

ANSI/AWS D1.2-90
An American National Standard

1990

Structural Welding Code

Aluminum



American Welding Society

Keywords— aluminum plate, castings, dynamically loaded structures, gas metal arc welding (GMAW), gas tungsten arc welding (GTAW), inspection, qualification, structural details, statically loaded structures, structural shapes, stud welding, tubular structures, welded joint details, workmanship

ANSI/AWS D1.2-90
An American National Standard

Approved by
American National Standards Institute
February 8, 1990

Structural Welding Code— Aluminum

Second Edition

Superseding
ANSI/AWS D1.2-83

Prepared by
AWS Structural Welding Committee

Under the Direction of
AWS Technical Activities Committee

Approved by
AWS Board of Directors

Abstract

This Code covers the welding requirements for any type structure made from aluminum structural alloys, except for aluminum pressure vessels and fluid-carrying pipe lines. Sections 1 through 7 and 11 constitute a body of rules for the regulation of welding in aluminum construction. Sections 8, 9, and 10 contain additional rules applicable to specific types of structures (i.e., statically loaded structures, dynamically loaded structures, and tubular structures, respectively), and supplement the first seven sections. A Commentary on the Code is also included with the document.



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International Standard Book Number: 0-87171-324-1

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Foreword

(This Foreword is not a part of ANSI/AWS D1.2-90, *Structural Welding Code—Aluminum*, but is included for information purposes only.)

In 1928, the first edition of the *Code for Fusion Welding and Gas Cutting in Building Construction* was published by the American Welding Society. In 1936, the first edition of a similar code for highway and railroad bridges was published. For a number of years separate codes were continued for each type of steel structure.

The separate committees preparing the two codes were consolidated in 1963 into a single committee, the Structural Welding Committee. In 1972, the Committee consolidated the two codes into a single version applicable to structural welding in general, along with specific requirements for buildings, bridges, and tubular structures. A series of consolidated codes have been published since that initial one, representing the latest state-of-the art for welding of structural steel.

In the early 1970's, interest was expressed in developing a similar consolidated code for the structural welding of aluminum. Because of the interest of both The Aluminum Association and the American Welding Society, it was decided to begin in the mid-70's the task of developing a Structural Welding Code for aluminum. Initially, the effort was undertaken by a task force of The Aluminum Association. In 1979, this task force became a subcommittee of the AWS Structural Welding Committee and the *Structural Welding Code—Aluminum* resulted from the continued activity of that subcommittee.

Many of the users of this Code will also be users of the *Structural Welding Code—Steel*. As a result, it was felt that as much similarity as possible between the codes for steel and aluminum should be achieved. Thus, the same general format has been used in the development of the aluminum code that has been and is used in the steel code.

Sections 1 through 7 and 11 constitute a body of rules for the regulation of welding on aluminum structures. Sections 8, 9, and 10 contain additional rules applicable to specific types of nontubular and tubular structures and should be used as a supplement to the first seven sections. A key feature of each of the last three sections is the list of dimensional tolerances and weld quality. These are given for nontubular structures under static and dynamic loadings. For tubular structures, two classes of structures are identified. Class I structures are those in the general class of luminaires, traffic signal, and overhead sign supports. All other tubular structures are Class II. Many of the requirements (dimensional and weld quality) are more stringent for the Class II structures.

Recommended joint details have been prepared for numerous complete joint penetration and partial joint penetration groove welded joints. Herein lies one of the major differences between the *Structural Welding Code—Steel* and this code. While the Steel Code allows for prequalified welding procedures, this code does not. This is mainly because of the many and varied possible welding conditions that can be obtained with semiautomatic welding variables most often used with aluminum and the wide range of both heat treatable and nonheat treatable alloys that may be welded under this code. Therefore, all of the joint details and the welding procedures used with this code shall be individually qualified and included in the Welding Procedure Specification.

Procedures and standards are outlined for several methods of nondestructive testing. Methods included are visual, radiographic, and dye-penetrant. Ultrasonic testing is permitted, but the procedure and acceptance criteria shall be specified in the Contract documents.

This code does not concern itself with such design considerations as the arrangements of parts, loading, and the computation of stresses for proportioning the load-carrying members of a structure and their connection. Such considerations, it is assumed, are covered elsewhere in a general code or specification, such as, the *Specifications for Aluminum Structures* (The Aluminum Association).

Comments and suggestions for the improvement of this standard are welcome. They should be sent to the Secretary of the Structural Welding Committee, American Welding Society, 550 N.W. LeJeune Road, P.O. Box 351040, Miami, Florida 33135.

Official interpretations of any of the technical requirements of this standard may be obtained by sending a request, in writing, to the Technical Director, American Welding Society, 550 N.W. LeJeune Road, P.O. Box 351040, Miami, Florida 33135 (See Appendix H).

Preface

(This Preface is not a part of ANSI/AWS D1.2-90, *Structural Welding Code—Aluminum*, but is furnished for information purposes only.)

The first edition of the Structural Welding Code—Aluminum (hereafter referred to as the Code) represented the continuing AWS policy to provide standards for structural welding. This Code is provided for the construction industry as a set of rules and regulations for the welding of structural aluminum. Some of the more important aspects of this second edition of the Code are outlined in the following paragraphs.

Changes in Code Requirements. Where changes have been made in code requirements, double vertical lines appear in the margin immediately adjacent to the paragraph affected. New requirements are also indicated in this manner. Major editorial changes are indicated by a single vertical line in the margin immediately adjacent to the subsection affected.

Tables. Four new tables have been added, and fifteen tables have been revised. New tables are indicated by double vertical lines in the margin.

Drawings. Four new figures have been added, and five figures have been revised. New figures are indicated by double vertical lines in the margin.

Stud Welding. A new section on stud welding has been added to the Code. The previous section 7, Strengthening and Repair of Existing Structures, has been moved to the end of the Code and renumbered as section 11.

Commentary. After the first edition of this Code was published, the Committee prepared a *Commentary on the Structural Welding Code—Aluminum*, similar to the Commentary for the ANSI/AWS D1.1, *Structural Welding Code—Steel*. The Commentary was issued separately in 1984. In this edition, the Committee has updated the Commentary in line with the revised provisions, and it has been bound into the Code after the Appendixes. The Commentary is not intended to supplement Code requirements, but only to provide a useful document for interpretation and application of the Code. None of its provisions are binding.

Welding Inspector Qualifications. All users are urged to review the provisions relating to the Welding Inspector qualification requirements in 6.1.3 and its subsections. The requirements in this Code are identical with those requirements for welding inspector qualification given in ANSI/AWS D1.1-90, *Structural Welding Code—Steel*. Users interested in further explanation of these provisions should contact the Secretary at AWS Headquarters.

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AWS D1.2-90

Structural Welding Code — Aluminum**1. General Provisions****1.1 Scope**

This Code covers welding requirements applicable to any type of welded aluminum alloy structure. It is to be used in conjunction with appropriate complementary codes or specifications for materials design and construction. It is not intended to supplant codes developed for use in specialized fabrication, such as the *ASME Boiler and Pressure Vessel Code*, aerospace codes, or military specifications; it is appropriate for use in fabrication of supporting structures and appurtenances. Requirements that are essentially common to all types of structures are covered in sections 1 through 7, while provisions applying exclusively to nontubular statically loaded structures, nontubular dynamically loaded structures, or tubular structures are included in sections 8, 9, and 10, respectively.

The inclusion of recommended joints in Appendixes B1 and B2 is not intended as a substitute for engineering judgment with respect to the suitability of application of these joints to a welded assembly or connection.

1.2 Approval

All reference to a need for approval shall be interpreted to mean approval by the Building Commissioner¹, the Engineer, or the duly designated person acting for and on behalf of the owner in all matters within the scope of this Code. Hereinafter, the term *Engi-*

neer will be used, and it is to be construed to mean the Building Commissioner, the Engineer, or the duly designated person who acts for and on behalf of the owner in all matters within the scope of this Code.

1.3 Materials**1.3.1 Base Metals**

1.3.1.1 Aluminum alloys approved for use in this code are listed under ASTM specifications in Table 1.1. Other aluminum alloys may be used only when approved by the Engineer.²

1.3.1.2 To reduce the number of welding procedure qualifications required, the following groupings of base materials listed in Table 1.1 have been established. They

2. Selection of the alloy or alloys to be used will be dependent on the type of structure to be constructed, design considerations, and the characteristics of the various alloys, e.g., weldability, corrosion resistance, strength, etc. The selection of the temper may be influenced by the strength and characteristics required in parts of the structure at some distance from the welds.

For nonheat treatable alloys, the ultimate tensile strength of a welded joint is essentially independent of the original temper or condition of the material. Hence, the tensile strength of a welded joint is generally equal to the strength of the metal in the annealed condition, and the procedure qualification requirements are based on this property.

For heat treatable alloys, the tensile strength of a welded joint will depend somewhat on the welding process and the heat input per pass. Generally, the tensile strength of a welded joint in heat treatable material is somewhat greater than the tensile strength of the material in the annealed condition, hence, the procedure qualification requirements are developed from test data.

1. The term *Building Commissioner* refers to the official or bureau, by whatever term locally designated, delegated to enforce the local building law or specifications or other construction regulations.

Table 1.1
Aluminum Alloy Products Available for Structural Applications (see 1.3.1.1)

Alloy No. ¹	Rolled		Extruded Rod and Wire Shapes	Extruded Structural Shapes	Seamless Extruded Tube and Pipe			Seamless Drawn Tube and Pipe			Welded Tube	Welded Fittings	Forgings	Sand Castings	Permanent		High Strength Castings					
	Sheet and Plate	Cold Finished Rod Bar and Wire			ASTM	ASTM	ASTM	ASTM	ASTM	ASTM					ASTM	ASTM		ASTM	ASTM	ASTM	ASTM	ASTM
Wrought Alloys																						
AA 1060	X		X			X		X		X		X										
AA 1100	X		X			X		X		X		X		X								
AA 2219	[X] ²	[X]	[X]			[X]								X	[X]							
AA 3003	X		X			X		X		X		X		X								
Alclad 3003	X		X			X						X		X								
AA 3004	X		X							X												
Alclad 3004	X									X												
AA 5005	X							X		X												
AA 5050	X							X		X												
AA 5052	X		X					X		X												
AA 5083	X		X			X		X		X			X									
AA 5086	X		X			X		X		X			X									
AA 5154	X									X			X									
AA 5254	X					X		X					X									
AA 5454	X		X			X		X														
AA 5456	X		X			X				X												
AA 5652	[X]					[X]																
AA 6005			X																			
AA 6061	X		X			X		X		X			X									
Alclad 6061	X									[X]			X									
AA 6063			X			X		X		X												
AA 6351			X			[X]																
AA 7005			X																			

Table 1.1 (Continued)

Table 1.1 (Continued)																								
Alloy No. ¹	Rolled		Extruded Rod, Bar and Wire	Extruded Structural Shapes	Seamless Extruded Tube and Pipe				Seamless Drawn Tube and Pipe				Welded Tube	Welded Fittings	Forgings	Sand Castings	Permanent		Investment Castings	High Strength Castings				
	Sheet and Plate	ASTM			ASTM	ASTM	ASTM	ASTM	ASTM	ASTM	ASTM	ASTM					Mold Castings	ASTM						
B209	B211	B221	A308	B241	B429	B210	B483	B313	B361	B247	B26	B108	B618	B686										
Cast Alloys																								
AA A201.0																								
AA 354.0																								
AA C355.0																								
AA 356.0																								
AA A356.0																								
AA 357.0																								
AA A357.0																								
AA 359.0																								
AA 443.0																								
AA 514.0																								
AA 535.0																								

Notes:

1. Wrought alloys 1xxx, 3xxx, 5xxx, and cast alloys 4xx, x and 5xx, x are nonheat treatable alloys. Wrought alloys 2xxx, 6xxx, and 7xxx and cast alloys x2xx, x and x3xx, x are heat treatable alloys.

2. [X] indicates a revision to ANSI/AWS D1.2-83.

AA = Aluminum Association No.

4/General Provisions

are based essentially on comparable base metal characteristics, such as composition, weldability, and mechanical properties:

M-Number Listing

M21 — 1060, 1100, 3003, ALCLAD 3003, 5005, 5050
 M22 — 3004, ALCLAD 3004, 5052, 5154, 5254, 5454, 5652
 M23 — 6005, 6061, ALCLAD 6061, 6063, 6351
 M24 — 2219
 M25 — 5083, 5086, 5456
 M26 — A201.0, 354.0, C355.0, 356.0, A356.0, 357.0, A357.0, 359.0, 443.0, 514.0, 535.0
 M27 — 7005

These groupings do not imply that base metals within a group may be interchanged in a structure without consideration of compatibility from the standpoints of metallurgical and mechanical properties, design and service requirements, and without the approval of the Engineer.

1.3.2 Filler Metals

1.3.2.1 Filler metals shall comply with all the requirements set forth in the latest edition of ANSI/AWS A5.10, *Specification for Bare Aluminum and Aluminum Alloy Welding Electrodes and Rods*. Table 1.2 lists filler alloys recommended for use with pertinent base aluminum alloys for general structural applications.

Table 1.2
Recommended Aluminum Alloy Filler Metals for Structural Welding
of Various Base Aluminum Alloys (see 1.2.2.1)

Base Metal to Base Metal	1060 1100 3003 Alclad 3003	2219 A201.0	3004 Alclad 3004	5005 5050	5052 5652 ³	5083 5456	5086 514.0 535.0	5154 5254 ³
356.0, A356.0, 357.0, A357.0, 359.0, 443.0	4043 (8)	4145 (5), (8)	4043 (8)	4043 (8)	4043 (4), (8)	5356 (7)	5356 (7)	4043 (4)
354.0, C355.0	4145 (5), (8)	4145 (5), (8), (10)	4145 (5), (8)	4145 (5), (8)	4043 (8)	NR	NR	NR
7005	5356 (5), (7)	4145 (5), (8)	5356 (5), (7)	5356 (5), (7)	5356 (4)	5556 (7)	5356 (7)	5356 (4)
6005, 6061, Alclad 6061, 6063, 6351	4043 (8)	4145 (5), (8)	5356 (4), (5)	4043 (7), (8)	5356 (4), (5)	5356 (7)	5356 (7)	5356 (4)
5454	4043 (7), (8)	4043 (8)	5356 (4), (5)	5356 (4), (5)	5356 (4), (5)	5356 (7)	5356 (7)	5356 (4)
5154, 5254 ³	4043 (7), (8)	NR	5356 (4)	5356 (4)	5356 (4)	5356 (7)	5356 (7)	5356 (4)
5086, 514.0, 535.0	5356 (7)	NR	5356 (7)	5356 (7)	5356 (7)	5356 (7)	5356 (7)	
5083, 5456	5356 (7)	NR	5356 (7)	5356 (7)	5356 (7)	5556 (7)		
5052, 5652 ³	4043 (7), (8)	4043 (8)	4043 (7), (8)	4043 (7), (8)	5356 (4), (5)			
5005, 5050	4043 (8), (11)	4145 (5)	4043 (7), (8)	4043 (8), (11)				
3004, Alclad 3004	4043 (7), (8)	4145 (5)	4043 (7), (8)					
2219, A201.0	4145 (5), (8)	2319 (5), (8), (9)						
1060, 1100, 3003, Alclad 3003	1100 (5), (6), (8), (12)							

Note: Numbers in parentheses refer to Notes 1 through 13.

