welds shall be brought into as close contact as practicable. The gap between parts shall not exceed 3/16 in [5 mm] except in cases involving shapes or plates 3 in [75 mm] or greater in thickness if, after straightening and in assembly, the gap cannot be closed sufficiently to meet this tolerance. In such cases, a maximum gap of 5/16 [8 mm] is acceptable provided a sealing weld or suitable backing material is used to prevent melting through. If the separation is 1/16 in [2 mm] or greater, the leg of the fillet weld shall be increased by the amount of the separation or the contractor shall demonstrate that the required effective throat has been obtained.
3. The separation between faying surfaces of lap and of butt weld joints landing on a backing shall not exceed 1/16 in [2 mm]. The use of fillers is prohibited except as specified on the drawings or as approved by the Engineer.
4. Angles smaller than 60° are permitted; however, in such cases the weld is considered to be a partial penetration groove weld.

Figure 2—Details of Fillet Welds

the load carrying capabilities of intermittent loads, the stress shall be considered as shear stress in the effective area, for any direction of applied load. The effective area shall be the effective weld length, multiplied by the effective throat.

4.6 Plug and Slot Welds

4.6.1 Plug and slot welds may be used to carry loads, provided the requirements of Clause 5, Design Stresses, are satisfied.

4.6.2 The effective area shall be the nominal area of the hole or slot in the plane of the faying surface. These welds shall be computed to resist only shear stresses in the effective area.

4.6.3 The thickness of the weld in a plug or slot weld in material 5/8 in [16 mm] thick or less shall be equal to the thickness of the material. The thickness of the weld in a plug or slot weld in material over 5/8 in [16 mm] thick shall be at least one-half the thickness of the material but not less than 5/8 in [16 mm].

4.6.4 The diameter of the hole for a plug weld should be not less than the thickness of the part containing it, plus 5/16 in [8 mm], preferably rounded to the next greater 1/16 in [2 mm], nor shall it be greater than 2-1/4 times the thickness of the weld.

4.6.5 The minimum center-to-center spacing of plug welds shall be four times the diameter of the hole.

4.6.6 The length of a slot for a slot weld shall not exceed ten times the thickness of the weld. The width of the slot shall be not less than the thickness of the part containing it, plus 5/16 in [8 mm], preferably rounded to the next greater 1/16 in [2 mm], nor shall it be greater than 2-1/4 times the thickness of the weld.

4.6.7 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 that extend to the edge of the part.

4.6.8 The minimum spacing of lines of slot welds in a direction transverse to their length shall be 4 times the width of the slot. The minimum center-to-center spacing in a longitudinal direction on any line shall be 2 times the length of the slot.

5. Design Stresses

5.1 General. A press, as described in Annex F, is a machine subject to cyclic loading that induces fluctuating working stress in every element. The magnitude of the fluctuation between maximum and minimum working stress is the working stress range. This specification

will establish the allowable stress and allowable stress range for steel weldments subject to static and dynamic loading. This specification will not assign nor instruct how to compute values for the factors in 5.1.2 that influence working stress; nor will the press designer or manufacturer be told how to select component loads, calculate stress in weld and base metal, or select a factor of safety.

5.1.1 Stress range is the algebraic difference between the maximum stress and the minimum stress. Tension stress is considered to have the opposite algebraic sign from compression stress.

5.1.2 The magnitude of the working stress and working stress range in an operating press are influenced by factors such as: press tonnage, type of operating mechanism, component size, shock or impact, accidental overloads, corrosion, wear, misalignment, stress concentration, and weld joint design.

5.1.3 Allowable stress and allowable stress range is the maximum working stress and working stress range permitted in an element. A lower stress and stress range may be used at the discretion of the designer.

5.1.4 Working stress and working stress range shall not exceed the allowable stress or allowable stress range in an element.

5.1.5 Calculated stress and calculated stress range is the designer's estimate of working stress and working stress range.

5.1.6 The manufacturer is responsible for selecting an appropriate factor of safety to assure calculated stress and calculated stress range do not exceed the working stress and working stress range.

5.1.7 In lieu of making stress calculations, the design requirements of this clause and Annex C for a press weld joint, weldment, or assembly of weldments may be satisfied by prototype testing. The prototype testing shall comply with the performance criteria of 7.2.3 and demonstrate that all design requirements are met. The tests and test results shall be documented and recorded.

5.2 Fatigue. Fatigue is the process of progressive localized damage that may result in cracks or complete fracture after a sufficient number of significant cycles. A significant cycle is one in which:

(1) The working stress in plain base metal exceeds the working endurance limit stress, or

(2) The working stress range of base metal or weld metal in a weld joint exceeds the allowable stress range for the applicable stress category (see Annex C).

Fatigue life is the number of significant stress fluctuations or cycles sustained before failure.

5.2.1 This specification shows and quantifies in Annex C the allowable stress and allowable stress range values, in the weld metal and base metal, under static or dynamic load conditions for various welded steel joint arrangements.

5.2.2 Fatigue life of a steel weld joint is dependent on the weld joint detail and stress category. The weld joint stress category is a function of joint geometry, type of weld, direction of load application and weld quality. See Annex C, Table C.4 and Figure C.3.

5.2.3 Fatigue life of a welded steel joint is dependent on the working stress range. As the magnitude of the working stress range increases, the fatigue life decreases. See Annex C, Table C.5.

5.2.4 Fatigue life of a welded steel joint is independent of base-metal tensile strength. Therefore, fatigue life of a welded steel joint does not increase with increased material tensile strength (see C5 in Annex C).

6. Workmanship

6.1 General. This clause contains guidelines for workmanship that shall be followed during the fabrication and inspection of presses and press components.

6.2 Preparation of Materials

6.2.1 Surfaces on which the weld metal will be deposited shall be uniform and free from notches, tears, cracks or other visual defects that would adversely affect the quality or strength of the weld or member. For repair of base material, see 9.5. Surfaces to be welded and surfaces within 1/2 in [13 mm] of either side of the weld joint shall be free from moisture, scale, slag, rust, grease, or other foreign material that will reduce the quality of the weld joint.

6.2.2 Preparation of edges by cutting processes shall preferably be done by machine with workmanship in accordance with 6.2.1. All inside corners of cut materials shall be formed to provide gradual transition with a fillet radius not less than 3/4 in [20 mm]. The fillet and its adjacent cuts shall meet without offset or cutting past the point of tangency. Inside corners may be formed by thermal cutting followed by grinding, if necessary, to meet the surface appearance requirements of 6.2.1.

6.2.3 Weld joints may be prepared by machining, grinding, chipping, thermal cutting, oxygen gouging, or carbon arc gouging and in such a manner that the remaining base metal forms the required configuration for the weld joint. Any residual dross, slag or carbon deposits shall be removed and be in compliance with 6.2.1. Oxygen

gouging should not be used on quenched and tempered steels without the approval of the Engineer.

6.3 Assembly

6.3.1 The parts to be joined by fillet welds shall be brought into close contact. The gap between parts shall not exceed:

+1/8 in [3 mm] for materials <3 in [75 mm] thick

+3/16 in [5 mm] for materials ≥3 in [75 mm] thick

Any gap exceeding 1/16 in [2 mm] separation shall have the size of the fillet weld increased by the amount of separation. The separation between faying surfaces of lap joints or between the backing strip and plate of a groove weld shall not exceed 1/16 in [2 mm]. The use of fillers as a permanent part of the weld is prohibited, except as specified on the drawing. Slugging of the weld joint is prohibited in all cases. When the gap between pieces exceeds 1/8 in [3 mm], corrective action shall be taken (such as building up the edges prior to making the final weld).

6.3.2 Dimensions of the cross section of groove welded joints shall not vary from those shown on the detail drawing by more than the workmanship tolerances shown in Table 5. Root openings wider than those permitted by Table 5, but no greater than the thickness of the thinner parts, may be built up by welding to acceptable dimensions, prior to the joining of the parts by welding.

6.4 Preheat. The minimum preheat and interpass temperature shall conform to Table 6 for the welding process used and material class being welded. Other preheat and interpass temperatures approved by the Engineer may be used; however, temperatures lower than those of Table 6 require procedure qualification in conformance to either Method B (see 7.2.2) or Method C (see 7.2.3). The parts to be welded shall be preheated above the minimum temperature for a distance equal to the thickness of the part being welded, but not less than 3 in [75 mm], in all directions from the point of welding. In joints involving dissimilar base metals, preheat shall be specified for the higher material class being welded.

Welding shall not be done when the ambient temperature in the area of the weld joint is below 0°F [−18°C], but a heated structure or shelter around the weldment could maintain the temperatures adjacent to the weldment at 0°F [−18°C] or higher. Welding shall not be done when the base metal temperature is below the preheat, or when surfaces are wet, exposed to rain, snow, or high wind, or when welders are exposed to inclement weather conditions.