(Continued)

Table 1.2 (Continued)

Base Metal to Base Metal					
	5454	6005 6061 Alclad 6061 6063 6351	7005	354.0 C355.0	356.0 A356.0 357.0 A357.0 359.0 443.0
356.0, A356.0, 357.0, A357.0, 359.0, 443.0	4043 (4)	4043 (8), (9)	4043 (8)	4145 (5), (6), (8)	4043 (6), (8), (9)
354.0, C355.0	4043 (8)	4145 (5), (8)	4145 (5), (8)	4145 (5), (6), (8)	
7005	5356 (4)	5356 (4), (5), (8)	5356 (7)		
6005, 6061, Alclad 6061, 6063, 6351	5356 (4), (5)	4043 (4), (8), (13)			
5454	5554 (5), (7), (8)				

Notes:

1. The filler metal shown for each combination of base alloys is that most commonly used. However, the specific filler metal depends upon usage and type of joint, and in a number of cases, acceptable alternates are recommended [Notes (4)–(13)]. When NR is indicated, welding that combination of base alloys is not recommended.

2. Filler metals conform to the requirements of ANSI/AWS A5.10.

3. Exposure to specific chemicals or a sustained high temperature [over 150°F (66°C)] may limit the choice of filler metals. Filler alloys 5183, 5356, 5556 and 5654 should not be used for sustained elevated temperature service. Filler alloy 5654 is suitable for use with base alloys 5652 and 5254 for hydrogen peroxide service.

4. 5183, 5356, 5554, 5556 and 5654 may be used. In some cases, they provide (1) improved color match after anodizing treatment, (2) higher weld ductility, and (3) higher weld strength. 5554 is suitable for elevated temperature service.

5. 4043 may be used for some applications.

6. Filler with the same analysis as the base metal alloy is sometimes used.

7. 5183, 5356, or 5556 may be used.

8. 4047 may be used for some applications.

9. 4145 may be used.

10. 2319 may be used.

11. 1100 may be used.

12. 1188 may be used.

13. 4643 may be used. This is useful primarily when 1/2 in. (12.7 mm) and thicker weldments are post weld solution heat treated and precipitation age hardened.

1.3.2.2 The filler metals listed below have been arranged in the following F number grouping based upon their useability characteristics:

Group Designation	AWS Electrode Classification
F21	ER1100, ER1188, R1100, R1188
F22	ER5183, ER5356, ER5554, ER5556, ER5654, R5183, R5356, R5554, R5556, R5654
F23	ER4043, ER4047, ER4145, ER4643, R4043, R4047, R4145, R4643
F24	R206.0, R357.0, R-A356.0, R-A357.0, R-C355.0
F25	ER2319, R2319

These groupings do not imply that filler metals within the same F number grouping may be interchanged without consideration of compatibility from the standpoints of metallurgical and mechanical properties, design and service requirements, and without the approval of the Engineer.

1.3.2.3 Filler metals shall be stored in their original packages or cartons, in a dry place adequately protected from the weather until actually needed at the fabrication site. Recommendations of the manufacturer concerning special protection during storage and use shall be explicitly followed.

1.3.3 Shielding Gases

1.3.3.1 The shielding gas in conventional welding of aluminum shall be welding-grade argon complying with

6/General Provisions

CGA specifications.³ Where special circumstances exist, i.e., the need for deep penetration (as in welding very thick sections), the use of welding-grade helium or a mixture of welding grade argon and welding-grade helium may be used.

1.3.3.2 Shielding gases shall be stored in and used from the containers in which they are supplied or from a central storage tank-distribution system which is replenished by the gas supplier. The entire handling system shall be designed to prevent contamination.

1.4 Welding Processes

This code covers the requirements for welding aluminum alloys by the following processes:

- (1) GMAW — gas metal arc welding
- (2) GTAW — gas tungsten arc welding.
- (3) PAW-VP — plasma arc welding with variable polarity.
- (4) SW — stud welding.

The welding procedures for these processes shall comply with the provisions of sections 1 through 5 and, in addition, sections 8, 9, or 10, as applicable. A summary of safety practices in employing these welding processes is given in Appendix J.

1.5 Definitions

The welding terms used in this Code shall be interpreted in accordance with the definitions given in the

3. Available from Compressed Gas Association, 1235 Jefferson Davis Avenue, Arlington, Virginia 22202.

latest edition of ANSI/AWS A3.0, *Standard Welding Terms and Definitions*.

1.6 Welding Symbols

Welding symbols used in drawings, sketches, erection plans, procedure specifications, etc., shall be those shown in the latest edition of ANSI/AWS A2.4, *Symbols for Welding, Brazing, and Nondestructive Examination*. Special conditions shall be fully explained by added notes or details.

1.7 Safety Precautions

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

Adequate safety precautions, including ventilation of the work area, shall be taken in accordance with the requirements of the latest edition of ANSI/ASC Z49.1, *Safety in Welding and Cutting* (see Appendix A).

See Appendix J for additional information relating to the basic elements of safety general to arc welding processes.

1.8 Standard Units of Measurement

The values stated in U.S. customary units are to be regarded as the standard. The metric (SI) equivalents of U.S. customary units given in this Code may be approximate.

2. Design of Welded Connections

Part A General Requirements

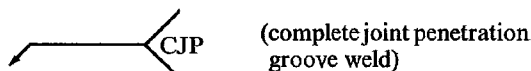
2.1 Drawings

2.1.1 Full and complete information regarding the materials of construction, type, and dimensions of the members being joined and the location, type, size, and extent of all welds shall be clearly shown on the drawings.⁴ The drawings shall clearly distinguish between shop and field welds.

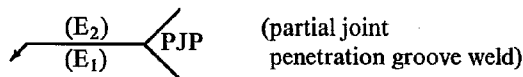
2.1.2 A joint or group of joints for which welding sequence is important either to minimize shrinkage stress, control distortion, or ensure accessibility for welding shall be clearly identified on shop drawings.

2.1.3 Contract design drawings shall specify the effective weld length and, for partial joint penetration groove welds, the required weld size as defined in 2.3.1.3. For such welds, the shop or working drawings shall specify the depth of preparation (S) needed for the welding procedures to be used.

2.1.3.1 It is recommended that contract design drawings show complete joint penetration or partial joint penetration groove weld requirements. A welding symbol without dimensions designates a complete joint penetration groove weld as follows:



The welding symbol with dimensions above or below the arrow designates a partial joint penetration weld as follows:



4. The term *drawings* refers to plans, design and detail drawings, sketches and erection plans.

where

E_2 = weld size, other side

E_1 = weld size, arrow side

2.1.3.2 Special groove details shall be specified and described where needed.

2.1.4 The detail drawings shall clearly indicate, by means of welding symbols or sketches, the preparation and fit-up of material for the required joints. If joints with backing are to be used, the material, width, thickness, and contour (if any), for such backing shall be shown.

2.1.5 Any joint requiring special inspection requirements should be identified on the drawings.

2.2 Basic Stresses

Basic stresses for base metals and for effective areas of weld metal shall be as referenced in Part B of sections 8, 9, and 10 for applications to nontubular statically loaded structures, nontubular dynamically loaded structures, and tubular structures, respectively, or as otherwise referenced in applicable specifications. Designers should be aware that heat-treatable structural aluminum alloys lose significant strength when welded. Such losses shall be considered in designing welded structures.

2.3 Effective Weld Areas, Lengths, Throats, and Weld Sizes

2.3.1 Groove Welds. The effective area shall be the product of the effective weld length multiplied by the weld size.

2.3.1.1 The effective weld length for any groove weld, whether skewed or not, shall be the width of the narrower of the parts joined, perpendicular to the direction of stress.

2.3.1.2 The weld size of a complete joint penetration groove weld shall be the thickness of the thinner part joined. No increase is permitted for weld reinforcement.

2.3.1.3 The weld size of a partial joint penetration groove weld shall be as follows:

(1) Depth of preparation less 1/8 in. (3 mm) for (a) all positions when GTA welding of V- or bevel-groove joints with an included angle θ such that, $45^\circ < \theta < 60^\circ$ or (b) horizontal and overhead position GMA welding such that, $45^\circ < \theta < 60^\circ$

(2) Depth of preparation for (a) flat and vertical position GMA welding of V- or bevel-groove joints with included angle θ such that, $45^\circ < \theta < 60^\circ$, (b) all position GMA and GTA welding of V- or bevel-groove joints with included angle θ greater than or equal to 60° and (c) all position GMA and GTA welding of J- or U-groove joints

(3) As determined by tests using a qualified welding procedure and verified by random macroetched sections taken from production welds

2.3.1.4 The minimum weld size of a partial joint penetration groove weld shall be as specified in Table 2.1.

2.3.2 Fillet Welds. The effective area shall be the product of the effective weld length multiplied by the effective throat. Stress in a fillet weld shall be considered as shear applied to this effective area, for any direction of applied load.

2.3.2.1 The effective length of a fillet weld shall be the overall length of the full-size fillet, including boxing end returns, with lengths not greater than the width of the narrower member. No reduction in effective length need be made for either the start or the crater of the weld if the weld is of full size throughout its length.

2.3.2.2 The effective length of a curved fillet weld shall be measured along the centerline of the effective throat.

If this effective length of a fillet weld in a hole or slot leads to an effective area greater than the area found from 2.3.3, then this latter area shall be used as the effective area of the fillet weld.

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

2.3.2.4 The effective throat shall be the shortest distance from the root to the face of the diagrammatic weld. (See Appendix C).

2.3.3 Plug and Slot Welds. The effective area shall be the nominal area of the hole or slot in the plane of the faying surfaces.

2.3.4 Combination Welds. The weld size of a combination partial joint penetration groove weld and a fillet weld shall be the shortest distance from the root to the face of the diagrammatic weld minus 1/8 in. (3 mm) for any groove detail requiring such deduction.

Part B Structural Details

2.4 Filler Plates

2.4.1 Filler Plates may be used in:

- (1) Welding parts of different thicknesses
- (2) Connections that, due to existing geometric alignment, must accommodate offsets to permit simple framing

2.4.2 A filler plate less than 1/4 in. (6.4 mm) in thickness shall not be used to transfer loads, but shall be kept flush with the welded edges of the load-carrying part. The weld sizes along such edges shall be increased over the required sizes by an amount equal to the thickness of the filler plate (see Figure 2.1).

2.4.3 Any filler plate 1/4 in. (6.4 mm), or more, in thickness shall extend beyond the edges of the base metal. It shall be welded to the part on which it is fitted, and the joint shall have sufficient strength to transmit the load on the base metal as an eccentric load. The welds joining the base metal to the filler plate shall be sufficient to transmit the load on the base metal and shall be long enough to avoid overstressing the filler plate along the toe of the weld (see Figure 2.2).

2.5 Partial Joint Penetration Groove Welds

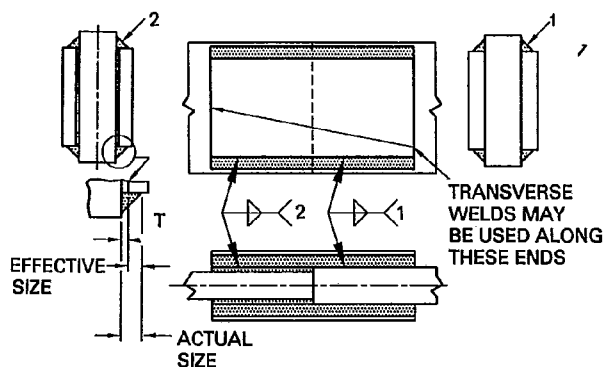
Partial joint penetration groove welds subject to tension normal to their longitudinal axis shall not be used where design criteria indicate that cyclic loading could

Table 2.1
Minimum Weld Size for Partial Joint Penetration Groove Welds (see 2.3.1.4)

Base Metal Thickness of Thicker Part Joined	Minimum Weld Size**	
	in.	mm
1/8 (3.2) to 3/16 (4.8) incl.	1/16*	2
Over 3/16 (4.8) to 1/4 (6.4) incl.	1/8*	3
Over 1/4 (6.4) to 1/2 (12.7) incl.	3/16	5
Over 1/2 (12.7) to 3/4 (19.0) incl.	1/4	6
Over 3/4 (19.0) to 1-1/2 (38.1) incl.	5/16	8
Over 1-1/2 (38.1) to 2-1/4 (57.1) incl.	3/8	10
Over 2-1/4 (57.1) to 6 (152) incl.	1/2	13
Over 6 (152)	5/8	16

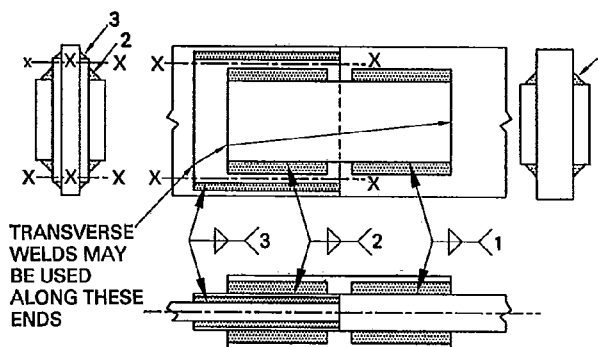
* Minimum size for dynamically loaded structures is 3/16 in. (5 mm).

** Except the depth of preparation need not exceed the thickness of the thinner part.



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

Figure 2.1 — Filler Plates Less Than 1/4 in. (6.4 mm) in Thickness (see 2.4.2)



Notes:

1. The effective area of weld 2 shall equal that of weld 1. The length of weld 3 shall be sufficient to avoid overstressing the filler plate along the toe of the weld.
2. The effective area of weld 3 shall be at least equal that of weld 1 and there shall be no overstress of the ends of weld 3 resulting from the eccentricity of the forces acting on the filler plates.

Figure 2.2 — Filler Plates 1/4 in. (6.4 mm) or More in Thickness (see 2.4.3)

produce fatigue failure. Joints containing such welds, made from one side only, shall be restrained to prevent localized rotation.

2.6 Joint Qualification

2.6.1 Joint details conforming with the details described in 2.7 through 2.10, and 10.5, and illustrated in Appendixes B1 and B2 are recommended. Other details may be used.

2.6.2 The joint details and welding procedure shall be qualified by test as required by 5.2, and the procedure shall be recorded as a Welding Procedure Specification (WPS). A form for recording the WPS is given in Appendix E.

2.7 Details of Fillet Welds

2.7.1 The minimum fillet weld size, except for fillet welds used to reinforce groove welds, shall be as shown in Table 2.2.

2.7.2 The maximum fillet weld size permitted along edges of material shall be:

- (1) The thickness of the base metal, for metal less than 1/4 in. (6.4 mm) in thickness.
- (2) 1/16 in. (1.6 mm) less than the thickness of base metal, for metal 1/4 in. (6.4 mm) or more in thickness, unless the weld size is designated on the drawing or the weld is designated on the drawing to be built out to obtain full throat thickness.
- (3) The distance between the edge of the base metal and toe of the weld may be less than 1/16 in. (1.6 mm), provided the edge is clearly visible and the weld size clearly verifiable.

2.7.3 Fillet welds in holes or slots in lap joints may be used to transfer shear or to prevent buckling or separation of lapped parts. These fillet welds may overlap, subject to the provisions of 2.3.2.2. Fillet welds in holes or slots are not to be considered as plug or slot welds.

2.7.4 Fillet welds may be used in skewed T-joints having a dihedral angle of not less than 60° nor more than 135° (see Figure 2.3, details A and B).

2.7.5 The minimum length of an intermittent fillet weld shall be 1-1/2 in. (38 mm) or four times the nominal size, but not less than 1-1/2 in.