Table 5
Cross-Sectional Tolerances for Groove Welds

	Root Not Backgouged	Root Backgouged ^a
Root face of joints	$\frac{+1}{8}$ in [3 mm] $\frac{-1}{16}$ in [2 mm]	Not Limited
Root opening of joints without steel backing	$\frac{+1}{8}$ in [3 mm] $\frac{-1}{16}$ in [2 mm]	$\frac{+1}{8}$ in [3 mm]
Root opening of joints with steel backing	$\frac{+1}{4}$ in [6 mm] $\frac{-1}{16}$ in [2 mm]	Not Applicable
Groove angle of joint	+10° -5°	+10° -5°

^a Backgouging: The forming of a bevel or groove on the other side of a partially welded joint to assure complete penetration upon subsequent welding from that side.

Table 6
Minimum Preheat and Interpass Temperatures^{a, b}

Thickness of Thickest Part at Point of Welding		SMAW with Other than Low-Hydrogen Electrodes		SMAW with Low-Hydrogen Electrodes; SAW, GMAW, or FCAW			SMAW with Low-Hydrogen Electrodes; SAW with Carbon or Alloy Steel Wire, Neutral and Active Flux ^c GMAW or FCAW	SAW with Carbon Steel Wire and Alloy Flux
		Material Class I	Material Class II	Material Class I	Material Class II & Class III	Material Class IV	Material Class V ^e	Material Class V ^e
in	mm	°F [°C]	°F [°C]	°F [°C]	°F [°C]	°F [°C]	°F [°C]	°F [°C]
≤3/4	≤20	None ^d	None ^d	None ^d	None ^d	50 [10]	50 [10]	50 [10]
>3/4 to 1-1/2	>20 to 40	None ^d	150 [65]	None ^d	50 [10]	150 [65]	125 [50]	200 [95]
>1-1/2 to 2-1/2	>40 to 65	100 [40]	225 [105]	None ^d	150 [65]	225 [105]	175 [80]	300 [150]
>2-1/2	>65	200 [95]	300 [150]	150 [65]	225 [105]	300 [150]	225 [105]	400 [205]

^a When the base metal is below the temperature listed for the welding process being used and the thickness of material being welded, it shall be preheated (except as otherwise provided) in such manner that the surfaces of the parts on which weld metal is being deposited are at or above the specified minimum temperature for a distance equal to the thickness of the part being welded, but not less than 3 in [75 mm], both laterally and in advance of the welding. Temperature above the minimum shown may be required for highly restrained welds.

^b In joints involving combinations of base metals, preheat shall be as specified for the higher strength steel being welded.

^c Active flux: flux from which the amount of elements deposited in the weld metal is dependent on the welding conditions, primarily on the arc voltage. Neutral flux: flux that will not cause a significant change in the weld metal composition when there is a large change in the arc voltage.

^d When the base metal is below 32°F [0°C], the base metal shall be preheated to a minimum of 70°F [20°C] and maintained during welding.

^e For quenched and tempered steel, the maximum preheat and interpass temperature should not exceed 400°F [205°C] for thickness up to 1-1/2 in [40 mm] inclusive, nor 450°F [230°C] for greater thickness. When welding quenched and tempered steel, heat input should not exceed the steel producer's recommendation.

6.5 Tack Welds

6.5.1 Tack welds shall be subject to the same quality requirements as the final welds.

6.5.2 Tack welds which are incorporated into the final weld shall be made with electrodes meeting the requirements of the final welds and shall be cleaned thoroughly prior to final welding. Multiple-pass tack welds shall have cascaded ends.

6.5.3 Tack welds which are not to be incorporated into final welds shall be removed prior to final welding.

6.6 Temporary Welds. Temporary welds shall be subject to the same welding procedure as final welds. When they are removed, the surface shall be made flush with the original surface. Where depressions exist, they shall be filled using the same welding procedure.

6.7 Control of Distortion and Shrinkage Stresses

6.7.1 If shrinkage stresses or distortion are likely to affect the structure, the welder shall be provided with instructions that specify the sequence of welding.

6.7.2 Peening may be used on intermediate and final weld layers for control of shrinkage stresses in thick welds to prevent cracking (see 10.3). No peening shall be done on the root pass.

6.7.3 In making welds under conditions of severe external shrinkage restraint, the welding shall be carried continuously to completion or to a point that will ensure freedom from cracking before the joint is allowed to cool below the minimum specified preheat temperature. Where preheat and interpass temperatures are not specified, welding shall continue to a point where freedom from cracking is assured.

6.8 Dimensional Tolerance. The dimensions of welded structural members shall be within the tolerances specified by the Manufacturer.

6.9 Cleaning. Slag, spatter, and arc strikes shall be cleaned from all weld metal and adjacent base metal to facilitate visual inspection.

6.10 Covering of Welds. No weld shall be covered, or made inaccessible, until inspection has been completed.

6.11 Weld Quality Requirements

6.11.1 All weld joints shall meet the quality and inspection requirements of Table 1 and Clause 8, Inspection.

6.11.2 Roughness exceeding 1000 microinches [25 microns] RMS and notches or gouges not more than 3/16 in [5 mm] on otherwise satisfactory surfaces shall be removed by machining or grinding. Larger notches

and gouges may, with the approval of the Engineer, be repaired by welding (see Clause 9, Modification or Repair).

7. Qualification

7.1 Scope. It is the manufacturer's responsibility to assure all qualification requirements are met. All welding procedures, welders, welding operators, and tack welders shall be qualified under one of the following options:

(1) The methods included under Parts B, C, D, and E of this clause;

(2) AWS B2.1, *Specification for Procedure and Performance Qualification*;

(3) AWS D1.1, *Structural Welding Code—Steel*; or

(4) ASME *Boiler and Pressure Vessel Code*, Section IX, *Welding and Brazing Qualifications*.

The Fabricator may choose the qualifying option and shall maintain the qualification test records. The customer should accept evidence of previous AWS or ASME qualification of the welders, welding operators, and tack welders to be employed by the Fabricator.

A Welding Procedure Specification (WPS) shall be prepared, and qualified as required by this specification, to assure that a suitable weld is produced. The following factors shall be specified in the WPS:

(1) Base metal,

(2) Welding process,

(3) Filler metal,

(4) Joint preparation,

(5) Welding variables (including amperage, polarity, voltage, travel speed, number of passes, type of gas or flux, gas flow rate, preheat and interpass temperatures, and position of welding).

Each of the above factors, as established by procedure qualification, shall remain a fixed part of the welding procedure. All procedures used shall be prepared by the Fabricator as written procedure specifications (see Annex E for suggested forms).

Part A Procedure Qualification

7.2 Qualification of Welding Procedures. To qualify a welding procedure, the Fabricator shall choose one of the following qualifying methods and maintain records of all

tests demonstrating that weld quality requirements are met:

- (1) Method A, Prequalification (see 7.2.1);
- (2) Method B, Procedure Qualification (see 7.2.2); or
- (3) Method C, Prototype Testing (see 7.2.3).

7.2.1 Method A—Prequalified Procedures. Groove welds conforming to 4.3, 4.4, and Figures B.1 and B.2 in Annex B, fillet welds conforming to 4.5, and plug welds conforming to 4.6, are designated as prequalified and may be used without performing welding procedure qualification tests provided the applicable requirements of 7.2.1.1 through 7.2.1.3 are met. Standard Welding Procedure Specifications published by the AWS Committee on Welding Qualification in accordance with the latest edition of AWS B2.1, *Specification for Welding Procedure and Performance Qualification*, shall also be accepted as prequalified procedures.

7.2.1.1 One or a combination of the following processes is used:

- (1) Shielded metal arc welding (SMAW),
- (2) Submerged arc welding (SAW),
- (3) Gas metal arc welding (GMAW),
- (4) Flux cored arc welding (FCAW).

7.2.1.2 Base metal, filler metal, and preheat temperatures meet the following requirements:

- (1) Steels are selected from one of the five prequalified material classes listed in 2.2 or conform to the composition and strength limits given in Table 3;
- (2) The preheat and interpass temperatures are no lower than those given in Table 6;
- (3) The steels meet the mechanical and chemical requirements of the engineering specification;
- (4) Filler metals listed in Table 7a or Table 7b are used for complete joint penetration groove welds when the engineering specification requires that the filler metal equal the tensile strength of the base metal; for weld joints not requiring filler metals with a tensile strength equal to the base metal, and for joints other than complete joint penetration groove welds, a lower strength filler metal may be specified.

7.2.1.3 Welding procedures for the SMAW welding process listed in 7.2.1.1 shall meet the following requirements:

- (1) The classification and size of electrode, voltage, polarity, and amperage shall be suited to the thickness of

the material, type of groove, welding positions, and other circumstances attending the work.

(2) The maximum size of electrodes shall be as follows:

- (a) 5/16 in [8 mm] for all welds made in the flat position, except root passes;
- (b) 1/4 in [6 mm] for horizontal fillet welds;
- (c) 1/4 in [6 mm] for root passes of fillet welds made in the flat position and of groove welds made in the flat position with backing and with a root opening of 1/4 in [6 mm] or more;
- (d) 5/32 in [4 mm] for welds made with EXX14 and low-hydrogen electrodes in the vertical and overhead positions; and

(e) 3/16 in [5 mm] for root passes of groove welds and for all other welds not included in the above.

(3) The minimum size of a root pass shall be such as to prevent cracking.

(4) The maximum thickness of layers subsequent to the root pass of fillet welds and of all layers of groove welds shall be as follows:

- (a) 1/4 in [6 mm] for root passes of groove welds;
- (b) 1/8 in [3 mm] for subsequent layers of welds made in the flat position; or
- (c) 3/16 in [5 mm] for subsequent layers of welds made in the vertical, overhead, and horizontal positions.

(5) The maximum size fillet weld that may be made in one pass shall be as follows:

- (a) 3/8 in [10 mm] in the flat position,
- (b) 5/16 in [8 mm] in horizontal or overhead positions, and
- (c) 1/2 in [13 mm] in the vertical position.

(6) When welding in a vertical position, the progressions for all passes shall be upward, except that undercut may be repaired vertically downward when preheat is in conformance to Table 6 but not lower than 70°F [20°C]. However, in tubular structures, the progression of vertical welding may be upward or downward, but only in the direction or directions for which the welder is qualified.

(7) Complete joint penetration groove welds made without the use of steel backing shall have the root gouged to sound metal before welding is started from the second side.

Table 7a
Matching Filler Metal Requirements^{a, b, c}
(U.S. Customary Table)

Base Metal ^d	Welding Process			
	SMAW	SAW	GMAW	FCAW
Class I Class II	E60XX, E70XX E70XX-X (AWS A5.1 or A5.5)	F6XX-EXXX F7XX-EXXX F7XX-EXX-XX (AWS A5.17 or A5.23)	ER70S-X (AWS A5.18) E70C-XX (AWS A5.18 or A5.28)	E6XT-X, E7XT-X, or E7XTX-X (except -2, -3, -10, -13, -14, or -GS) ^e (AWS A5.20 or A5.29)
Class III	E70X ^f E70XX-X ^f (AWS A5.1 or A5.5 ^a)	F7XX-EXXX F7XX-EXX-XX (AWS A5.17 or A5.23)	ER70S-X (AWS A5.18) E70C-XX (AWS A5.18 or A5.28)	E7XT-X, E7XT-X, or E7XTX-X (except -2, -3, -10, -13, -14, or -GS) ^e (AWS A5.20 or A5.29)
Class IV UTS >70 ksi [>485 MPa]	E80XX-X ^f (AWS A5.5)	F8XX-EXX-XX (AWS A5.23)	ER80S-X E80C-XX (AWS A5.28)	E8XTX-X (AWS A5.29)
UTS ≤70 ksi [≤485 MPa]	E70XX-X ^f E70XX ^f (AWS A5.1 or A5.5)	F7XX-EXX F7XX-EXX-X (AWS A5.17 or A5.23)	ER70S-X E70C-XX (AWS A5.18)	E7XT-X or E7XTX-X (except -2, -3, -10, -13, -14 or -GS) ^e (AWS A5.20)
Class V Thickness <2.5 in [<65 mm]	E110XX-X ^f E11018M (AWS A5.5)	F11XX-EXX-XX (AWS A5.23)	ER110S-X (AWS A5.28)	E11XTX-X (AWS A5.29)
≤2.5 in [≤ 65 mm]	E100XX-X ^f E10018M (AWS A5.5)	F10XX-EXX-XX (AWS A5.23)	ER100S-X (AWS A5.28)	E10XTX-X (AWS A5.29)

^a The use of the same type of filler metal having the next higher strength classification as listed in AWS filler metal specifications is permitted. A filler metal of a lower strength may be used where the Engineer has stipulated less than 100% joint efficiency.

^b Filler metals of alloy groups B3, B3L, B4L, B5, B6, B6L, B7, B7L, B8, B8L, or B9, in AWS A5.5, A5.23, A5.28, or A5.29, are not prequalified for use in the as-welded condition.

^c When welds are to be thermally stress-relieved, the deposited weld metal shall not exceed 0.05% vanadium.

^d In joints involving base metals of different yield points or strengths, filler metals applicable to the lower strength metal may be used.

^e If E7XT-2 filler metals are qualified by prototype testing (see 7.2.3), this qualifies the use of these filler metals for production.

^f Low-hydrogen classifications only (i.e., EXX15, EXX16, EXX18, EXX28, EXX48).

7.2.1.4 Welding procedures for the SAW welding process with a single electrode shall meet the following requirements:

(1) All submerged arc welds, except fillet welds, shall be made in the flat position. Fillet welds may be made in either the flat or horizontal position except that single-pass fillet welds made in the horizontal position shall not exceed 5/16 in [8 mm].

(2) The thickness of weld layers, except root and surface layers, shall not exceed 1/4 in [6 mm]. When the

root opening is 1/2 in [13 mm] or greater, a multiple-pass split-layer technique shall be used when the width of the layer exceeds 5/8 in [16 mm]. The thickness of weld layers may exceed these limitations, provided the manufacturer can demonstrate, by nondestructive examination or macroetch examination of sample welds, that sound welds are produced.

(3) The welding current, arc voltage, and speed of travel shall be such that each pass will have complete fusion with the adjacent base metal and weld metal and there will be no overlap or unacceptable undercutting.

Table 7b
Matching Filler Metal Requirements^{a, b, c}
(SI Units Table)

Base Metal ^d	Welding Process			
	SMAW	SAW	GMAW	FCAW
Class I Class II	E43XX, E49XX E49XX-X (AWS A5.1M or A5.5M)	F43XX-EXXX F49XX-EXXX F49XX-EXX-XX (AWS A5.17M or A5.23M)	ER49S-X (AWS A5.18M) E49C-XX (AWS A5.18M or A5.28M)	E43XT-X, E49XT-X, or E49XTX-X (except -2, -3, -10, -13, -14, or -GS) ^e (AWS A5.20M or A5.29M)
Class III	E49Xf E49XX-X ^f (AWS A5.1M or A5.5Ma)	F49XX-EXXX F49XX-EXX-XX (AWS A5.17M or A5.23M)	ER49S-X (AWS A5.18M) E49C-XX (AWS A5.18M or A5.28M)	E49XT-X, E49XT-X, or E49XTX-X (except -2, -3, -10, -13, -14, or -GS) ^e (AWS A5.20M or A5.29M)
Class IV UTS >70 ksi [>485 MPa]	E55XX-X ^f (AWS A5.5M)	F55XX-EXX-XX (AWS A5.23M)	ER55S-X E55C-XX (AWS A5.28M)	E55XTX-X (AWS A5.29M)
UTS ≤70 ksi [≤485 MPa]	E49XX-X ^f E49XX ^f (AWS A5.1M or A5.5M)	F49XX-EXX F49XX-EXX-X (AWS A5.17M or A5.23M)	ER49S-X E49C-XX (AWS A5.18M)	E49XT-X or E49XTX-X (except -2, -3, -10, -13, -14 or -GS) ^e (AWS A5.20M)
Class V Thickness <2.5 in [<65 mm]	E76XX-X ^f E7618M (AWS A5.5M)	F76XX-EXX-XX (AWS A5.23M)	ER76S-X (AWS A5.28M)	E76XTX-X (AWS A5.29M)
≤2.5 in [≤ 65 mm]	E69XX-X ^f E6918M (AWS A5.5M)	F69XX-EXX-XX (AWS A5.23M)	ER69S-X (AWS A5.28M)	E69XTX-X (AWS A5.29M)

^a The use of the same type of filler metal having the next higher strength classification as listed in AWS filler metal specifications is permitted. A filler metal of a lower strength may be used where the Engineer has stipulated less than 100% joint efficiency.

^b Filler metals of alloy groups B3, B3L, B4L, B5, B6, B6L, B7, B7L, B8, B8L, or B9, in AWS A5.5M, A5.23M, A5.28M, or A5.29M, are not prequalified for use in the as-welded condition.

^c When welds are to be thermally stress-relieved, the deposited weld metal shall not exceed 0.05% vanadium.

^d In joints involving base metals of different yield points or strengths, filler metals applicable to the lower strength metal may be used.

^e If E49XT-2 filler metals are qualified by prototype testing (see 7.2.3), this qualifies the use of these filler metals for production.

^f Low-hydrogen classifications only (i.e., EXX15, EXX16, EXX18, EXX28, EXX48).

7.2.1.5 Welding procedures for the GMAW and FCAW welding processes shall meet the following requirements:

(1) Essential requirements for prequalified procedures are as follows:

(a) GMAW spray, globular, or pulsed arc transfer modes with an average arc energy greater than the transition current for short circuit transfer are prequalified. Low-energy modes of metal transfer, including short circuit transfer and pulsed arc transfer modes with an aver-

age arc energy less than the transition current for short circuit transfer, are not prequalified.

(b) The maximum electrode diameter shall be 5/32 in [4 mm] for the flat and horizontal position, 3/32 in [2.4 mm] for the vertical position, and 5/64 in [2 mm] for the overhead position.

(c) The maximum size of a fillet weld made in one pass shall be 1/2 in [13 mm] for the flat and vertical positions; 3/8 in [10 mm] for the horizontal position and 5/16 in [8 mm] for the overhead position.