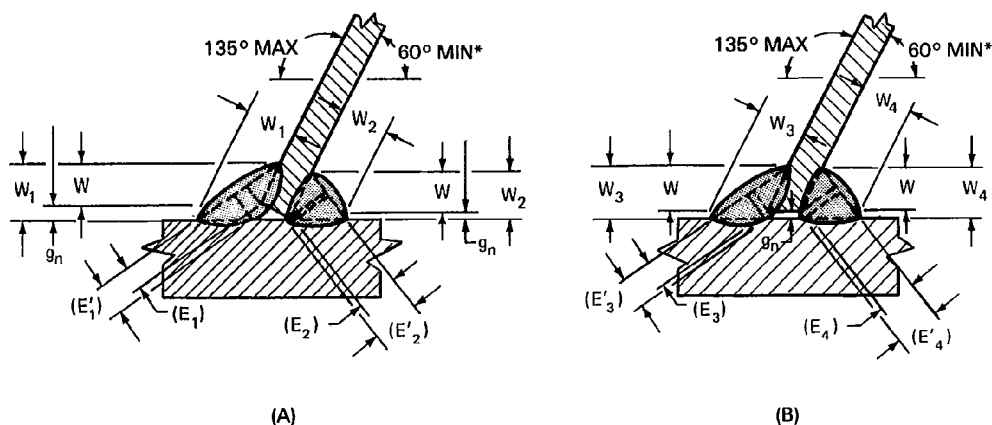
2.7.6 Minimum spacing and dimensions of holes or slots when fillet welding is used shall conform to the requirements of 2.8.

Table 2.2
Minimum Fillet Weld Size (see 2.7.1)

Base Metal Thickness of Thicker Part Joined (T)		Minimum Size of Fillet Weld*		
in.	mm	in.	mm	
T≤1/4	T≤ 6.4	1/8**	3	Single-pass welds shall be used
1/4<T≤1/2	6.4<T≤12.7	3/16	5	
1/2<T	12.7<T	1/4	6	

* Except that the weld size need not exceed the thickness of the thinner part joined. For this exception, particular care should be taken to provide sufficient preheat to ensure weld soundness.

** Minimum size for dynamically loaded structures is 3/16 in. (5 mm).



Skewed T-joints

Note: $(E)_{(n)}$, $(E')_{(n)}$ = effective throats dependent on magnitude of gap (g_n) . See 3.3.4. Subscript (n) represents 1, 2, 3, or 4.

*Angles smaller than 60° are permitted; however, in such cases, the weld is considered to be a partial joint penetration groove weld.

Figure 2.3 — Fillet Weld Details (see 2.7.4)

2.8 Details of Plug and Slot Welds⁵

2.8.1 The diameter of the hole for a plug weld shall be no less than that specified in Table 2.3.

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

2.8.3 The length of the slot for a slot weld shall not exceed ten times the thickness of the base metal. The width of the slot shall be no less than that specified in Table 2.3.

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

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

2.8.6 The depth of filling of plug or slot welds in metal $5/8$ in. (15.9 mm) in thickness or less shall be equal to the thickness of the material. In metal over $5/8$ in. in thickness, it shall be at least one-half the thickness of the material, but not less than $5/8$ in. except for M27 alloys where the depth of filling shall be the thickness of the material.

5. See Appendix D for the technique for making plug and slot welds.

Table 2.3

Minimum Diameter of Hole for Plug Welds or Width of Slot for Slot Welds (see 2.8.1)

Material Thickness T	Minimum Hole Diameter or Slot Width
Less than $1/8$ in. (3.2 mm)	3 T
$1/8$ or greater	2.5 T

2.9 Details of Complete Joint Penetration Groove Welds

2.9.1 Groove welds welded from one side on an approved backing material and groove welds welded from both sides with the root of the first weld back gouged to sound metal before welding the second side are considered complete joint penetration groove welds.

2.9.2 Recommended details of complete joint penetration groove welds in butt, corner, and T-joints are given in Appendix B1 and are subject to the limitations in 2.9.3.

2.9.3 Dimensional Tolerance. Dimensions of groove welds specified on design or detailed drawings may vary from those shown in Appendix B1 within the following limits.

2.9.3.1 The specified thickness of base metal or weld size is the maximum thickness that may be used.

2.9.3.2 The groove angle is minimum; it should be detailed to exceed the dimensions shown by no more than 10° .

2.9.3.3 The radius of J-grooves and U-grooves is minimum. It should be detailed to exceed the dimensions shown by no more than $1/8$ in. (3 mm). U-grooves may be prepared before or after fit-up.

2.9.3.4 Double-groove welds may have grooves of unequal depth, but the depth of the shallower groove shall be no less than 25% of the thickness of the thinner part joined, unless otherwise designated in Appendix B1.

2.9.3.5 The root face of the joint is minimum except where shown as a range. It should be detailed to exceed the dimension shown by no more than $1/16$ in. (1.6 mm).

2.9.3.6 The root opening of joints is minimum except where shown as a range. It should be detailed to exceed the dimension by no more than $1/16$ in. (1.6 mm).

2.10 Details of Partial Joint Penetration Groove Welds

2.10.1 Definition. Groove welds without backing, welded from one side, and groove welds welded from both sides, but without back gouging, are considered partial joint penetration groove welds.

2.10.2 Recommended details of partial joint penetration groove welds in butt, corner, and T-joints are given in

Appendix B2 and are subject to the limitations in 2.10.3 and 2.10.4.

2.10.3 Dimensional Tolerances. Dimensions of groove welds specified on design or detail drawings may vary from those shown in Appendix B2 within the following limits:

2.10.3.1 The groove angle is minimum; it should be detailed to exceed the dimensions shown by no more than 10° .

2.10.3.2 The radius of the J-grooves and U-grooves is minimum. It should be detailed to exceed the dimensions shown by no more than $1/8$ in. (3 mm). U-grooves may be prepared before or after fit-up.

2.10.3.3 Double-groove welds may have grooves of unequal depth, provided the weld deposit on each side of the joint conforms to the recommendations of Appendix B2.

2.10.3.4 The minimum root face of the joint should be $1/8$ in. (3 mm).

2.10.4 The minimum weld size of partial joint penetration square-, single- or double-V-, bevel-, J-, and U-groove welds shall be as shown in Table 2.1.

2.10.5 Shop or working drawings and the welding procedure specification shall specify the depth of preparation (S) applicable for the weld size (E) required for the welding process and the position of welding to be used.

3. Workmanship

3.1 General

3.1.1 All applicable subsections in this section shall be adhered to in the production and inspection of welded assemblies and structures produced under this Code.

3.1.2 All welding and cutting equipment shall be so designed and manufactured and shall be maintained in such operating condition that qualified welders, welding operators and tack welders are able to follow the procedures and attain the results prescribed elsewhere in this Code.

3.1.3 Welding shall not be done when the ambient temperature is lower than 32°F (0°C). This does not mean the ambient environmental temperature, but the temperature in the immediate vicinity of the weld. If the ambient environmental temperature is below 32°F, a heated structure or shelter may be provided which will maintain the temperature adjacent to the weldment at 32°F or higher. When the temperature of the weld area and surrounding base metal is below the allowed minimum temperature, the base metal shall be preheated so that the parts on which weld metal is being deposited are at, or above, the allowed minimum temperature for a distance equal to the thickness of the parts being welded, but not less than 3 in. (75 mm) both laterally and in advance of the welding. This heating is to be done before welding is started to drive moisture from the region of the weld.

3.1.4 Welding shall not be done when the surfaces are wet or exposed to rain, mist, snow, sleet, frost, or excessive wind, or when welders, welding operators or tack welders are exposed to such inclement conditions.

3.1.5 The sizes and lengths of welds shall be those specified by the design requirements and detail drawings.

3.1.6 The locations of welds shall not be changed from those shown on the drawings without prior approval of the Engineer.

3.1.7 The use of anti-spatter compound shall be prohibited, unless subjected to test and the approval of the Engineer, and its use shall be restricted to the flat position to reduce running. Masking shall be employed to prevent the compound from entering within 1 in. (25 mm) of the weld joint area. Where permitted, the use of anti-spatter compound shall be incorporated into the Welding Procedure Specification.

3.2 Preparation of Base Material

3.2.1 Edge preparation can be accomplished by shearing, sawing, plasma arc cutting, chipping, planing, milling or routing. Grinding of aluminum, except as a final weld contouring and finishing operation, is not recommended.

3.2.1.1 When grinding is necessary, care shall be taken to select nonloading type abrasives specifically intended for use on aluminum, and the abrasives shall be maintained free of lubricants and other foreign material.

3.2.1.2 For heat treatable aluminum alloys, 1/8 in. (3 mm) of material shall be removed from plasma arc cut edges by machining, except that plasma-arc cut edges of heat treatable aluminum alloy material may be used without machining when the cut area is separated from the immediate weld area and is not part of the welded joint.

3.2.2 Surfaces and edges to be welded shall be smooth, uniform, and free from fins, tears, and cracks.

3.2.3 In plasma arc cutting, the arc shall be adjusted and manipulated so as to avoid cutting beyond (inside) the prescribed lines. The surface roughness of the cut surfaces shall be no greater than that defined by the American National Standards Institute (ANSI B46.1, *Surface Texture*) value of 1000 μ in. (25 μ m) for material up to 4 in. (102 mm) thick and 2000 μ in. (50 μ m) for material 4 in.

to 8 in. (203 mm) thick, except that the ends of members not subject to calculated stress at the ends may meet the surface roughness value of 2000 μ in. Roughness exceeding the permissible amount and occasional notches or gouges more than 3/16 in. (5 mm) deep, on otherwise satisfactory surfaces, shall be faired into the cut surface by machining or grinding to a slope not exceeding one in ten. In cut edges, occasional notches or gouges less than 7/16 in. (11 mm) deep in material up to 4 in. in thickness, or less than 5/8 in. (16 mm) deep in material more than 4 in. thick may, with the approval of the Engineer, be repaired by welding. All approved repairs by welding shall be made by suitably preparing the site of the discontinuity, welding, and finishing the weld smooth and flush with the adjacent surface.

3.2.4 Visual Inspection and Repair of Cut Edges⁶

3.2.4.1 In the determination of limits of internal discontinuities revealed on sheared or cut edges and caused by tearing, inclusions, or delamination (seldom encountered in aluminum products), the amount of metal removed shall be the minimum necessary to remove the discontinuity or to determine that the permissible limit of the discontinuity is not exceeded. The removal of metal for this purpose may be done from either the plate surface or a cut edge. Cut edges may exist at any angle with respect to the direction of rolling.

3.2.4.2 The limits of acceptability and the repair of edge discontinuities shall be in accordance with Table 3.1, in which the length of the discontinuity is the visible

long dimension on the cut edge, and the depth is the distance that the discontinuity is determined to extend into the plate from the cut edge.

3.2.4.3 For discontinuities with both length and depth greater than 1 in. (25 mm), discovered by visual examination of the cut edge and determined to exceed 1 in. in depth for each discontinuity exhibited before welding or during examination of welded joints by radiographic or ultrasonic examination, the following procedures shall be followed:

(1) Where discontinuities, such as W, X, or Y in Figure 3.1, are discovered prior to completing the joint, the size and shape of the discontinuity shall be determined by ultrasonic inspection.

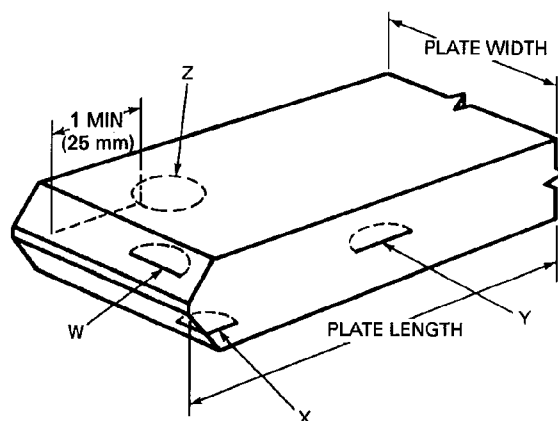


Figure 3.1 — Edge Discontinuities in Cut Plate (see 3.2.4.3)

6. The requirements of 3.2.4 are not applicable to cases in which the stress is applied normal to the plate surface.

Table 3.1
Limit of Acceptability and Repair of Cut Edge Discontinuities in Plate (see 3.2.4.2)

Description of Discontinuity	Plate Repair Required
Any discontinuity 1 in. (25 mm) in length or less	None, need not be explored.
Any discontinuity over 1 in. (25 mm) in length and 1/8 in. (3 mm) maximum depth	None, but the depth should be explored.*
Any discontinuity over 1 in. (25 mm) in length with depth over 1/8 in. (3 mm) but not greater than 1/4 in. (6 mm)	Remove, need not weld.
Any discontinuity over 1 in. (25 mm) in length with depth over 1/4 in. (6 mm) but not greater than 1 in. (25 mm).	Completely remove and weld. Aggregate length of welding shall not exceed 20% of the length of the plate edge being repaired.
Any discontinuity over 1 in. (25 mm) in length with depth greater than 1 in.	See 3.2.4.3.

*A spot check of 10% of the discontinuities on the cut edge in question should be explored to determine depth. If the depth of any one of the discontinuities explored exceeds 1/8 in. (3 mm), then all of the discontinuities remaining on that edge shall be explored to determine depth. If none of the discontinuities explored in the 10% spot check have a depth exceeding 1/8 in. (3 mm), then the remainder of the discontinuities on that edge need not be explored.

(2) For acceptance, the area of the discontinuity (or the aggregate area of multiple discontinuities) shall not exceed 4% of the plate area (length x width) with the following exception: If the length of the discontinuity, or the aggregate length of discontinuities on any transverse section, as measured perpendicular to the plate length, exceeds 20% of the plate width, the 4% allowance shall be reduced by the percentage amount of the length exceeding 20%. (For example, if the length of a discontinuity is 30% of the plate width, the area of discontinuity cannot exceed 3.6% of the plate area.) The discontinuity on the cut edge of the plate shall be gouged out to a depth of 1 in. (25 mm) beyond its intersection with the surface by chipping or gouging, and blocked off by welding in layers not exceeding 1/8 in. (3 mm) in thickness.

(3) If a discontinuity, Z, not exceeding the allowable area in 3.2.4.3 (2) is discovered after the joint has been completed and is determined to be 1 in. (25 mm) or more away from the weld, no repair of the discontinuity is required. If the discontinuity Z is less than 1 in. away from the weld, it shall be gouged out to a distance of 1 in. from the fusion zone of the weld by chipping or gouging. The groove shall then be filled by welding in layers not exceeding 1/8 in. (3 mm) in thickness. Repair by welding shall be subject to the same NDT requirement as other groove welds.

(4) If the area of the discontinuity W, X, Y, or Z exceeds the allowable limits in 3.2.4.3 (2), the plate or subcomponent shall be rejected and replaced, or repaired at the discretion of the Engineer. The aggregate length of weld repair shall not exceed 20% of the length of the plate edge, without the approval of the Engineer.

(5) All repair welding shall be in accordance with a qualified procedure and the applicable subsections of this code, and performed by a qualified welder.

3.2.5 Reentrant corners, except for the corners of weld-access cope holes adjacent to a flange, shall have a fillet radius of no less than 1/2 in. (13 mm) for statically loaded and tubular structures and 3/4 in. (19 mm) for dynamically loaded structures. The fillet and its adjacent cuts shall meet without offset or cutting past the point of tangency.

3.2.6 Machining, sawing, gouging, or chipping may be used to back gouge, remove temporary welds, or remove unacceptable work or metal.

3.2.7 Edges of webs or built-up beams and girders shall be cut to the prescribed camber with allowance for shrinkage due to cutting and welding. Moderate variation from the specified camber may be corrected by procedures approved by the Engineer. Heat-shrink techniques should generally not be applied to aluminum structures.

3.2.8 All surfaces to be welded shall be free from thick aluminum oxide, paint, grease, cutting fluids and moisture.

3.2.8.1 Heavily oiled material should be degreased either chemically or with an approved solvent. Caution should be exercised in the use of flammable solvents. The health and safety concerns should be recognized (see ANSI/ASC Z49.1).

3.2.8.2 Thick aluminum oxide should be removed with a power-driven stainless steel brush or other approved material, or by chemical methods.

3.2.9 Degreasing should be followed by scratch brushing of surfaces to be welded, with a hand or power-driven stainless steel brush to ensure thick aluminum oxide is removed. In multi-pass welds scratch brushing may be necessary between passes. The brushes should be kept exclusively for use with aluminum and be kept clean.