(2) The thickness of weld layers, except root and surface layers, shall not exceed 1/4 in [6 mm]. When the root opening of a groove weld is 1/2 in [13 mm] or greater, a multiple-pass, split-layer technique shall be used. The split-layer technique shall also be used in making all multiple-pass welds when the width of the layer exceeds 5/8 in [16 mm].

(3) The welding current, arc voltage, gas flow, mode of metal transfer, and speed of travel shall be such that each pass has complete fusion with adjacent base metal and weld metal, and there is no excessive overlap, porosity, or undercutting.

(4) Complete joint penetration groove welds made without the use of backing shall have the root of the initial weld gouged, chipped, or otherwise removed to expose sound metal before welding is started from the second side.

(5) Gas metal arc or flux cored arc welding with external gas shielding shall not be done in turbulent air unless the weld is protected by a shelter. This shelter shall be of material and shape appropriate to reduce wind velocity to a maximum of 5 miles/h [8 km/h] in the vicinity of the weld.

(6) Roots of groove or fillet welds may be backed to prevent melting through by the use of copper, flux, glass tape, iron powder, or similar materials, or be sealed by means of root passes deposited by low-hydrogen electrodes or processes using low-hydrogen practices.

7.2.2 Method B—Procedure Qualification. If the welding procedure specification (WPS) does not meet all the prequalification requirements of 7.2.1, the procedure shall be qualified according to 7.3 through 7.11 or Method C, Prototype Testing (7.2.3), except for the electroslag and electrogas processes. Any procedure involving electroslag or electrogas welding shall be qualified in conformance to 7.3 through 7.11 of this specification. See Annex E for suggested forms.

The conditions used in production may vary from the qualified procedure. Variation which exceeds the allowable limits described in 7.2.2.1 through 7.2.2.5 for the following processes shall require requalification.

7.2.2.1 Shielded Metal Arc Welding (SMAW). A change in any of the following variables requires requalification of the WPS:

(1) A change to increase filler metal strength level; e.g., a change from E70XX-X to E80XX-X [48XX-X to 55XX-X], but not vice versa.

(2) A change from a low-hydrogen type electrode to a nonlow-hydrogen type of electrode, but not vice versa.

(3) An increase in the electrode diameter by more than 1/32 in [1 mm] over that used in the procedure qualification.

(4) A change of electrode amperage and voltage values that is not within the ranges recommended by the electrode manufacturer. When welding quenched and tempered steel, any change within the limitation of variables shall not increase the heat input beyond the steel producer's recommendations.

(5) For a specified groove, a change of more than $\pm 25\%$ in the specified number of passes. (If the area of the groove is increased, it is also permissible to increase the number of passes in proportion to the increased area.)

(6) A change in position in which welding is done as defined in 7.5.

(7) A change in the type of groove; e.g., a change from a V- to a U-groove.

(8) A change from the dimensions of the joint qualified involving:

(a) A decrease in the included angle of the groove;

(b) A decrease in the root opening of the groove;

(c) An increase in the root face (excluding length) of the groove; or

(d) The omission, but not the inclusion, of backing material.

(9) A decrease of more than 25°F [15°C] in the minimum specified preheat temperature.

(10) In the case of vertical welding, a change from the progression specified for any pass from upward to downward, or vice versa.

(11) A change in type of current (ac or dc) or polarity.

(12) The omission, but not inclusion, of backgouging.

(13) The addition or deletion of postweld heat treatment.

7.2.2.2 Submerged Arc Welding (SAW). A change in any of the following variables requires requalification of the WPS:

(1) A change in electrode and flux combination not covered by AWS A5.17/A5.17M, *Specification for Carbon Steel Electrodes and Fluxes for Submerged Arc Welding*, and AWS A5.23/A5.23M, *Specification for Low Alloy Steel Electrodes and Fluxes for Submerged Arc Welding*.

(2) A change to increase the specified minimum strength level of the filler metal.

(3) A change in electrode diameter when using an active flux.⁴

(4) A change in the number of electrodes used; e.g., a single electrode to multiple electrodes, or vice versa.

(5) A change in the type of current (ac or dc) or polarity.

(6) A change of more than 10% above or below the specified mean amperage for each size electrode used.

(7) A change of more than 7% above or below the specified mean arc voltage for each size electrode used.

(8) A change of more than 15% above or below the specified mean travel speed.

(9) A change of more than $\pm 10\%$ or 1/8 in [3 mm], whichever is greater, in the longitudinal spacing of the arcs.

(10) A change of more than $\pm 10\%$ or 1/16 in [2 mm], whichever is greater, in the lateral spacing of the arcs.

(11) A change of more than $\pm 10^\circ$ in the angular position of any parallel electrode.

(12) A change in the angle of electrodes in machine or automatic welding of more than:

- (a) $\pm 3^\circ$ in the direction of travel, or
- (b) $\pm 5^\circ$ normal to the direction of travel.

(13) For a specified groove, a change of more than $\pm 25\%$ in the specified number of passes. If the area of the groove is changed, it is also permissible to change the number of passes in proportion to the area.

(14) A change in position in which welding is done as defined in 7.5.

(15) A change in the type of groove; e.g., a change from a V- to a U-groove.

(16) A change from the dimensions of the joint qualified involving:

- (a) A decrease in the included angle of the groove;
- (b) A decrease in the root opening of a groove;
- (c) An increase in the root face (excluding length) of a groove; or
- (d) The omission, but not the inclusion, of backing material.

⁴ An active flux is a flux from which the amount of elements deposited in the weld metal is dependent on the welding conditions, primarily on the arc voltage.

(17) A decrease of more than 25°F [15°C] in the minimum specified preheat temperature.

(18) An increase in the diameter of the electrode used, greater than that called for in the procedure specification.

(19) The omission, but not inclusion, of backgouging.

(20) The addition or deletion of postweld heat treatment.

7.2.2.3 Gas Metal Arc Welding (GMAW). A change in any of the following variables requires requalification of the WPS:

(1) A change in electrode type and method of shielding not covered by AWS A5.18/A5.18M, *Specification for Carbon Steel Filler Metals for Gas Shielded Arc Welding*, and AWS A5.28/A5.28M, *Specification for Low-Alloy Steel Filler Metals for Gas Shielded Arc Welding*.

(2) A change to increase the specified minimum strength level of the filler metal.

(3) A change in electrode diameter.

(4) A change in the number of electrodes used; e.g., a single electrode to multiple electrodes, or vice versa.

(5) A change from a single gas to any other single gas or to a mixture of gases or a change in specified percentage composition of gas mixture not covered by AWS A5.18/A5.18M, *Specification for Carbon Steel Filler Metals for Gas Shielded Arc Welding*, and AWS A5.28/A5.28M, *Specification for Low-Alloy Steel Filler Metals for Gas Shielded Arc Welding*.

(6) A change of more than 10% above or below the specified mean amperage for each size electrode used.

(7) A change of more than 7% above or below the specified mean arc voltage for each size electrode used.

(8) A change of more than 10% above or below the specified mean travel speed.

(9) An increase of 25% or more or a decrease of 10% or more in the rate of flow of shielding gas mixture.

(10) For a specified groove, a change of more than 25% in the specified number of passes. (If the area of the groove is increased, it is also permissible to increase the number of passes in proportion to the increased area.)

(11) A change in the position in which welding is done as defined in 7.5.

(12) A change in the type of groove; e.g., a change from a V- to U-groove.

(13) A change from the dimensions of the joint qualified involving:

- (a) A decrease in the included angle of the groove;
- (b) A decrease in the root opening of a groove;
- (c) An increase in the root face of a groove; or
- (d) The omission, but not the inclusion, of backing material.

(14) A decrease of more than 25°F [15°C] in the minimum specified preheat temperature.

(15) In vertical welding, a change from the progression specified for any pass from upward to downward, or vice versa.

(16) A change in type of welding current (ac or dc), polarity, or mode of metal transfer across the arc.

(17) The omission, but not inclusion, of backgouging.

(18) The addition or deletion of postweld heat treatment.

7.2.2.4 Flux Cored Arc Welding (FCAW). A change in any of the following variables requires requalification of the WPS:

(1) A change in electrode type and method of shielding not covered by AWS A5.20/A5.20M, *Specification for Carbon Steel Electrodes for Flux Cored Arc Welding*, and AWS A5.29/A5.29M, *Specification for Low-Alloy Steel Electrodes for Flux Cored Arc Welding*.

(2) A change to increase the specified minimum strength level of the filler metal.

(3) An increase in the diameter of electrode used over that called for in the procedure specification.

(4) A change in the number of electrodes used; e.g., a single electrode to multiple electrodes, or vice versa.

(5) A change from a single gas to any other single gas or to a mixture of gases, or a change in specified percentage composition of gas mixture not covered by AWS A5.20/A5.20M, *Specification for Carbon Steel Electrodes for Flux Cored Arc Welding*, and AWS A5.28/A5.28M, *Specification for Low-Alloy Steel Filler Metals for Gas Shielded Arc Welding*.

(6) A change of more than 10% above or below the specified mean amperage for each size electrode used.

(7) A change of more than 7% above or below the specified mean arc voltage for each size electrode used.

(8) A change of more than 10% above or below the specified mean travel speed.

(9) An increase of 25% or more or a decrease of 10% or more in the rate of flow of shielding gas or mixture.

(10) For a special groove, a change of more than $\pm 25\%$ in the specified number of passes. (If the area of the groove is increased, it is also permissible to increase the number of passes in proportion to the increased area.)

(11) A change in the position in which welding is done as defined in 7.5.

(12) A change in the type of groove; e.g., a change from a V- to U-groove.

(13) A change from the dimensions of the joint qualified involving:

(a) A decrease in the included angle of the groove;

(b) A decrease in the root opening of a groove;

(c) An increase in the root face of a groove; or

(d) The omission, but not the inclusion, of backing material.

(14) A decrease of more than 25°F [15°C] in the minimum specified preheat temperature.

(15) In vertical welding, a change from the progression specified for any pass from upward to downward, or vice versa.

(16) A change in type of welding current (ac or dc), polarity, or mode of metal transfer across arc.

(17) The omission, but not inclusion, of backgouging.

(18) The addition or deletion of postweld heat treatment.

7.2.2.5 Electroslag and Electrogas Welding. The following changes in a qualified electroslag or electrogas procedure shall require requalification of the procedure by radiographic or ultrasonic testing in conformance to the requirements of 8.3 or 8.4.

(1) A change in filler metal diameter exceeding 1/32 in [0.8 mm].

(2) A change in filler metal oscillation traverse speed exceeding 10 in/min [250 mm/min].

(3) A change in filler metal oscillation traverse dwell time exceeding 2 s, except as necessary to compensate for variation in joint opening.

(4) A change in filler metal oscillation traverse length affecting proximity of filler metal to the molding shoes by more than 1/8 in [3 mm].

(5) A change in flux burden exceeding 30%.

(6) A change in type of shielding gas or a change in shielding gas flow rate exceeding 25%.

(7) A change in the design of the molding shoes, either fixed or movable, as follows:

(a) Nonfusing solid to water-cooled, or vice versa; or

(b) Metallic to nonmetallic, or vice versa; or

(c) Nonfusing to fusing, or vice versa; or

(d) A reduction in any cross-sectional dimension or area of solid nonfusing shoe exceeding 25%.

(8) A change of welding position from vertical by more than 10°.

(9) A change in the type of current (ac or dc) or polarity.

(10) A change in welding power volt-ampere characteristics from constant voltage to constant current, or vice versa.

(11) A change in voltage exceeding 10%.

(12) A change in square-groove root opening exceeding 1/4 in [6 mm].

(13) A change in the speed of vertical travel, if not an automatic function of arc length or deposition rate, exceeding 20%, except as necessary to compensate for variations in joint opening

7.2.3 Method C—Prototype Testing

7.2.3.1 Welding procedures may be qualified under Method C by utilizing prototype structures or components that comply with the minimum performance criteria as follows:

(1) Simulated service tests of a welded assembly or a mockup of the welded joint. The simulated service test shall include impact loading, loading in bending, static loading, or fatigue testing to duplicate the type of loading the joint will be subjected to in service.

(2) A field test of the welded assembly on a machine loaded and performing the work for which it was designed.

7.2.3.2 For simulated service or field tests, the following shall be documented and recorded:

(1) The weldment drawing to which the test part or assembly was made;

(2) The material specifications of all items included in the assembly;

(3) The detailed welding procedure employed including welding process, filler metal, joint preparation, pre-heat, welding conditions, and sequence of weld passes (see Annex E);

(4) The type of loading applied, direction, and magnitude of forces (by calculation or instrumentation), frequency and total number of applications, or specific duration of the test;

(5) The results of visual examination and nondestructive examination of all welded joints subjected to loading in the test; and

(6) The results of destructive tests of weldments.

7.2.3.3 The welding procedure employed for the test assembly shall be considered qualified provided:

(1) Visual and any required nondestructive examinations, prior to test, meet the requirements of Clause 8, Inspection; and

(2) Specified examinations conducted after test assure performance criteria are met.

7.2.3.4 A test assembly welding procedure shall be requalified when a change in an essential variable exceeds the limits for the welding process (see 7.2.2.1 through 7.2.2.5).

7.3 Types of Tests and Purposes. The types of tests outlined below are to determine the mechanical properties and soundness of welded joints made under a given procedure specification.

7.3.1 Groove Welds. The tests for groove welds are as follows:

(1) Reduced-section tension test (for tensile strength);

(2) Root-bend test (for soundness);

(3) Face-bend test (for soundness);

(4) Side-bend test (for soundness);

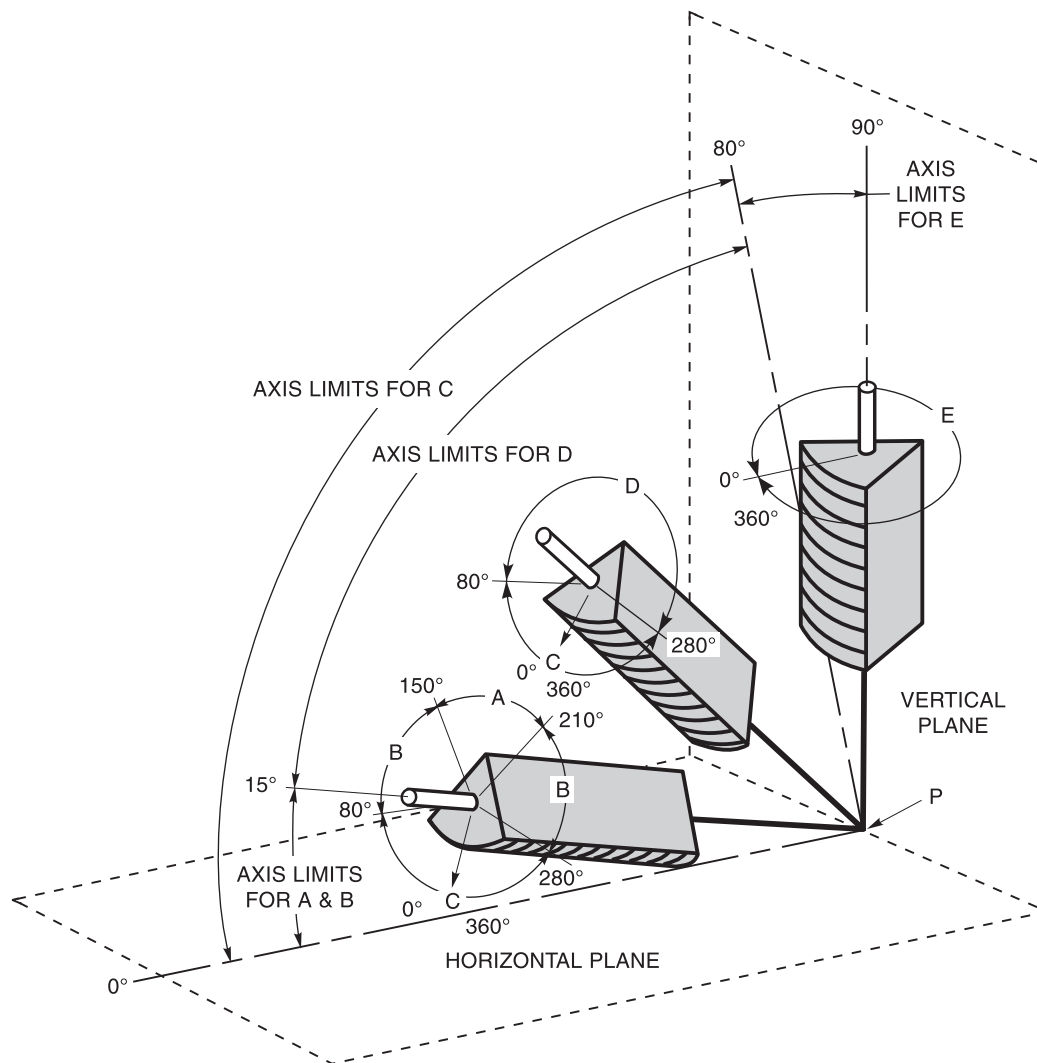
(5) All-weld-metal test (for mechanical properties, electroslog or electrogas).

7.3.2 Fillet Welds. The test for fillet welds is macro-etch test (for soundness and fusion).

7.4 Base Metal and Its Preparation. The base metal and its preparation for welding shall comply with the weld procedure specification. For all types of welded joints, the length of the weld and the dimensions of the base metal shall be such as to provide sufficient material for the required test specimens.

7.5 Position of Test Welds. All welds that will be encountered in actual construction shall be classified as being (1) flat, (2) horizontal, (3) vertical, or (4) overhead in conformance to the definitions of welding positions given in Figures 3 and 4. Each procedure shall be tested for each position for which it is to be qualified.

Tabulation of Positions of Groove Welds			
Position	Diagram Reference	Inclination of Axis	Rotation of Face
Flat	A	0° to 15°	150° to 210°
Horizontal	B	0° to 15°	80° to 150° 210° to 280°
Overhead	C	0° to 80°	0° to 80° 280° to 360°
Vertical	D	15° to 80°	80° to 280°
	E	80° to 90°	0° to 360°



Notes:

1. The horizontal reference plane is always taken to lie below the weld under consideration.
2. The inclination of axis is measured from the horizontal reference plane toward the vertical reference plane.
3. The angle of rotation of the face is determined by a line perpendicular to the theoretical face of the weld which passes through the axis of the weld. The reference position (0°) of rotation of the face invariably points in the direction opposite to that in which the axis angle increases. When looking at point P, the angle of rotation of the face of the weld is measured in a clockwise direction from the reference position (0°).