The interval between cleaning of the joint and welding shall be as short as possible. If contamination with dirt or moisture occurs after cleaning and prior to welding, the joint should be recleaned.

3.3 Assembly

3.3.1 Abutting parts to be joined by groove welds shall be properly aligned. Where the parts are effectively restrained against bending due to an offset in alignment, an offset not exceeding 10% of the thickness of the thinner part, but in no case more than 1/8 in. (3 mm), may be allowed as a departure from the theoretical alignment. In correcting misalignment in such cases, the parts shall not be drawn in to a greater slope than 1/2 in. in 12 in. (13 mm in 305 mm). Measurement of offset shall be based on the midplanes of the parts, unless otherwise shown on the drawings.

3.3.2 Welding grooves which vary from those shown on the detail drawings and procedure specifications by more than the following tolerances shall be referred to the Engineer for approval, correction or rejection:

- | | |
|--|---|
| (1) Root face of joint | $\pm 1/16$ in. (1.6 mm) |
| (2) Root opening of joints without backing | $\pm 1/16$ in. (1.6 mm) |
| (3) Root opening of joints with integral backing | + 1/4 in. (6 mm)
- 1/16 in. (1.6 mm) |
| (4) Groove angle of joint | + 10°, - 5° |

3.3.3 Parts to be joined by partial joint penetration groove welds parallel to the length of the member, except for bearing joints, shall be brought into contact as closely as practicable. The root opening between parts shall not exceed 3/16 in. (5 mm) except in cases involving rolled or extruded shapes, or plates 3 in. (76.2 mm) or more in thickness. When after straightening, the root opening cannot be closed sufficiently to meet this tolerance, a maximum root opening of 5/16 in. (8 mm) is acceptable,

provided a sealing weld or suitable backing material is used to prevent melt-through.⁷

3.3.4 Parts to be joined by fillet welds shall be brought into contact as closely as practicable. The separation between parts shall not exceed 1/16 in. (1.6 mm), except in cases involving rolled or extruded shapes or plates 3 in. (76.2 mm) or more in thickness. When after straightening and in assembly, the root opening cannot be closed sufficiently to meet this tolerance, a maximum separation of 5/16 in. (8 mm) is acceptable, provided a sealing weld or suitable backing is used to prevent melt-through. If the separation is greater than 1/16 in. (1.6 mm), 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.

3.3.5 The work shall be positioned for flat-position welding whenever practicable.

3.3.6 The separation between faying surfaces of lap joints and of butt joints landing on a backing shall not exceed 1/16 in. (1.6 mm). The use of filler plates is prohibited except as specified on the drawings or as specifically approved by the Engineer and made in accordance with 2.4.

3.3.7 Members to be welded shall be brought into correct alignment and held in position by fixtures and strongbacks, bolts, clamps, wedges, guy lines, struts, other suitable devices, or by tack welds until the welding has been completed. The use of fixtures is recommended when practicable. The fixtures shall have sufficient stiffness and strength to counteract the forces resulting from the temperature changes in the weldment. Similarly, tack welds shall have sufficient effective throat or weld size and length to develop the necessary strength.

3.3.7.1 Tack welds shall be made in accordance with a qualified tack welding procedure, by a qualified tack welder, and subject to the same quality requirements as the final welds. Tack welds which are to be incorporated into the final weld shall be made with filler metal of the same composition and shall be cleaned thoroughly before incorporation. Tack welds not incorporated into final welds shall be removed by mechanical means, unless otherwise permitted to remain by the Engineer.

3.3.7.2 Temporary welds shall be made by a qualified welding procedure, by a qualified welder, and be subject

7. Backing to prevent melt-through may be of ceramic, glass tape, austenitic stainless steel or an alloy with the M-number classification of the base metal. The backing shall be in intimate contact with the root side of the components being welded. If aluminum alloy backing is to be left permanently in place, it may be attached by continuous fillet welds. Tolerances for bearing joints shall be in accordance with the Contract Documents.

to the same quality requirements as the final weld. Strongbacks, clips, hangers and other temporary parts that have been welded in place to facilitate assembly shall be removed and the welds made flush with the metal surface. Surface defects that extend below the plane of the metal surface shall be welded and finished flush.

3.4 Control of Distortion and Shrinkage

3.4.1 In assembling and joining parts of a structure or of built-up members, and in welding reinforcing parts to members, the procedure and sequence shall be such as will minimize distortion and shrinkage.

3.4.2 Insofar as practicable, all welds shall be deposited in a sequence that will balance the applied heat of welding while the welding progresses.

3.4.3 The contractor shall prepare a welding sequence specification for a member or structure which, in conjunction with the joint welding procedures and overall fabrication methods, will produce members or structures meeting the quality requirements specified. The welding sequence and distortion-control program shall be submitted to the Engineer, for information and comment, before the start of welding on a member in which shrinkage or distortion is likely to affect the adequacy of the member or structure.

3.4.4 Prior crimping of edges may be used to reduce the warpage and shrinkage.

3.4.5 The direction of the general progression in welding on a member shall be from points where the parts are relatively fixed in position with respect to each other toward points where they have a greater relative freedom of movement.

3.4.6 Joints expected to have significant shrinkage should usually be welded before joints expected to have lesser shrinkage.

3.4.7 All shop welds in each component part of a cover-plated beam or built-up member shall be made before the component part is welded to other component parts of the member. Long girders or girder sections may be made by shop splicing subsections, each made in accordance with this subsection.

3.4.8 In making welds under conditions of severe external shrinkage restraint, the welding shall be completed or completed to a point that will ensure freedom from cracking, before the joint is allowed to cool.

3.5 Dimensional Tolerances

The dimensions of welded structural members shall conform to the tolerance of (a) the general specifications

governing the work and (b) the following special dimensional tolerances:

3.5.1 Straightness of Columns. Permissible variations from straightness of welded columns and primary truss members, regardless of cross section, shall not exceed:

lengths of 45 ft (14 m) and under:

$$1/8 \text{ in.} \times \frac{\text{Total length, in feet}}{10}$$

$$3 \text{ mm} \times \frac{\text{Total length, in meters}}{3}$$

but not over 3/8 in. (10 mm)

lengths over 45 ft:

$$3/8 \text{ in.} + 1/8 \text{ in.} \times \frac{\text{Total length, in feet,} - 45}{10}$$

$$10 \text{ mm} + 3 \text{ mm} \times \frac{\text{Total length, in meters,} - 14}{3}$$

3.5.2 Straightness of Beams and Girders. Variations in straightness at any point along either flange of welded beams or girders, regardless of cross section, where there is no specified sweep, shall not exceed:

$$1/8 \text{ in.} \times \frac{\text{Total length, in feet}}{10}$$

$$3 \text{ mm} \times \frac{\text{Total length, in meters}}{3}$$

3.5.3 Camber of Beams and Girders. Departures from the specified camber at any point along welded beams or girders (as fabricated members before placement in the structure), regardless of cross section, shall not exceed:

$$-0, + 1/4 \text{ in. (6 mm)}$$

or,

$$-0, + 1/4 \text{ in.} \times \frac{\text{Total length, in feet}}{10}$$

$$-0, + 6 \text{ mm} \times \frac{\text{Total length, in meters}}{3}$$

but not to exceed 3/4 in. (19 mm) or

$$-0, + 1/8 \text{ in.} \times \frac{\text{Distance to nearest end, in feet}}{10}$$

$$-0, + 3 \text{ mm} \times \frac{\text{Distance to nearest end, in meters}}{3}$$

3.5.4 Deviation Between Web and Flange. Lateral deviation between the centerline of the web and the centerline of the flange of built-up H or I members at the contact surface shall not exceed 1/4 in. (6 mm).

3.5.5 Flatness of Webs. For permissible deviations from flatness of webs of girders in nontubular statically and

dynamically loaded structures, see 8.5 and 9.5, respectively.

3.5.6 Warpage of Flanges. The combined warpage and tilt of a flange of welded beams and girders shall be determined by measuring the offset at the toe of the flange from a line normal to the plane of the web through the intersection of the centerline of the web with the outside surface of the flange plate. This offset shall not exceed 1% of the total flange width or 1/4 in. (6 mm), whichever is greater, except that abutting parts to be joined by groove welds shall fulfill the requirements of 3.3.1.

3.5.7 Depth of Beams and Girders. The deviation from the specified depth of welded beams and girders, measured at the web centerline, shall not exceed the following:

for depths up to 36 in. (0.9 m)	± 1/8 in. (3 mm) inclusive.
---------------------------------	-----------------------------

for depths over 36 in. (0.9 m) to 72 in. (1.8 m), inclusive.	± 3/16 in. (5 mm)
--	-------------------

for depths over 72 in. (1.8 m)	+ 5/16 in. (8 mm) - 3/16 in. (5 mm)
--------------------------------	--

3.5.8 Fit of Bearing Stiffeners. The bearing ends of bearing stiffeners shall be flush and square with the web and shall have at least 75% of the area in contact with the inner surface of the flange plate.

3.5.9 Straightness of Bearing Stiffeners. The out-of-straightness of bearing stiffeners shall not exceed 50% of the thickness of the stiffener, or 1/4 in. (6 mm) in girders and beams up to 6 ft (1.8 m) in depth, or 1/2 in. (13 mm) in girders or beams more than 6 ft (1.8 m) in depth.

3.5.10 Bearing on Bases and Seats. For beams and girders with bearing stiffeners and bearing against a base or seat, the outer surface of the flange shall fit within 0.010 in. (0.25 mm) over 75% of the bearing area defined by the bearing length of the web and the width of the stiffeners and within 1/32 in. (1 mm) over the remaining 25% of the bearing area. For beams and girders bearing on a base or seat, but having no bearing stiffeners, the outer surface of the flange shall fit within 0.010 in. (0.25 mm) over the bearing length of the web, and the included angle between the web and flange plate shall not exceed 90° in the bearing length.

3.5.11 Fit of Intermediate Stiffeners. Where a tight fit of intermediate stiffeners is specified, the fit shall be defined as allowing a gap of up to 1/16 in. (1.6 mm) between stiffener and flange.

3.5.12 Straightness of Intermediate Stiffeners. The out-of-straightness of intermediate stiffeners shall not exceed 1/2 in. (13 mm), with due regard to members which frame into them.

3.5.13 Other Dimensional Tolerances. Dimensional tolerances not covered by 3.5 or the contract documents shall be individually determined and mutually agreed upon by the contractor and the Engineer, with proper regard for erection conditions and requirements.

3.6 Weld Profiles

3.6.1 The faces of fillet welds may be slightly convex, flat, or slightly concave as shown in Figures 3.2(A) and 3.2(B), with none of the unacceptable profiles shown in Figure 3.2(C). Except at outside corner joints, the convexity, C, of a weld or individual surface bead shall not exceed 0.07 times the actual face width of the weld or individual bead, respectively, plus 0.06 in. (1.5 mm).

3.6.2 Groove welds shall be made with slight or minimum reinforcement unless otherwise specified. In the case of butt and corner joints, the weld reinforcement and melt-through height shall not exceed the values listed in Figures 3.2(D) and 3.2(E) and shall have a gradual transition to the plane of the base metal surface. The weld shall be free of discontinuities of the types shown for butt joints in Figure 3.2(F).

3.6.3 Surfaces of butt joints required to be flush shall be finished so as not to reduce the thickness of either of the base metals or weld metal by more than 1/32 in. (1 mm) or 5% of the thickness, whichever is smaller, or leave reinforcement that exceeds 1/32 in. All reinforcement shall blend smoothly into the plate surfaces with transition areas free from edge weld undercut. Where the weld forms part of a faying or contact surface, all reinforcement shall be removed. Chipping may be used, provided it is followed by grinding or other smoothing operation. Where surface finishing is required, its roughness value (ANSI B46.1, Surface Texture), in microinches (micrometers) shall not exceed 500 μ in. (12.0 μ m).

3.6.4 Welds shall be free from overlap.

3.7 Repairs

3.7.1 The removal of weld metal or portions of the base metal may be done by mechanical means in accordance with 3.2.1. The removal shall be done so that the remaining weld metal and base metal are not nicked or undercut. Unacceptable portions of the weld shall be removed without substantial removal of base metal. Metal added to compensate for any deficiency in the size of the weld shall be deposited by a qualified welder with filler of the same composition in accordance with an approved welding procedure. The surfaces shall be cleaned thoroughly before welding.

3.7.2 The contractor has the option of either repairing an unacceptable weld, or removing and replacing the

entire weld, except as required by 3.7.5. If the contractor elects to repair the weld, it shall be corrected as follows:

3.7.2.1 Overlap or Excessive Convexity. Excess weld metal shall be removed by machining, chipping, or grinding.

3.7.2.2 Excessive Concavity of Weld or Crater, Under-size Welds, Undercutting. Surfaces shall be prepared and additional weld metal deposited, in accordance with the specified welding procedure.

3.7.2.3 Excessive Weld Porosity or Incomplete Fusion. Unacceptable portions shall be removed and the area rewelded in accordance with the specified welding procedure.

3.7.2.4 Cracks in Weld or Base Metal. The extent of the crack shall be ascertained by use of dye penetrant, X-ray examination, or other NDT means. The crack shall be removed and the area rewelded in accordance with the specified welding procedure. If dye penetrant is used, all traces of penetrant and developer shall be removed before rewelding is begun.

3.7.3 If the contractor elects to remove and replace the entire weld, a procedure approved by the Engineer shall be used and such replacement welds shall be recorded on the shop drawings.

3.7.4 The repaired or replaced weld shall be tested or examined by the method originally used and the same technique and quality acceptance criteria shall be applied.

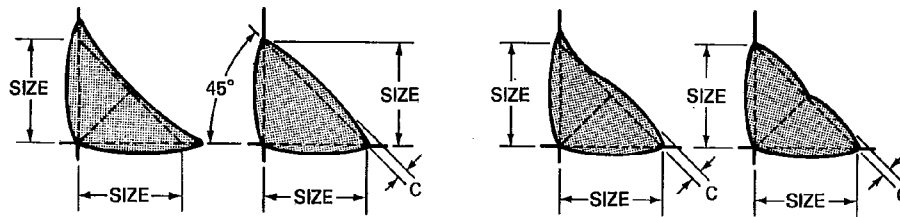
3.7.5 Members distorted by welding shall be straightened at ambient temperature by mechanical means or by carefully supervised application of a controlled amount of localized heat in conjunction with mechanical means. If localized heating is to be applied in any straightening operation, the complete procedure shall be filed with and approved by the Engineer. This procedure shall adhere to the maximum temperature values listed in Table 3.2 and the following:

3.7.5.1 Except for those stresses resulting from the mechanical straightening method used in conjunction with the application of heat, the part to be heated for straightening shall be substantially free of stress and from external forces.

3.7.5.2 Maximum holding times for the forming and straightening of aluminum alloys at various temperatures are given in Table 3.2.

3.7.5.3 For 1XXX, 3XXX, and 5XXX series alloys with magnesium contents less than 3% and for cast alloy 443.0, there are no restrictions on the temperature except that, as temperature is increased, properties are diminished.

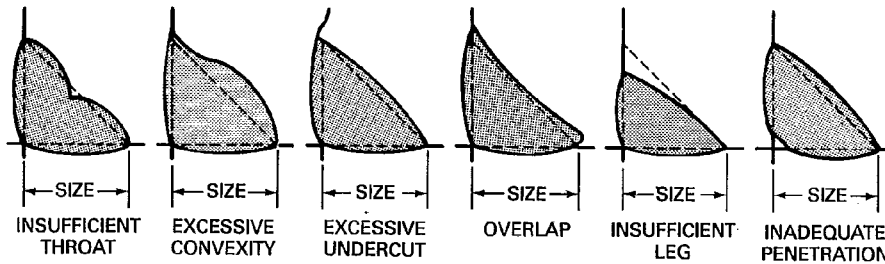
3.7.5.4 For 5XXX series wrought alloys and cast alloys 514.0 and 535.0 with magnesium content greater



Note: Convexity, C, of a weld or individual surface bead shall not exceed 0.07 times the actual face width of the weld or individual bead, respectively, plus 0.06 in. (1.5 mm).

(A) DESIRABLE FILLET WELD PROFILES

(B) ACCEPTABLE FILLET WELD PROFILES



(C) UNACCEPTABLE FILLET WELD PROFILES

MAXIMUM REINFORCEMENT FOR A GIVEN PLATE THICKNESS—JOINT WELDED FROM BOTH SIDES

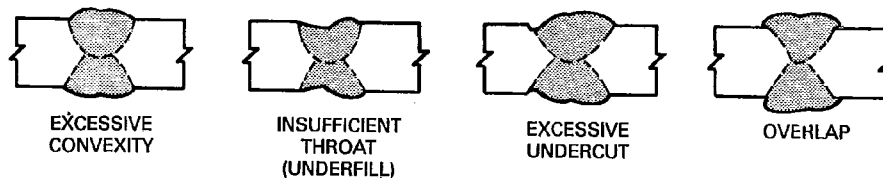
THICKNESS, t		MAXIMUM REINFORCEMENT	
in.	mm	in.	mm
$t \leq 3/8$	$t \leq 9.5$	3/32	2.4
$3/8 < t \leq 3/4$	$9.5 < t \leq 19$	1/8	3
$t > 3/4$	$t > 19$	3/16	5

(D) ACCEPTABLE PROFILE: DOUBLE GROOVE WELD IN BUTT JOINT

MAXIMUM REINFORCEMENT FOR A GIVEN PLATE THICKNESS—JOINT WELDED FROM ONE SIDE

THICKNESS, t		MAXIMUM REINFORCEMENT	
in.	mm	in.	mm
$t \leq 1/4$	$t \leq 6.4$	3/32	2.4
$1/4 < t \leq 1/2$	$6.4 < t \leq 12.7$	1/8	3
$1/2 < t \leq 1$	$12.7 < t \leq 25.4$	5/32	4
$t > 1$	$t > 25.4$	3/16	5

(E) ACCEPTABLE PROFILE: GROOVE WELD IN BUTT JOINT WELDED FROM ONE SIDE



(F) UNACCEPTABLE PROFILES: GROOVE WELDS IN BUTT JOINTS

Figure 3.2 — Acceptable and Unacceptable Weld Profiles (see 3.6)

Table 3.2
Maximum Heat Exposure Time at Temperature
Preparatory to Forming Aluminum Alloys (see 3.7.5)

Holding Temperature (Note 1)		2219-T31, T351, T37 6005-T5 6061-T4, T5 Alclad 6061-T4, T5 6063-T5 6351-T5 (Note 2)	1060, 1100, 3003, 3004 Alclad 3003, Alclad 3004 5005, 5050, 5052, 5652 5454 443.0 (Note 3)	5083 5086 5154 5254 5456 514.0 535.0 (Note 3)	7005-T53 (Note 4)	A201.0-T4 354.0-T4 C355.0-T4 356.0-T4 A356.0-T4 357.0-T4 A357.0-T4 359.0-T4 (Note 5)
°F	°C					
800	427	NR ⁶	50 Hours	50 Hours	50 Hours	NR
500	260	NR	50 Hours	50 Hours	NR	NR
450	232	5 Minutes	50 Hours	50 Hours	NR	NR
425	218	15 Minutes	50 Hours	50 Hours	NR	NR
400	204	30 Minutes	50 Hours	50 Hours	NR	NR
375	191	1-2 Hours	50 Hours	NR	NR	NR
350	177	8-10 Hours	50 Hours	NR	NR	NR
230-325	121-163	50 Hours	50 Hours	NR	NR	Note 5

Notes:

1. Equal formability may be obtained with shorter periods of heating at correspondingly higher temperatures. Time at temperature for clad alloys should be kept at a minimum to prevent diffusion of the cladding into the core alloy. Heating should be as rapid as possible, particularly for temperatures 400°F (204°C) and above. Excessive time to approach the desired temperatures can have deleterious effects similar to those resulting from excess time at temperature.
2. Losses in strength for these alloys in the T6 temper will not exceed about 5% when heated at the temperature and for the periods shown. Strength of the T4 temper alloys will increase.
3. These alloys will be annealed at 650°F (343°C) and above.
4. Refer to 3.7.5.6.
5. Refer to 3.7.5.7.
6. NR = Not Recommended

than 3%, holding within the temperature range from 150°F to 450°F (65°C to 230°C) must be avoided in order to minimize the possibility of sensitization to exfoliation and stress corrosion cracking. The length of time at temperature is a critical factor in determining the degree of sensitization. Hot forming techniques shall include quick heatup to a temperature not to exceed 550°F (290°C) in order to minimize the loss of mechanical properties. Forming shall be complete before the metal cools below 450°F (230°C). The metal should then be fan cooled to drop the metal temperature from 450°F to 150°F (230°C to 66°C) in the minimum time possible to prevent sensitization.

3.7.5.5 For alloy 2219 and 6XXX alloys, distortion removal shall be done at a temperature below 450°F (230°C). The time that the structure is held at temperature while removing the weld distortion shall not exceed those times shown in Table 3.2.

3.7.5.6 For 7005 alloy, distortion removal shall be done preferably in the O-annealed⁸ or W, solution heat-treated condition, and then the structure shall be given the appropriate thermal treatment after straightening.

3.7.5.7 For A201.0 and the 3XX.0 casting alloys, straightening shall be done in the T4 condition before age hardening. The preheat shall not exceed 300°F (150°C) for these castings and should be of short duration for the 3XX.0 alloys so as not to affect the

8. A soak of several hours at temperatures of 650°F - 750°F (340°C - 400°C) will anneal 7005. Annealing is normally followed by a slow cool (50°F/hr) (28°C/hr) to about 400°F (200°C) to prevent room temperature aging. If severe forming is required, it should be accomplished within 12 hours after annealing or solution heat treatment. Forming 7005 alloy in an artificially aged temper may produce residual stresses which can cause stress-corrosion cracking.

heat-treated properties. Casting alloy A201.0 may be preheated to 300°F for a longer duration (up to 5 hours).

3.7.6 Approval of the Engineer shall be obtained for such corrections as weld repairs to mill defects in the base metal, repair of major or delayed cracks, or a revised design to compensate for deficiencies.

3.7.7 The Engineer shall be notified before improperly fitted and welded members are cut apart.

3.7.8 If, after an unacceptable weld has been made, work is performed which has rendered that weld inaccessible or has created new conditions which make correction of the unacceptable weld dangerous or ineffective, then the original conditions shall be restored

by removing the added welds or members, or both, before the corrections are made. If this is not done, the deficiency shall be compensated for by additional work performed according to an approved revised design.

3.8 Cleaning of Completed Welds

3.8.1 Welded joints shall not be painted or otherwise covered before the welding is examined and approved.

3.8.2 Where appearance is important, weld spatter, adhesions, scratches, etc., shall be removed by wire brushing, grinding, sanding, or polishing and the surface cleaned with a chemical cleaner.

4. Technique

Part A **General Requirements for Gas Metal Arc, Gas Tungsten Arc, and Plasma Arc (Variable Polarity) Welding**

4.1 Material Requirements

4.1.1 The filler metal shall comply with all the requirements set forth in the latest edition of ANSI/AWS A5.10, *Specification for Bare Aluminum and Aluminum Alloy Welding Electrodes and Rods*.

4.1.2 Filler metal alloys to be used with specific base metals and combinations of base metals shall be as shown in Table 1.2.

4.1.3 When requested by the Engineer, the contractor or fabricator shall furnish the electrode manufacturer's certification that the filler metal has met the requirements of the latest edition of ANSI/AWS A5.10.

4.2 Welding Processes

The welding process shall be either gas metal arc (GMAW), gas tungsten arc (GTAW), or plasma arc with variable polarity (PAW-VP).

4.3 Shielding Gases

4.3.1 Argon, helium, or mixtures of argon and helium used for shielding shall be a welding grade having a dew point of -63°F (-53°C) or lower.

4.3.2 When requested by the Engineer, the contractor or fabricator shall furnish the gas manufacturer's certification that the gas or gas mixture is suitable for the intended application and conforms to the dew point required in 4.3.1.

4.4 Preheat Requirements

Preheating is sometimes used for welding thick aluminum sections to avoid cold-start defects, to achieve heat balance with dissimilar thicknesses, or to remove moisture. Special care shall be taken to ensure close temperature control, particularly when fabricating the heat treatable aluminum alloys and the 5000 series aluminum alloys containing more than 3% magnesium. Preheating temperatures for these types of alloys shall not exceed 250°F (120°C). Holding times at this temperature shall not exceed 15 minutes.

4.5 Interpass Temperature Requirements

When fabricating the heat treatable aluminum alloys and the 5000 series alloys containing more than 3% magnesium, interpass temperatures shall not exceed 300°F (150°C) to provide optimum weld properties and to decrease the possibility of sensitization to exfoliation and stress-corrosion cracking.

4.6 Arc Strikes

Arc strikes outside the area of permanent welds should be avoided on any base metal. Blemishes caused by arc strikes shall be finished to a smooth contour and checked to ensure no loss of soundness of the base metal. Cracks caused by arc strikes shall be removed. The cracks shall be repair-welded and the weld finished flush with the metal surface.

4.7 Cleaning Prior to Welding

All joint faces and the surfaces adjacent to the area to be welded shall be prepared in accordance with 3.2.8.

4.8 Weld Termination

4.8.1 Welds shall be started and stopped in a manner that ensures sound welds. Whenever possible, the start-

ing and stopping shall be done by the use of extension bars or run-on and run-off plates.

4.8.2 Extension bars or run-on and run-off plates shall be removed (preferably by mechanical cutting) upon completion and cooling of the weld. The ends of the weld shall be made smooth and fit flush with the edges of the adjacent parts.

4.8.3 When it is impossible to terminate a weld on an extension bar or run-on or run-off plate, prior consideration to weld termination should be given so as to terminate the weld in a low stress area.

4.8.4 The techniques for terminating a fillet weld or a cover pass bead within a joint shall consist of the following, or any combination of the following:

- (1) Reversing the direction of travel for a minimum distance of 2 in. (50 mm)
- (2) Increasing travel speed to reduce crater size
- (3) Providing suitable build-up and remolding the crater area flush with the weld surface by mechanical means

4.8.5 Craters existing in tack welds that will be incorporated into final welds, extension of fillet welds, and within intermediate or root passes of root welds, shall be removed by mechanical means prior to additional welding.

4.9 Backing to Prevent Melting Through

4.9.1 Permanent backing for groove welds shall be of aluminum of the same M-Number as the base metal. The weld shall be thoroughly fused to the backing.

4.9.2 Backing shall be made continuous for the full length of the weld. All welds in the backing shall be complete joint penetration groove welds with the reinforcement ground smooth. These welds shall meet the workmanship requirements of section 3 of this Code.

4.9.3 In statically loaded and tubular structures, permanent backing need not be removed unless specified on the drawings or by the Engineer.

4.9.4 On dynamically loaded structures, backing that is transverse to the direction of the computed stress shall be removed, and the joint shall be finished smooth. Backing that is parallel to the direction of the computed stress, or is not subject to computed stress, need not be removed, unless specified on the drawings or by the Engineer.

4.9.5 Temporary backing for groove welds may be of austenitic stainless steel, glass tape, ceramic, or anodized aluminum of the same M-number. Copper shall not be used as temporary backing because of the dangers of weld contamination and corrosion problems.

4.10 Peening

Weld peening may be used subject to the approval of the Engineer.

4.11 Thermal Stress-Relief Treatment

4.11.1 Where required by contract documents, welded assemblies shall be stress relieved by thermal treatment. Specific thermal practices should be determined for each alloy and temper considered for stress relief. Finish machining shall preferably be done after stress relief.

4.11.2 The stress relief treatment procedure shall be approved by the Engineer prior to beginning the work, and shall conform to the following requirements:

(1) The temperature of the furnace shall not exceed 200°F (95°C) at the time the welded assembly is placed in it.

(2) The maximum temperature developed in any part of the assembly and the exposure time shall not exceed the applicable values stated in Table 3.2, unless the assembly is completely reheat-treated.

(3) During the heating period, the variation in temperature throughout the weldment shall be no greater than 100°F (38°C) within any 15 ft (4.5 m) interval of length.

4.11.3 Complete annealing in the case of nonheat treatable alloys can be accomplished by bringing all parts of the assembly in the furnace to 650°F (340°C). The heat treatable alloys can be completely annealed by bringing the work to 775°F (410°C), holding for two or three hours at 775°F, cooling slowly at a rate not to exceed 50°F (28°C) per hour until 500°F (260°C) is reached, and then furnace or air cooling to room temperature. However, these temperatures may cause the aluminum alloys to be altered to an extent that may make them unsuitable for the intended purpose.

Part B Gas Metal Arc Welding

4.12 General

This part covers specific requirements for gas metal arc welding in addition to requirements of Part A of this section.

4.13 Restrictions on Gas Metal Arc Welding with Single Electrode

4.13.1 The following are restrictions on the welding procedures:

4.13.1.1 The maximum size of a stringer bead fillet weld made in one pass shall be 1/2 in. (13 mm) for the flat and vertical positions and 3/8 in. (10 mm) for the horizontal and overhead positions.

For heat treatable aluminum alloys that are to be postweld precipitation-age-hardened only, the maximum size of stringer bead fillet welds made in one pass shall be 5/16 in. (8 mm) for all welding positions.

4.13.1.2 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 exceeds 3/8 in. (10 mm), 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 1/2 in. (13 mm).

4.13.1.3 The welding current, voltage, gas flow and travel speed shall be such that the arc is in the spray transfer mode and that each pass will have complete fusion with adjacent weld metal and base metal. There shall be no overlap or excessive porosity or undercutting.

4.13.1.4 The progression of all passes of vertical position welding shall be upwards.

4.13.1.5 Welding shall employ the forehand technique. A backhand technique shall be permitted for root pass deposition when the welder is qualified for that technique.

4.13.2 Except as noted in section 10, complete joint penetration groove welds made without the use of back-

ing shall have the root of the initial pass backgouged, chipped, or otherwise removed to sound metal, and all trace of root discontinuity shall be eliminated before welding is started on the second side.

4.13.3 Gas metal arc welding shall not be done in a draft or wind. Where drafty conditions exist, a windbreak or shelter shall be employed. The shelter shall be of an appropriate material and shape to reduce the wind velocity in the vicinity of the weld to a maximum of five miles per hour (eight kilometers per hour).

4.13.4 Copper inclusions deposited during meltback time (burnback) shall be gouged, chipped, or otherwise removed to sound metal.

Part C Gas Tungsten Arc Welding

4.14 General

This part covers specific requirements for gas tungsten arc welding in addition to the requirements of Part A of this section.

4.15 Tungsten Electrodes

For gas tungsten arc welding, the levels of welding current shall be compatible with the diameter of the electrode. Table 4.1 shows the operating current ranges for tungsten electrodes of various diameters and types,

Table 4.1
Typical Current Ranges for Tungsten Electrodes^a (see 4.15)

Electrode Diameter		Direct Current, A		Alternating Current, A					
		Straight Polarity	Reverse Polarity	Unbalanced Wave			Balanced Wave		
		EWP	EWP						
		EWTh-1 EWTh-2 EWTh-3	EWTh-1 EWTh-2 EWTh-3	EWP	EWTh-1 EWTh-2 EWZr	EWTh-3	EWP	EWTh-1 EWTh-2 EWZr	EWTh-3
in.	mm								
0.010	0.25	up to 15	b	up to 15	up to 15	b	up to 15	up to 15	b
0.020	0.51	5-20	b	5-15	5-20	b	10-20	5-20	10-20
0.040	1.02	15-80	b	10-60	15-80	10-80	20-30	20-60	20-60
1/16	1.59	70-150	10-20	50-100	70-150	50-150	30-80	60-120	30-120
3/32	2.38	150-250	15-30	100-160	140-235	100-235	60-130	100-180	60-180
1/8	3.18	250-400	25-40	150-210	225-325	150-325	100-180	160-250	100-250
5/32	3.97	400-500	40-55	200-275	300-400	200-400	160-240	200-320	160-320
3/16	4.76	500-750	55-80	250-350	400-500	250-500	190-300	290-390	190-390
1/4	6.35	750-1000	80-125	325-450	500-630	325-630	250-400	340-525	250-525

Notes:

a. All values are based on the use of argon as the shielding gas. Other current values may be employed depending on the shielding gas, type of equipment, and application.

b. These combinations are not commonly used.

and Table 4.2 shows the chemical composition of the AWS classifications.