Figure 3—Positions of Groove Welds

Tabulation of Positions of Fillet Welds			
Position	Diagram Reference	Inclination of Axis	Rotation of Face
Flat	A	0° to 15°	150° to 210°
Horizontal	B	0° to 15°	125° to 150° 210° to 235°
Overhead	C	0° to 80°	0° to 125° 235° to 360°
Vertical	D	15° to 80°	125° to 235°
	E	80° to 90°	0° to 360°

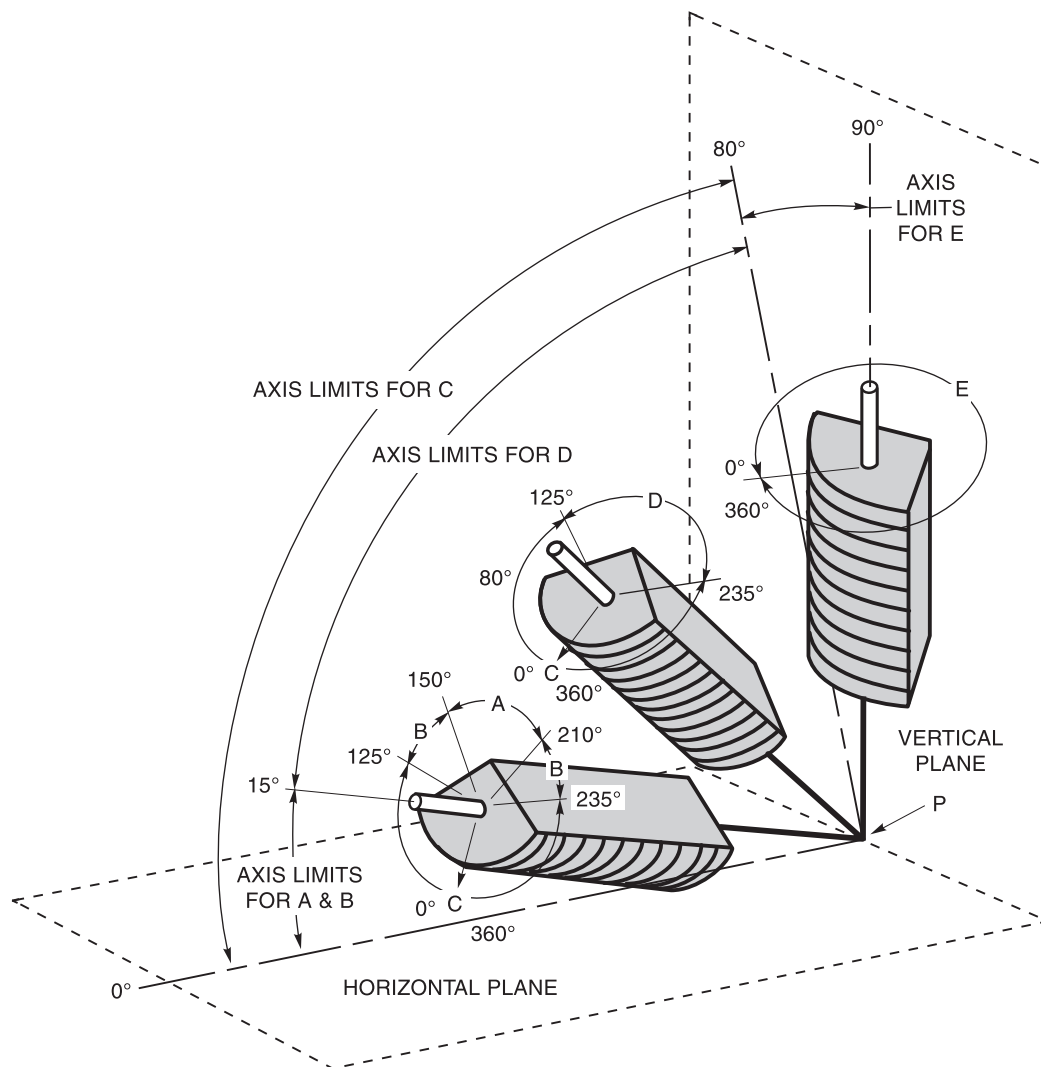


Figure 4—Positions of Fillet Welds

7.5.1 Groove Plate Test Welds. When making the tests to qualify groove welds (see Figure 5), the test plates shall be welded in each of the positions to be qualified as follows:

7.5.1.1 Position 1G (Flat). The test plates shall be placed in an approximately horizontal plane and the weld metal deposited from the upper side, as shown in Figure 5(A).

7.5.1.2 Position 2G (Horizontal). The test plates shall be placed in an approximately vertical plane, with the groove approximately horizontal, as shown in Figure 5(B).

7.5.1.3 Position 3G (Vertical). The test plates shall be placed in an approximately vertical plane with the groove approximately vertical, as shown in Figure 5(C).

7.5.1.4 Position 4G (Overhead). The test plates shall be placed in an approximately horizontal plane and the weld metal deposited from the underside, as shown in Figure 5(D).

7.5.2 Groove Pipe Test Welds. When performing the tests to qualify complete joint penetration groove welds in pipe or tubing (see Figure 6), the test pipe shall be welded in each of the positions to be qualified as follows:

7.5.2.1 Position 1G (Pipe Horizontal Rolled). The test pipe shall be placed with its axis horizontal and the groove approximately vertical. The pipe shall be rotated during welding so the weld metal is deposited from the upper side, as shown in Figure 6(A).