4.16 Restrictions on Gas Tungsten Arc Welding

4.16.1 The following are restrictions on the welding procedures:

4.16.1.1 The maximum size of a fillet weld made in one pass shall be 1/4 in. (6 mm) for all positions.

4.16.1.2 The thickness of weld layers shall not exceed 1/4 in. (6 mm). When the root opening of a groove weld exceeds 3/8 in. (10 mm), a multiple pass, split-layer technique shall be used. The split-layer technique shall be used also in making all multiple pass welds when the width of the layer exceeds 3/8 in.

4.16.1.3 The welding current, voltage, gas flow, filler metal diameter and travel speed shall be such that each pass will have complete fusion with adjacent weld metal and base metal. There shall be no overlap, excessive porosity, or undercutting.

4.16.1.4 The welder shall employ the forehand technique.

4.16.2 Except as provided in section 10, complete joint penetration groove welds made without the use of backgouging shall have the root of the initial pass backgouged, chipped, or otherwise removed to sound metal, and all trace of root discontinuity shall be eliminated before welding is started from the second side.

4.16.3 Gas tungsten arc welding shall not be done in a draft or wind. When drafty conditions exist, a windbreak or shelter shall be employed. Such shelter shall be of an appropriate material and shape to reduce wind velocity

in the vicinity of the weld to a maximum of five miles per hour (eight kilometers per hour).

Part D Plasma Arc Welding

4.17 General

This part covers the specific requirements for variable polarity plasma arc welding in addition to, or which supersede the requirements of, Part A of this section.⁹

4.18 Tungsten Electrodes

For variable polarity plasma arc welding, the levels of welding currents shall be compatible with the range listed in Table 4.1 for electrodes operating with an unbalanced wave alternating current.

4.19 Restrictions on Variable Polarity Plasma Arc Welding

4.19.1 Complete joint penetration groove welds need not be backgouged if the penetration bead is smooth and properly fused.

4.19.2 Variable polarity plasma arc welding shall not be done in a draft or wind. When drafty conditions exist, a wind break or shelter shall be used. Such shelter shall be of an appropriate material and shape to reduce wind velocity in the vicinity of the weld to a maximum of five miles per hour (eight kilometers per hour).

9. Variable polarity plasma arc welding: plasma arc welding employing a power supply providing cyclic reversal of polarity with separate control of current amplitude and duration for each polarity.

Table 4.2
Typical Chemical Composition of Tungsten Electrodes^a (see 4.15)

AWS Classification	Tungsten, Min. Percent	Thoria, Percent	Zirconia, Percent	Total Other Elements, Max. Percent
EWP	99.5	—	—	0.5
EWTh-1	98.5	0.8 to 1.2	—	0.5
EWTh-2	97.5	1.7 to 2.2	—	0.5
EWTh-3 ^b	98.95	0.35 to 0.55	—	0.5
EWZr	99.2	—	0.15 to 0.40	0.5

Notes:

a. For additional information, see Volume 2 of the Seventh Edition of the Welding Handbook, pages 85–87, and page 90.

b. A tungsten electrode with an integral lateral segment throughout its length which contains 1.0 to 2.0% thoria. The average thoria content of the electrode shall be as specified in this table.

5. Qualification of Procedures and Personnel

Part A **General Requirements**

5.1 General

The qualification requirements of this code are to assure that the fabrication procedures actually used in production meet a recognized standard.¹⁰ To accomplish this objective, each contractor, fabricator, or manufacturer shall do the following:

- (1) Prepare a written Welding Procedure Specification in accordance with 5.13.2 for each condition. See Appendix E.
- (2) Qualify the procedure described by the Welding Procedure Specification in accordance with Part C of this section using materials, equipment, cleaning and preparation methods, welding condition, etc. that are specified in the Welding Procedure Specification.
- (3) Qualify the welders, welding operators, and tack welders in accordance with Part D of this section before doing any production work.
- (4) Maintain records of each of the above items on forms such as or similar to those shown in Appendix E.
- (5) Impart knowledge of the procedures to be used to the welders, welding operators, and tack welders.

5.2 Qualification of Welding Procedures

5.2.1 Only procedures qualified in accordance with Part C of this section shall be recognized as approved procedures.

¹⁰ The provisions of ANSI/AWS B2.1, *Standard for Welding Procedure and Performance Qualification*, may be used for the qualification of procedures and personnel. However, in instances where the provisions of ANSI/AWS B2.1 and ANSI/AWS D1.2 are in conflict, ANSI/AWS D1.2 should take precedence.

5.2.2 There are no welding procedures designated as prequalified. Previously qualified procedures shall be documented by sufficient test data to satisfy the requirements of Part C of this section and be approved by the Engineer.

5.2.3 The Engineer should accept properly documented evidence of previous qualification of the joint welding procedures to be employed, unless a new procedure qualification is required by the contract documents.

5.2.4 The essential variables of a welding procedure may be changed within the limitations of 5.16 without requalification. Changes outside these limits require qualification of the altered welding procedure.

5.2.5 Variables not listed in 5.16 are designated as non-essentials. They may be changed without qualification of the altered welding procedure.

5.3 Qualification of Welders, Welding Operators, and Tack Welders

5.3.1 Welders, welding operators, and tack welders to be employed on work under this Code shall have been qualified as in accordance with the provisions of Part D of this section.

5.3.2 The Engineer is encouraged to accept properly documented evidence of previous qualification performed in accordance with Part D of this section.

5.4 Qualification Responsibility

Except as permitted in 5.2 and 5.3, each contractor, fabricator, or manufacturer shall conduct the tests required by this Code to qualify the welding procedures and the welders, welding operators, and tack welders who will apply these procedures.

5.5 Records

Each contractor, fabricator, or manufacturer shall maintain a record of all welding procedure and performance qualifications of welders, welding operators, or tack welders. These records shall be maintained by the contractor, fabricator, or manufacturer and shall be made available to those authorized to examine them.

5.6 Position of Test Welds

5.6.1 Each welding procedure shall be qualified by positioning and welding the test assembly in the manner stated below for the position for which it is to be qualified. These positions are classified as: (1) flat, (2) horizontal, (3) vertical, or (4) overhead in accordance with Figures 5.1 and 5.2.

5.6.1.1 Groove Welds—Plate (Illustrated in Figure 5.3). In making the tests to qualify groove welds, test plates shall be welded in the following positions:

(1) **Position 1G (Flat)**—The test plates shall be placed in an approximately horizontal plane and the weld metal deposited from the upper side. See Figure 5.3(A).

(2) **Position 2G (Horizontal)**—The test plates shall be placed in an approximately vertical plane with the groove approximately horizontal. See Figure 5.3(B).

(3) **Position 3G (Vertical)**—The test plates shall be placed in an approximately vertical plane with the groove approximately vertical. See Figure 5.3(C).

(4) **Position 4G (Overhead)**—The test plates shall be placed in an approximately horizontal plane and the weld metal deposited from the under side. See Figure 5.3(D).

5.6.1.2 Groove Welds—Pipe (Illustrated in Figure 5.4). In making the tests to qualify groove welds, the test pipe¹¹ shall be welded in the following positions:

(1) **Position 1G (Pipe Horizontal-Rotated)**—The test pipe shall be placed with its axis approximately horizontal and the groove approximately vertical. The pipe shall be rotated during welding so the weld metal is deposited from the upper side. See Figure 5.4(A).

(2) **Position 2G (Pipe Vertical-Fixed)**—The test pipe shall be placed with its axis approximately vertical and the welding groove approximately horizontal. The pipe shall not be rotated during welding. See Figure 5.4(B).

(3) **Position 5G (Pipe Horizontal-Fixed)**—The test pipe shall be placed with its axis approximately horizontal and the groove approximately vertical. The pipes shall not be rotated during welding. See Figure 5.4(C).

(4) **Position 6G (Pipe Inclined-Fixed)**—The test pipe shall be inclined at approximately 45° with the horizon-

tal. The pipe shall not be rotated during welding. See Figure 5.4(D).

(5) **Position 6GR (Restricted, Pipe Inclined-Fixed)**. Test for complete joint penetration groove welds of tubular T-, Y-, and K-connections—The test pipe shall be provided with a restriction ring and be inclined at approximately 45° with the horizontal. The pipe shall not be rotated during welding. See Figure 5.4(E).

5.6.1.3 Fillet Welds—Plate (Illustrated in Figure 5.5). In making the tests to qualify welds on plate, test plates shall be welded in the positions outlined below:

(1) **Position 1F (Flat)**—The test plates shall be so placed that each fillet weld is deposited with its axis approximately horizontal and its throat approximately vertical. See Figure 5.5(A).

(2) **Position 2F (Horizontal)**—The test plates shall be so placed that each fillet weld is deposited on the upper side of a horizontal surface and against a vertical surface. See Figure 5.5(B).

(3) **Position 3F (Vertical)**—The test plates shall be placed in approximately vertical planes and each fillet weld deposited on vertical surfaces. See Figure 5.5(C).

(4) **Position 4F (Overhead)**—The test plates shall be so placed that each fillet weld is deposited on the under side of a horizontal surface and against a vertical surface. See Figure 5.5(D).

5.6.1.4 Fillet Welds—Pipes (Illustrated in Figure 5.6). In making the tests to qualify fillet welds on pipe, the test pipe shall be welded in the positions outlined below:

(1) **Position 1F (Pipe Inclined-Rotated)**—The test pipe shall be placed with its axis at approximately 45° and rotated during welding so that the filler metal is deposited in the flat position. See Figure 5.6(A).

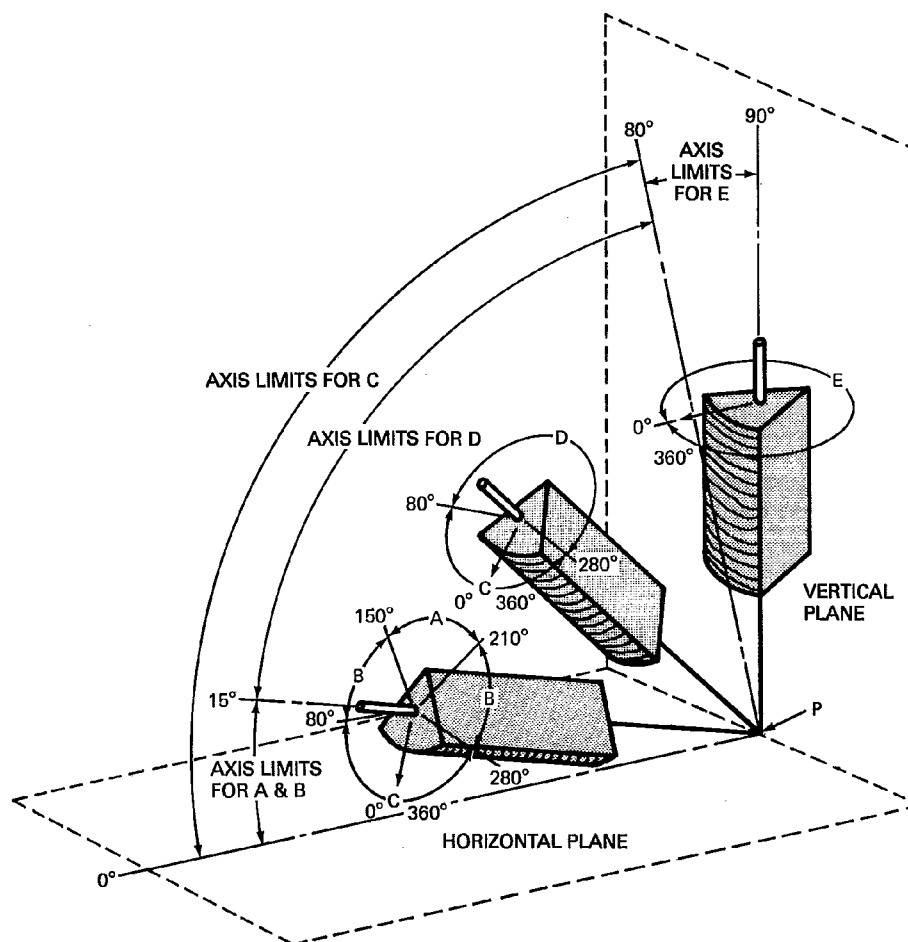
(2) **Position 2F (Pipe Vertical-Fixed)**—The test pipe shall be placed with its axis approximately vertical. The filler metal shall be placed on the outer surface of the pipe at its juncture with the abutting plate or pipe. The assembly shall not be rotated during welding. See Figure 5.6(B).

(3) **Position 2FR (Pipe Horizontal-Rotated)**—The test pipe shall be placed with its axis approximately horizontal and rotated during welding so that filler metal is deposited in the horizontal position. See Figure 5.6(C).

(4) **Position 4F (Overhead-Fixed)**—The test pipe shall be placed with its axis approximately vertical. The filler metal shall be placed against the outer surface of the pipe at its juncture with the abutting plate or pipe. The assembly shall not be rotated during welding. See Figure 5.6(D).

(5) **Position 5F (Pipe Horizontal-Fixed)**—The test pipe shall be placed with its axis approximately horizontal and with the welding joint vertical. The assembly shall not be rotated during welding. See Figure 5.6(E).

¹¹ The term *pipe* as used herein shall include all tubular shapes.

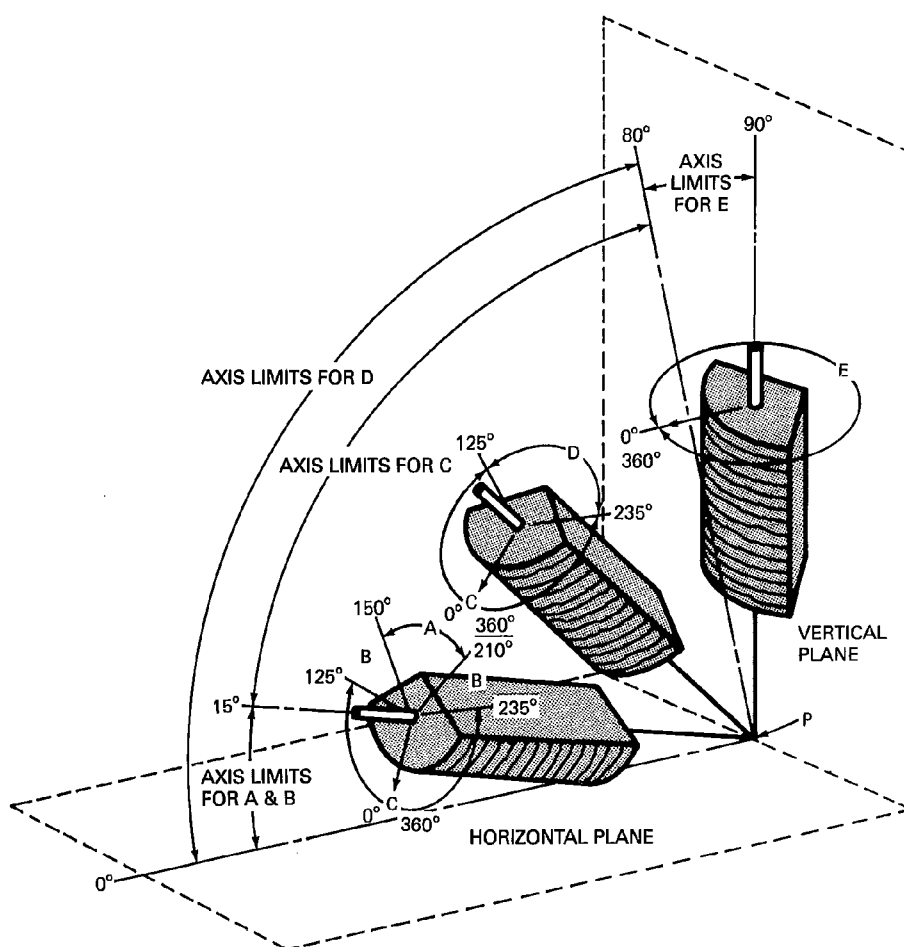


Tabulation of positions of groove welds			
Position	Diagram reference	Inclination of axis	Rotation of face
Flat	A	0° to 15°	150° to 210°
Horizontal	B	0° to 15°	80° to 150° 210° to 280°
Overhead	C	0° to 80°	0° to 80° 280° to 360°
Vertical	D	15° to 80°	80° to 280°
	E	80° to 90°	0° to 360°

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 5.1 — Positions of Groove Welds (see 5.6.1)



Tabulations 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°

Notes:

1. The horizontal reference plane is taken to lie always below the weld under consideration.
2. Inclination of axis is measured from the horizontal reference plane toward the vertical.
3. Angle of rotation of face is measured from a line perpendicular to the axis of the weld and lying in a vertical plane containing this axis. The reference position (0°) of rotation of the face invariably points in the direction opposite to that in which the axis angle increases. The angle of rotation of the face weld is measured in a clockwise direction from this reference position (0°) when looking at point P.