7.5.2.2 Position 2G (Pipe Vertical). The test pipe shall be placed with its axis vertical and the welding

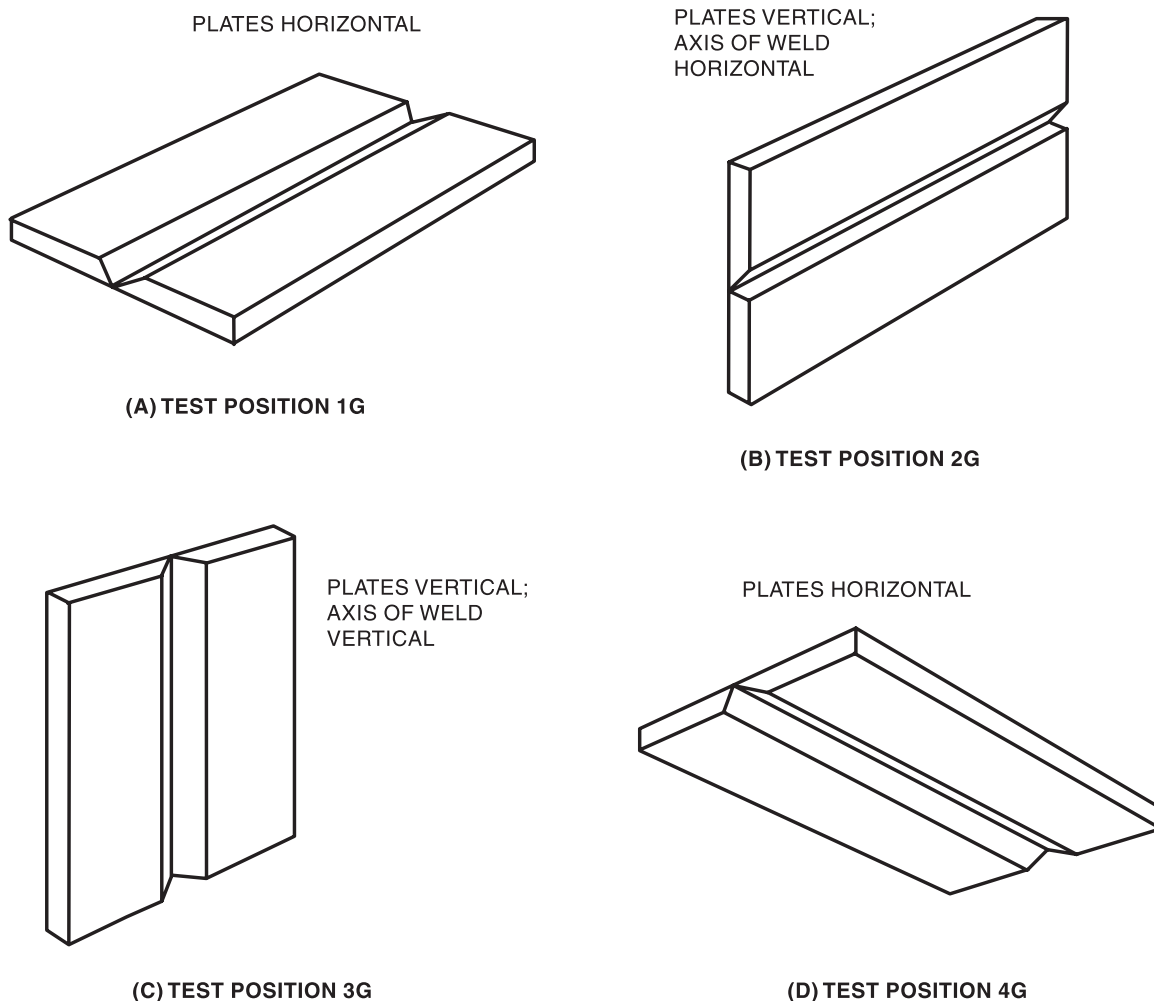


Figure 5—Positions of Test Plates for Groove Welds

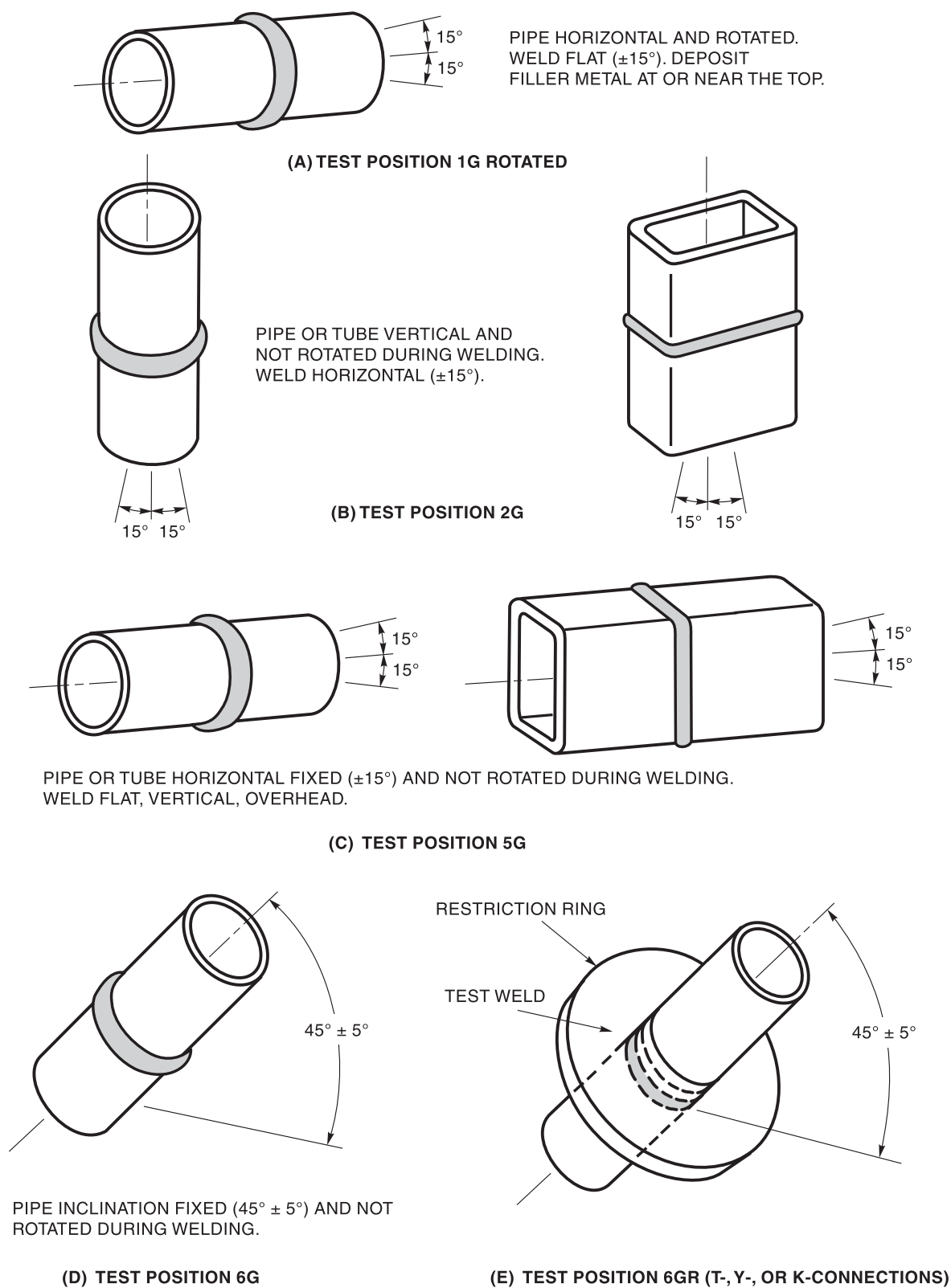


Figure 6—Positions of Test Pipe or Tubing for Groove Welds

groove approximately horizontal. The pipe shall not be rotated during welding, as shown in Figure 6(B).

7.5.2.3 Position 5G (Pipe Horizontal Fixed). The test pipe shall be placed with its axis horizontal and the groove approximately vertical. The pipe is not rotated during welding, as shown in Figure 6(C).

7.5.2.4 Position 6G (Pipe Inclined Fixed). The test pipe shall be inclined at 45° to the horizontal. The pipe is not rotated during welding as shown in Figures 6(D) and 7(E).

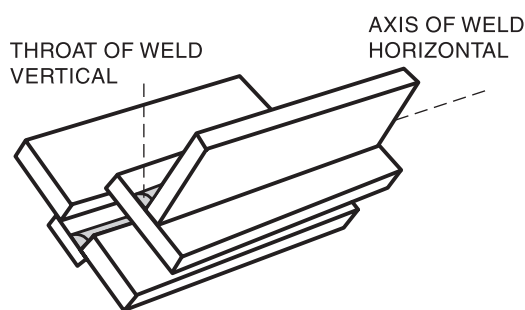
7.5.2.5 Position 6GR (Tubular Inclined Fixed T-, Y-, or K-Connections). The test pipe shall be inclined at

45° to the horizontal. The pipe or tube is not rotated during welding, as shown in Figure 6(E).

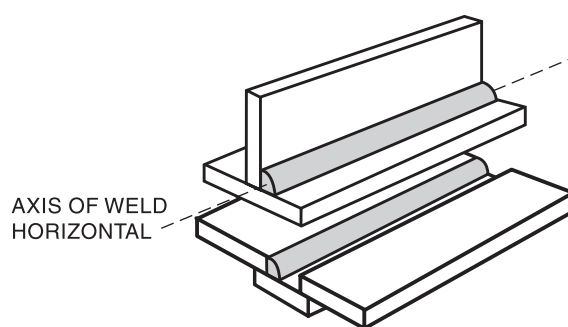
7.5.3 Fillet Welds. In making the tests to qualify fillet welds (see Figure 7), the test plates shall be welded in each of the positions to be qualified as follows:

7.5.3.1 Position 1F (Flat). The test plates shall be placed so that each fillet weld is deposited with its axis approximately horizontal and its throat approximately vertical, as shown in Figure 7(A).

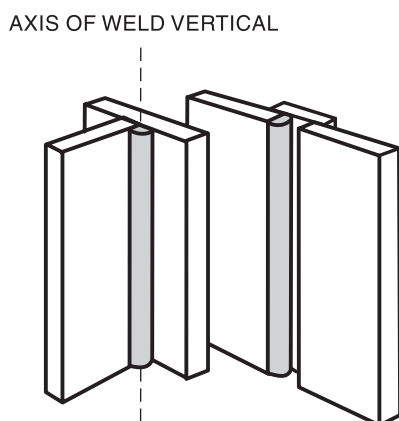
7.5.3.2 Position 2F (Horizontal). The test plates shall be placed so that each fillet weld is deposited on the



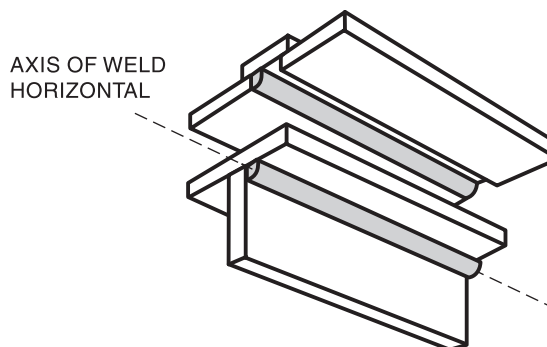
(A) FLAT POSITION 1F



(B) HORIZONTAL POSITION 2F



(C) VERTICAL POSITION 3F



(D) OVERHEAD POSITION 4F

Figure 7—Positions of Test Plates for Fillet Welds

upper side of the horizontal surface and against the vertical surface, as shown in Figure 7(B).

7.5.3.3 Position 3F (Vertical). The test plates shall be placed in an approximately vertical plane and each fillet weld deposited on the vertical surface, as shown in Figure 7(C).

7.5.3.4 Position 4F (Overhead). The test plates shall be placed so that each fillet weld is deposited on the underside of the horizontal surface and against the vertical surface, as shown in Figure 7(D).

7.6 Welding of Test Samples. The welding procedure used to produce test samples shall comply in all respects with the welding procedure specification that will be used in production.