Figure 5.2 — Positions of Fillet Welds (see 5.6.1)

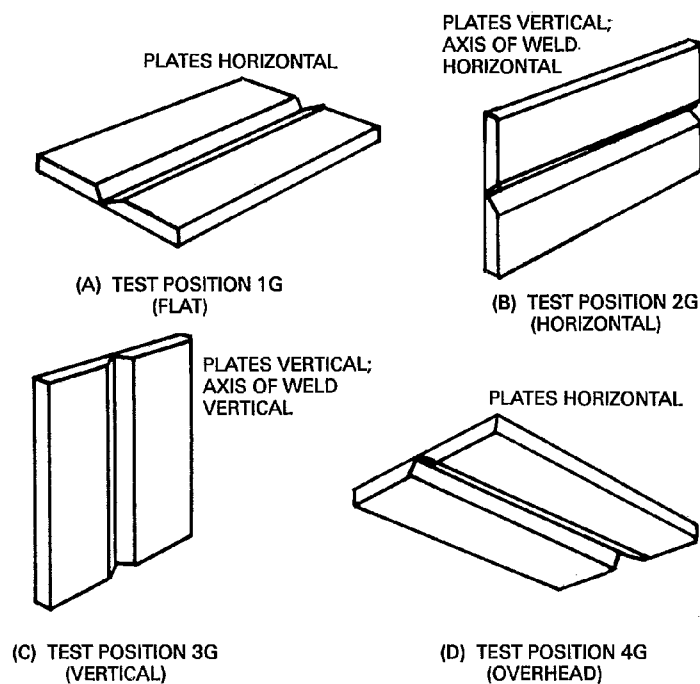


Figure 5.3 — Position of Test Plates for Groove Welds (see 5.6.1.1)

Part B

Types of Tests, Test Methods, and Acceptance Criteria

5.7 Types and Purposes of Tests

The tests described in Part B are intended to determine the strength or degree of soundness of welds made in accordance with the specified welding procedure or the soundness of welds made by a welder, welding operator, or tack welder.¹²

5.7.1 Visual examination for appearance is required for procedure qualification and performance qualification.

5.7.2 Mechanical Tests

5.7.2.1 Tension tests for strength of groove welds are required for procedure qualification.

5.7.2.2 Bend tests for soundness and ductility of groove welds are required for procedure qualification and performance qualification, except as permitted in 5.7.3.

5.7.2.3 Fillet weld fracture tests for soundness of fillet welds are required for procedure and performance qualification.

5.7.2.4 A fillet weld bend test for soundness of fillet welds is required for procedure and performance qualification.

5.7.3 Radiographic examination may be used in lieu of bend tests for performance qualification of welded groove joints in wrought materials. The radiographic procedure and technique shall be in accordance with the requirements of section 6, Part B of this Code.

5.8 Visual Examination

5.8.1 Examination Procedure. Visual inspection of the weld surface shall be performed on the test weldment prior to cutting any mechanical test specimens except that macroetching of cut sections is included in the examination of fillet welds and partial penetration groove welds. Liquid penetrants, magnifying lenses, scales or

12. The provisions of ANSI/AWS B4.0, *Standard Methods for Mechanical Testing of Welds*, may be used for the testing of welds made for procedure or performance qualification. However, in instances where the provisions of ANSI/AWS B4.0 and ANSI/AWS D1.2 are in conflict, ANSI/AWS D1.2 should take precedence.

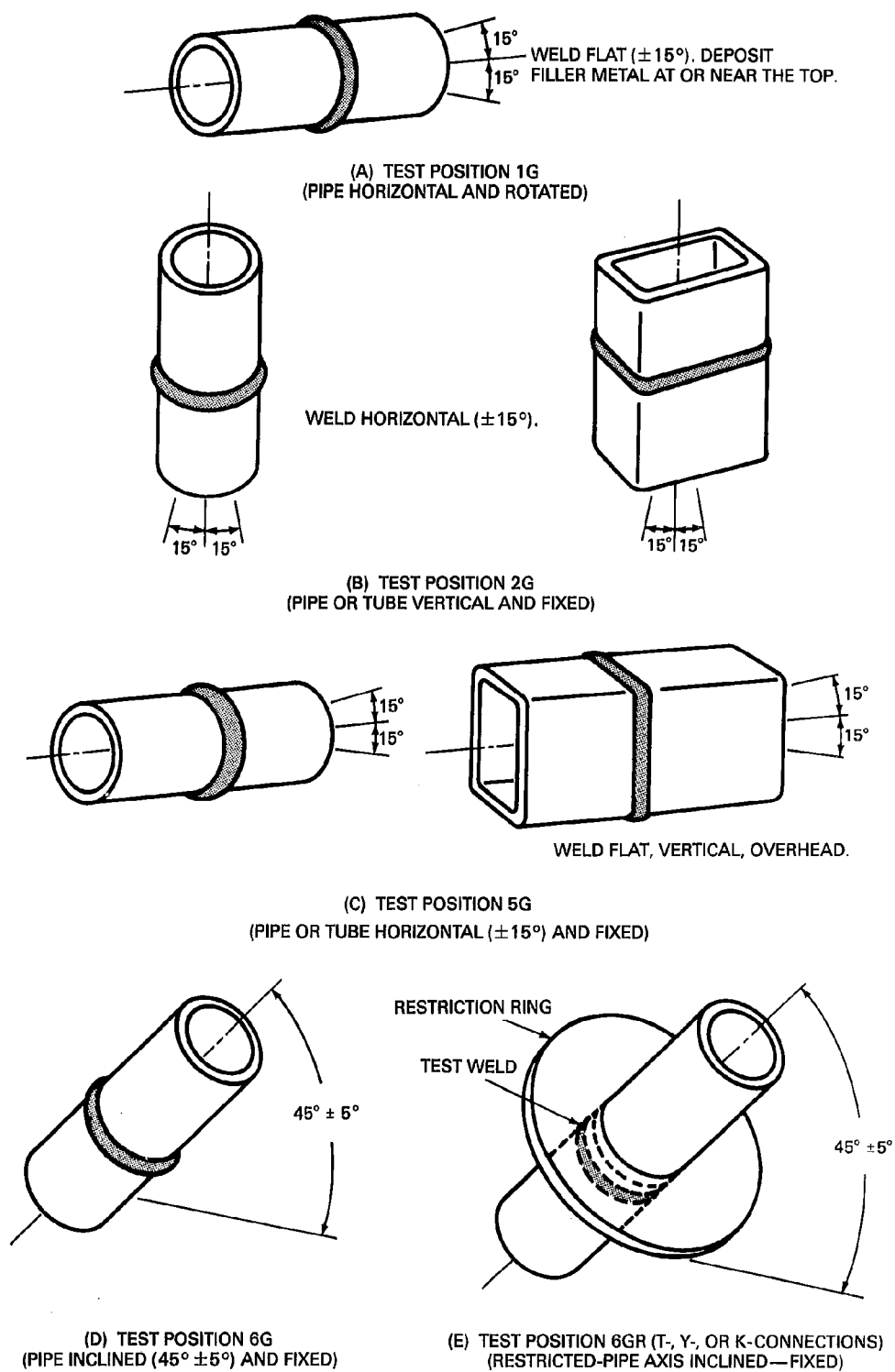


Figure 5.4 — Position of Test Plates for Pipe or Tubing for Groove Welds (see 5.6.1.2)

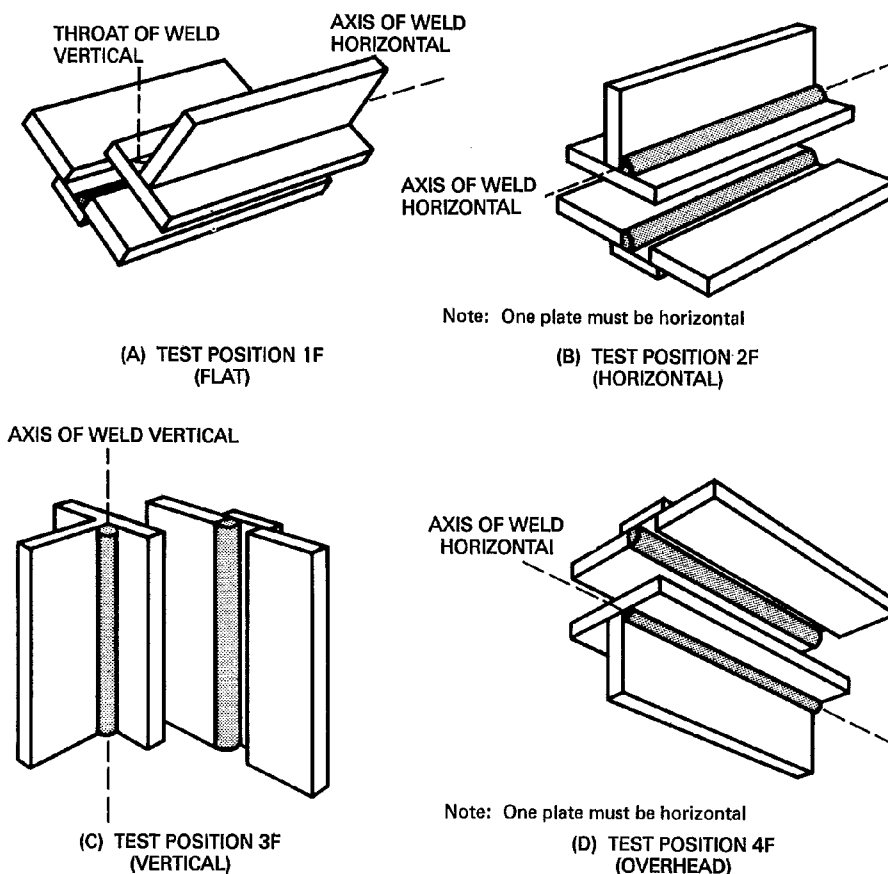


Figure 5.5 — Position of Test Plates for Fillet Welds (see 5.6.1.3)

templates may be used as aids in determining whether the sample weldment passes the criteria outlined in 5.8.2 or 5.8.3.

5.8.1.1 For detecting discontinuities that are open to the surface, liquid penetrant inspection may be used. The methods set forth in ASTM E165, *Standard Recommended Practice for Liquid Penetrant Inspection Method*, shall be used and the standards of acceptance shall be in accordance with 8.8.1, 9.8.1, or 10.15.1, whichever is applicable.

5.8.1.2 The macroetched specimen for the fillet weld test assembly or the partial penetration groove weld test assembly shall be taken from the end of the sample weldment. The macroetch specimens for fillet welded pipe, tubing, or casting groove welded assemblies shall be taken by sectioning longitudinally through the center of the pipe, tubing, or casting. One cut face of the specimen shall be smoothed and etched with a suitable etchant to give a clear definition of the weld metal and

heat-affected zone. Etching solutions, procedures, and safety requirements are given in Appendix G.

5.8.2 Acceptance Criteria — Visual Examination — Groove Welds, Plate and Pipe. Unless the test weldment passes the following visual examination, the test shall have failed.

- (1) Both the face and root surfaces shall be free of cracks.
- (2) All craters shall be filled to the full cross section of the weld.
- (3) The edges of the weld shall blend smoothly with the base metal.
- (4) Underfill shall not exceed 0.01 in. (0.25 mm).
- (5) The root shall show (a) complete fusion for full penetration welds, or (b) penetration equal to or greater than the weld size for partial penetration welds.
- (6) The maximum melt-through on groove welds in pipe or tubing shall not exceed 1/8 in. (3 mm).
- (7) The root concavity shall not exceed 1/16 in. (1.6 mm).

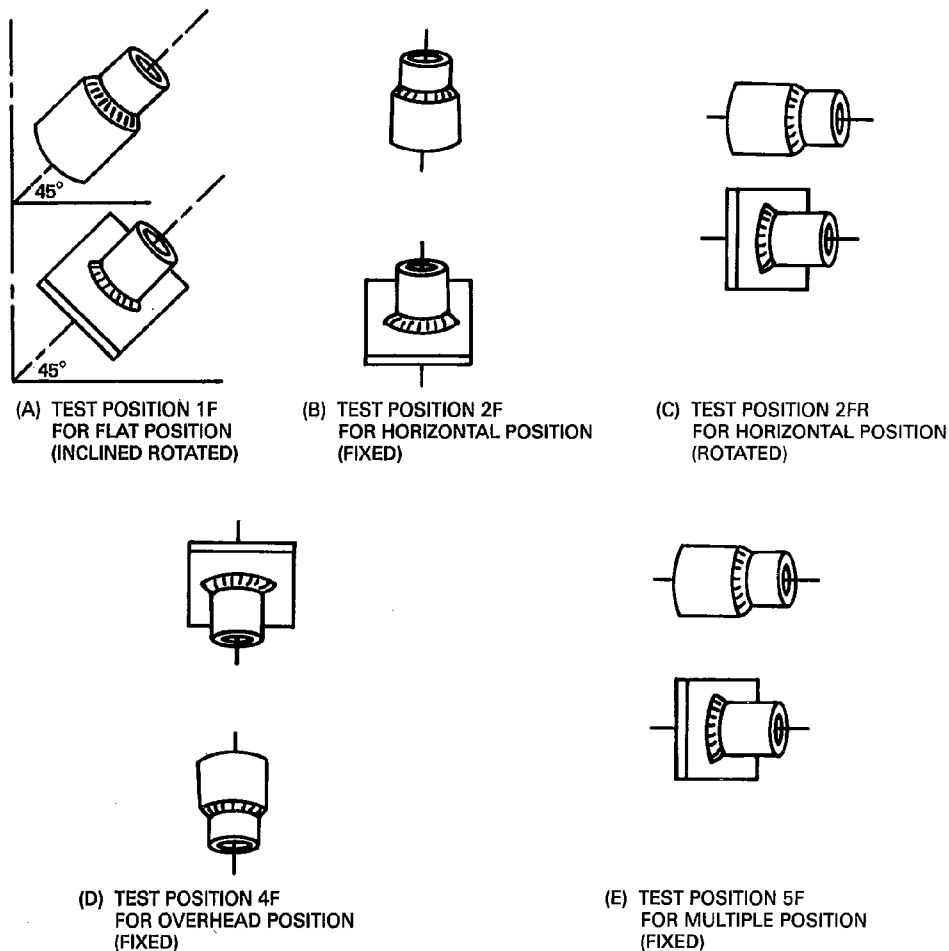


Figure 5.6 — Position for Test Pipes for Fillet Welds (see 5.6.1.4)

(8) Total weld thickness shall be equal to or greater than the thickness of the base metal, but the weld reinforcement shall not exceed the following:

Thickness, t		Maximum reinforcement	
in.	mm	in.	mm
$t \leq 3/8$	$t \leq 9.5$	3/32	2.4
$3/8 < t \leq 3/4$	$9.5 < t \leq 19$	1/8	3
$t > 3/4$	$t > 19$	3/16	5

5.8.3 Acceptance Criteria — Visual Examination of Fillet Welds for Plate or Pipe. Unless the test weldment passes the visual examination as follows, the test shall have failed:

- (1) The surface of the weld shall be free from cracks.
- (2) All craters shall be filled to the full cross-section of the weld.

(3) The edges of the weld shall blend smoothly with the base metal.

(4) Underfill shall not exceed 0.01 in. (0.25 mm).

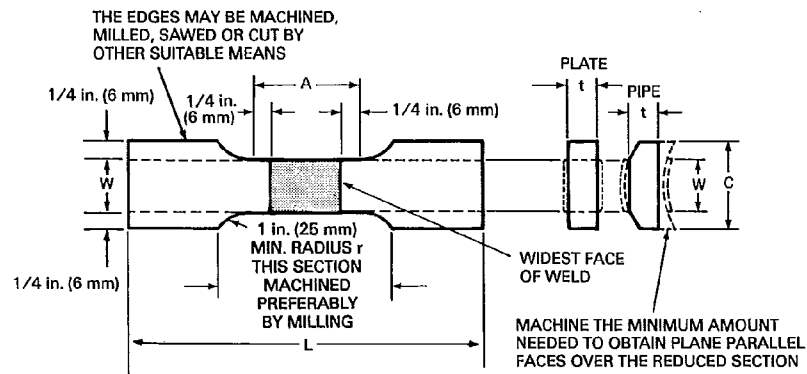
(5) The leg lengths shall meet the requirements of the procedure specification.

(6) The weld shall exhibit complete fusion in the root and to the base metal by the macroetch test.

5.9 Tension Tests — Groove Welds

5.9.1 Specimens. Tension test specimens shall conform to one of the types illustrated in Figures 5.7, 5.9 or 5.10.

5.9.1.1 Reduced Section Test Specimens — Plate. Reduced section specimens from plate conforming to the requirements given in Figure 5.7 shall be used for tension tests on all thicknesses of plate.



Dimensions (in.)				
	Test plate		Test pipe	
	$T_p \leq 1$ in.	$T_p > 1$ in.	3 in. or smaller diameter	greater than 3 in. diameter or large job size pipe
A — Length of reduced section	Widest face of weld + 1/2 in., 2-1/4 min		Widest face of weld + 1/2 in.	
L — Overall length, min (Note 2)	As required by testing equipment		As required by testing equipment	
W — Width of reduced section (Notes 3, 4)	$1-1/2 \pm 0.01$	1 ± 0.01	$1/2 \pm 0.01$	$3/4 \pm 0.01$
C — Width of grip section, min (Notes 4, 5)	2	1-1/2	1 approx.	1-1/4 approx.
t — Specimen thickness (Notes 6, 7)	T_p	T_p/n (Note 7)	Maximum possible with plane parallel faces within length A	
r — Radius of fillet, min	1	1	1	1

Dimensions (mm)				
	Test plate		Test pipe	
	$T_p \leq 25$ mm	$T_p > 25$ mm	75 mm or smaller diameter	greater than 75 mm diameter or large job size pipe
A — Length of reduced section	Widest face of weld + 13 mm, 58 min		Widest face of weld + 13 mm	
L — Overall length, min (Note 2)	As required by testing equipment		As required by testing equipment	
W — Width of reduced section (Notes 3, 4)	$38 \pm .25$	$38 \pm .25$	$13 \pm .25$	$19 \pm .25$
C — Width of grip section, min (Notes 4, 5)	51	38	25 approx.	32 approx.
t — Specimen thickness (Notes 6, 7)	T_p	T_p/n (Note 7)	Maximum possible with plane parallel faces within length A	
r — Radius of fillet, min	25	25	25	25

Notes:

1. T_p = thickness of the plate.
2. It is desirable, if possible, to make the length of the grip section large enough to allow the specimen to extend into the grips a distance equal to two-thirds or more of the length of the grips.
3. The ends of the reduced section shall not differ in width by more than 0.004 in. (.102 mm). Also, there may be a gradual decrease in width from the ends to the center, but the width at either end shall not be more than 0.015 in. (.381 mm) larger than the width at the center.
4. Narrower widths (W and C) may be used when necessary. In such cases, the width of the reduced section should be as large as the width of the material being tested permits. If the width of the material is less than W, the sides may be parallel throughout the length of the specimen.
5. For standard plate-type specimens, the ends of the specimen shall be symmetrical with the center line of the reduced section within 0.25 in. (6 mm) except for referee testing, in which case the ends of the specimen shall be symmetrical with the center line of the reduced section within 0.10 in (2.5 mm).
6. The dimension t is the thickness of the test specimen as provided for in the applicable material specifications. The minimum nominal thickness of 1-1/2 in. (38 mm) wide specimens shall be 3/16 in. (5 mm) except as permitted by the product specification.
7. For plates over 1 in. (25.4 mm) thick, specimens may be cut into the minimum number of approximately equal strips not exceeding 1 in. in thickness. Test each strip and each strip must meet the tensile requirements.

Figure 5.7 — Reduced Section Tension Specimens — Plate and Tubing
(see 5.9.1.1 and 5.9.1.2)

- (1) A single specimen of full plate thickness shall be used for thicknesses up to and including 1 in. (25 mm).
- (2) For plate thicknesses greater than 1 in. (25 mm), single or multiple specimens may be used.
- (3) When multiple specimens are necessary because of the limitations of the testing equipment, the entire thickness shall be cut mechanically into the minimum number of approximately equal slices of a thickness that can be tested in the available equipment. Each specimen (slice) shall be tested, and collectively shall represent a single required tension test.

5.9.1.2 Reduced Section Test Specimens — Pipe

(1) For pipe having an outside diameter greater than 3 in. (75 mm), reduced section specimens conforming to the requirements given in Figure 5.7 shall be used for tension tests on all thicknesses.

(a) A single specimen of the full thickness shall be used for thicknesses up to and including 1 in. (25 mm).

(b) For thicknesses greater than 1 in. (25 mm), single or multiple specimens may be used.

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

(2) For pipe having an outside diameter of 3 in. (75 mm) or less, test specimens conforming to the requirements given in Figure 5.9 may be used for tension tests.

5.9.1.3 Full-Section Pipe. For pipe having an outside diameter of 3 in. (75 mm) or less, full-section specimens conforming to the requirements given in Figure 5.10 may be used for tension tests.

5.9.1.4 Partial Joint Penetration Groove Welds — Plate and Pipe. For partial joint penetration groove welds in plate and pipe, the excess material on the root side of the joint shall be removed by machining to the thickness of the weld size. Tension test specimens shall be prepared in accordance with 5.9.1.

5.9.2 Tension Test Procedure. Each tension test specimen shall be ruptured under tensile load and the maximum load shall be determined. The tensile strength shall be computed by dividing the maximum load by the least cross-sectional area of the specimen as determined from measurements made before the load was applied.

5.9.3 Acceptance Criteria — Tension Tests — Plate and Pipe

5.9.3.1 The tensile strength shall be no less than the applicable requirement in Table 5.1. When multiple specimens are used, as allowed in 5.9.1.1 and 5.9.1.2, each specimen (slice) shall meet the requirement.

5.9.3.2 If base metals of different tensile strengths are used, the specified minimum tensile strength of the weaker of the two, as shown in Table 5.1, applies.

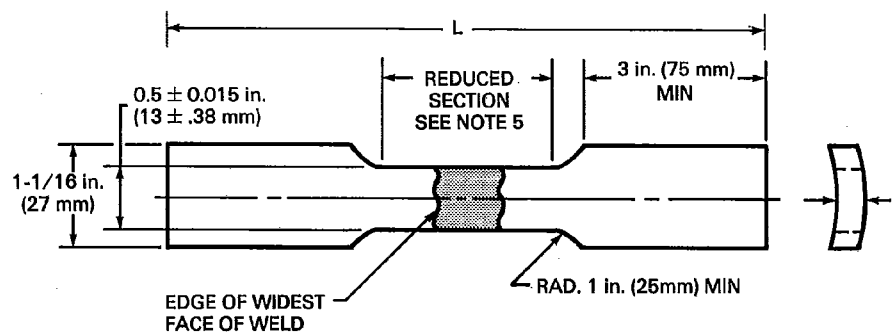
5.10 Bend Tests — Groove Welds — Plate and Pipe

5.10.1 Specimens. Except as allowed in 5.7.3, bend test specimens shall be prepared by cutting the test weldment to form specimens of approximately rectangular cross section conforming to one of the types shown in Figures 5.11, 5.12, or 5.13. The cut surfaces shall be designated the sides of the specimen. The original surfaces of the specimen shall be called the face and root surfaces, the face surface having the greater width of weld. Bend specimens are of five types, depending on whether the axis of the weld is transverse or parallel to the longitudinal axis of the specimen and which surface (side, face, or root) is on the convex (outer) side of the bent specimen. Longitudinal bend specimens may be used in lieu of transverse bend specimens for testing combinations of base and filler materials which differ markedly in bending properties.

5.10.1.1 Transverse Side Bend Specimen. The weld is transverse to the longitudinal axis of the specimen which is bent so that the side surface with the larger discontinuity, if any, becomes the convex surface of the bent specimen. Transverse side bend specimens shall conform to the dimensions shown in Figure 5.11. Specimens of base metal thickness greater than 1.5 in. (38.1 mm) may be bent at full width or cut into an odd number of strips of approximately equal width so that the axis of one interior strip coincides with root of the weld. Each specimen (strip) shall be tested and, collectively, shall represent a single required bend test.

5.10.1.2 Transverse Face Bend Specimen. The weld is transverse to the longitudinal axis of the specimen which is bent so that the face surface becomes the convex surface of the bent specimen. Except for pipe less than or equal to 4 in. (100 mm) in diameter, transverse face bend test specimens shall conform to the dimensions shown in Figure 5.12.

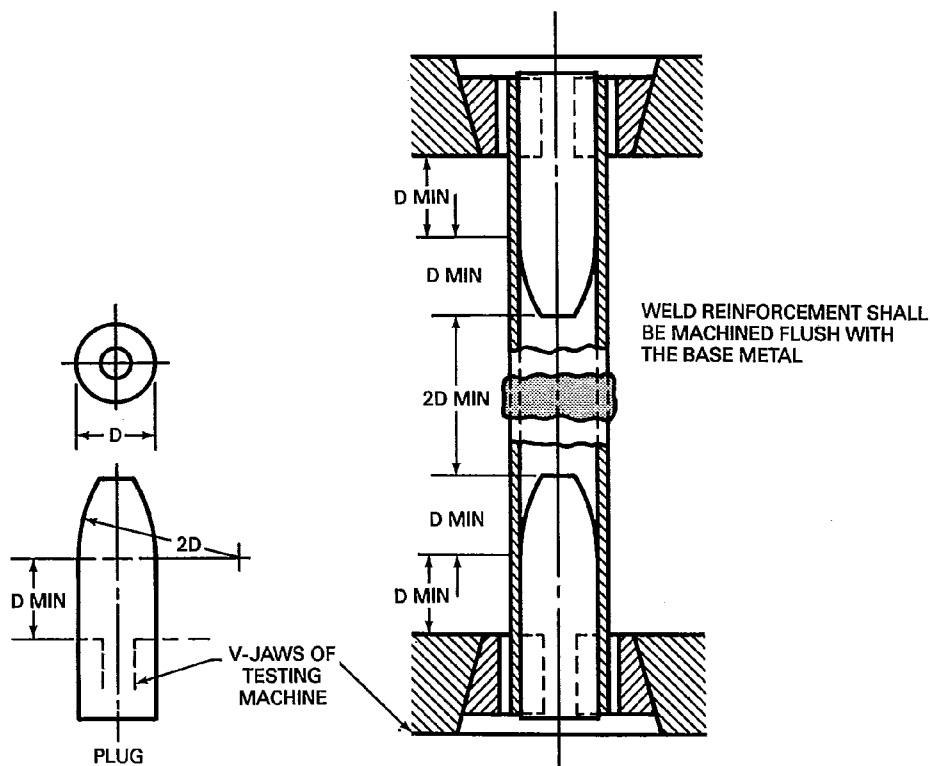
5.10.1.3 Transverse Root Bend Specimen. The weld is transverse to the longitudinal axis of the specimen which is bent so that the root surface becomes the convex surface of the bent specimen. Except for pipe less than or equal to 4 in. (100 mm) in diameter, transverse root bend test specimens shall conform to the dimensions shown in Figure 5.12. In specimens taken from partial joint penetration welds, the root of the joint shall be the weld size, and the weld assembly shall be cut to and tested at that plane.



Notes:

1. Cross-sectional area = $0.5 \times "t"$.
2. Test specimen thickness (t) shall be within the material thickness range allowed by the applicable material specification for the schedule/diameter of pipe being tested.
3. The specimen reduced section shall be parallel within 0.010 in. (.254 mm). Specimen width may be gradually tapered provided the ends are no more than 0.010 in. (.254 mm) wider than the center.
4. Weld reinforcement shall be removed so that weld thickness does not exceed the base metal thickness.
5. The reduced section shall not be less than the width of the welds plus two " t ".
6. Specimen edges shall not be arc or flame cut.

**Figure 5.9 — Alternate Reduced Section Tension Specimen for Pipe
[3 in. (75 mm) Diameter or Less] (see 5.9.1.2)**



**Figure 5.10 — Full Section Tension Specimens — Small Diameter Pipe
[3 in. (75 mm) Diameter or Less] (see 5.9.1.3)**

Table 5.1
Tensile Strength of Welded Aluminum Alloys (see 5.9.3.1)
(GTAW or GMAW with no Postweld Heat Treatment)

Material No.	Alloy and Temper(s)	Product-Thickness in in. (mm)		Minimum Tensile Strength in ksi (MPa)
21	1060-0, H12, H14, H16, H18, H22, H24, H26, H28, H112, H113, F	Sheet & Plate	Up thru 3.000 (76.2)	8 (55)
		Extrusions	All	8.5 (59)
21	1100-0, H12, H14, H16, H18, H22, H24, H26, H28, H112, H113, F	All	Up thru 3.000 (76.2)	11 (76)
24	2219-T62, T81, T851, T8510, T8511, T87	All	Up thru 2.999 (76.2)	35 (242)
		Plate	3.000 - 6.000 (76.2 - 152)	35 (242)
	2219-T6, T852	Forgings	3.000 - 4.000 (76.2 - 102)	35 (242)
21	3003-0, H12, H14, H16, H18 H22, H24, H26, H28, H112, H113, F	All	Up thru 3.000 (76.2)	14 (97)
21	Alclad 3003-0, H12, H14, H16, H18, H112, H113, F, H22, H24, H26	Tube	All	13 (90)
		Sheet & Plate	Up thru 0.499 (12.7)	13 (90)
		Plate	0.500 - 3.000 (12.7 - 76.2)	14 (97)
22	3004-0, H22, H24, H26, H28, H32, H34, H36, H38, H112, F	All	Up thru 3.000 (76.2)	22 (152)
22	Alclad 3004-0, H22, H24, H26 H32, H34, H36, H38, H112, F	Sheet & Plate	Up thru 0.499 (12.7)	21 (145)
		Plate	0.500 - 3.000 (12.7 - 76.