7.7 Test Specimens—Number, Type, and Preparation

7.7.1 Complete Joint Penetration Groove Welds

7.7.1.1 Table 8 shows the type and number of specimens to be tested to qualify a welding procedure. The range of thickness qualified for use in construction is based on the thickness of the test plate, pipe, or tubing used in making the qualification. The test plate shall be radiographically or ultrasonically tested before preparing the required mechanical test specimens.

7.7.1.2 Qualification of groove welds for T- or corner joints shall be butt joints having the same groove configurations as the T- or corner joints to be used in construction.

7.7.1.3 Test specimens shall be prepared by cutting the test plate, pipe, or tubing as shown in Figures 8 through 12, whichever is applicable. The specimens shall be prepared for testing in accordance with Figures 4.1 through 4.5 and Figures 6.4 through 6.7 in AWS B4.0, *Standard Methods for Mechanical Testing of Welds*, or AWS B4.0M, *Standard Methods for Mechanical Testing of Welds*, as applicable.

7.7.2 Partial Joint Penetration Groove Welds. A sample of the type of groove design which is the same as the joint to be used in construction shall be welded. The depth of groove need not exceed 1 in [25 mm]. A macroetch cross section shall be prepared to demonstrate that the designated effective throat is obtained, and the requirements of the procedure specifications are met.

7.7.3 Fillet Welds. For fillet welds, two test welds shall be made for each procedure and position to be used in construction. For each type of test weld, one shall be made with the maximum size single-pass fillet weld and one with the minimum size multiple-pass fillet weld that will be used in construction. For fillet welds, macroetch specimens shall be cut as shown in Figure 13. One end

of each macroetch specimen shall be polished before etching.

7.8 Methods of Testing Specimens

7.8.1 Reduced-Section Tension Specimens. The tensile test specimen shall be tested in accordance with ASTM A 370, *Test Methods and Definitions for Mechanical Testing of Steel Products*.

7.8.2 Macroetch Tests. Etching shall be made with a suitable solution to give a clear definition of the weld.

7.8.3 Root, Face, and Side Bend Specimens. Each specimen shall be bent in one of the jigs shown in Figures 6.1 through 6.3 in AWS B4.0, *Standard Methods for Mechanical Testing of Welds*, or AWS B4.0M, *Standard Methods for Mechanical Testing of Welds*. Any convenient means may be used to move the plunger member with relation to the die member. Refer to AWS B4.0 or B4.0M for test procedures.

7.8.4 All-Weld-Metal Tension Test. The tensile test specimen shall be tested in accordance with ASTM A 370, *Test Methods and Definitions for Mechanical Testing of Steel Products*.

7.8.5 The radiographic procedure and technique shall conform to the requirements of 8.3.

7.8.6 The ultrasonic procedure and technique shall conform to the requirements of 8.4.

7.9 Test Results Required. The requirements for the test results shall be as follows:

7.9.1 Reduced-Section Tension Test. The tensile strength shall be not less than the minimum of the specified tensile range of the base metal used.

7.9.2 Root, Face, and Side Bend Tests. The convex surface (tension side) of the specimen shall be examined for the appearance of cracks or other open defects. Any specimen in which a crack or other open defect, exceeding 1/8 in [3 mm] as measured in any direction, is present after the bending shall be considered as having failed. Cracks occurring on the corners of the specimen during testing shall not be considered.

7.9.3 Macroetch Tests. The specimens shall be examined for defects, and any which have defects prohibited by Table 9 and 8.1 shall be considered as failed. The specimens shall have the designated effective throat for partial joint penetration groove welds. Fillet weld specimens shall show fusion to the root, but not necessarily beyond, and both legs shall conform to 8.2.8.2. Convexity and concavity shall not exceed the limits specified in 8.2.5.6.

Table 8
Number and Type of Test Specimens and Range of Thickness Qualified—Procedure Qualification

Plate, Pipe, or Tube Size, As Welded		Plate, Pipe, or Tube Size, Qualified			Number of Sample Welds per Position	Visual Inspection	Number and Type of Tests Required				
Diameter in [mm]	Thickness (T) in [mm]	Diameter in [mm]	Thickness (T) in [mm]				Reduced-Section Tension	Root Bend	Face Bend	Side Bend	All-Weld-Metal Tension
			min.	max.							
Plate Test (except Electroslag and Electrogas Processes)											
	≤3/8 [10] >3/8 to ≤1 [>10 to ≤25] >1 [25]		1/8 [3] 1/8 [3] 1/8 [3]	2T 2T Unlimited	1 1 1	Yes Yes Yes	2 2 2	2 — —	2 — —	— 4 4	— — —
Plate Test (Electroslag and Electrogas Processes)											
	T		0.5T	1.1T	1	Yes	2	—	—	4	1
Pipe Test											
2 or 3 [50 or 75]	Sch. 40 or Sch. 80	≥3/4 to ≤4 [≥20 to ≤100]	1/8 [3]	3/4 [20]	2	Yes	2	2	2	—	—
6 or 8 [150 or 200]	Sch. 80 or Sch. 120	≥4 [100]	3/16 [5]	Unlimited	1	Yes	2	—	—	4	—
Pipe Test (Large Diameter Job Size)											
<24 [600]	<3/4 [20] ≥3/4 [20]	≥Test Diameter	1/8 [3] 3/8 [10]	2T Unlimited	1	Yes	2	—	—	4	—
≥24 [600]	<3/4 [20] ≥3/4 [20]	≥24 [600]	1/8 [3] 3/8 [10]	2T Unlimited	1	Yes	2	—	—	4	—

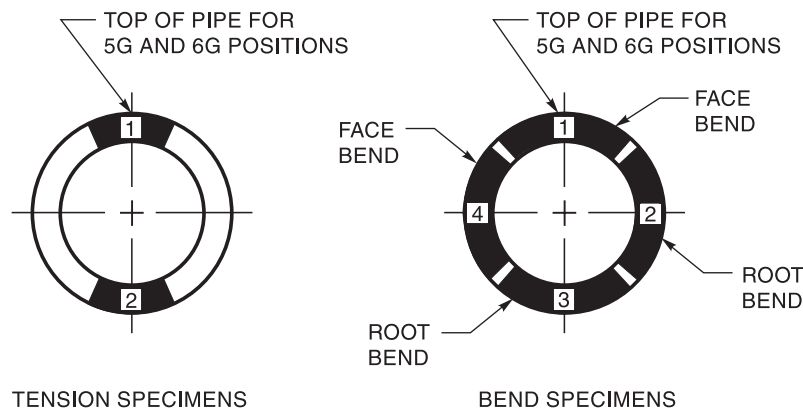


**Figure 8—Location of Test Specimens on Welded Test Pipe—
2 in or 3 in [50 mm or 75 mm] Diameter**

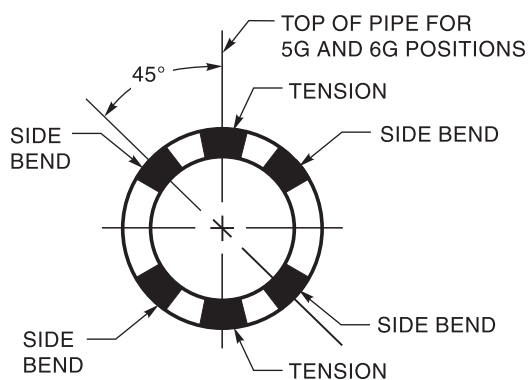


**Figure 9—Location of Test Specimens
on Welded Test Pipe—6 in or 8 in
[150 mm or 200 mm] Diameter**

7.9.4 All-Weld-Metal Tension (Electroslag and Electrode Gas Welding). The mechanical properties shall not be less than those of the base metals being welded.

7.9.5 Nondestructive Examination

7.9.5.1 For acceptable qualification, the weld, as revealed by radiographic or ultrasonic testing, shall conform to the applicable requirements of 8.3.6 or 8.4.6.

7.9.5.2 For acceptable qualification, the pipe weld, when inspected visually, shall conform to the following requirements:

- (1) The weld shall be free of cracks.
- (2) All craters shall be filled to the full cross section of the weld.
- (3) The face of the weld shall be at least flush with the outside surface of the pipe, and the weld shall merge smoothly with the base metal. Undercut shall not exceed 1/64 in [0.4 mm]. Weld reinforcement shall not exceed the requirements of Table 10.
- (4) The root of the weld shall be inspected and there shall be no evidence of cracks, incomplete fusion, or inadequate joint penetration.
- (5) If the total weld thickness is equal to or greater than that of the base metal, the maximum root surface concavity shall be 1/16 in [2 mm] and the maximum melt-through shall be 1/8 in [3 mm].

7.10 Records. Records of the test results shall be kept by the Manufacturer or Fabricator, or both, and shall be available to those authorized to examine them.

7.11 Retests. If any one test specimen fails to meet the test requirements when all other test specimens meet the test requirements, two retests for that particular type of test specimen may be performed with specimens cut from the same procedure qualification test material. The results of both retest specimens shall meet the test requirements. For material over 1-1/2 in [40 mm] in thickness, failure of a specimen shall require testing of all specimens of the same type from two additional locations in the test material.



Part B
Welder Qualification

7.13.1.3 For fillet weld qualification only, the welder shall weld a test plate according to Option 1 or 2, depending on the contractor's choice, as follows: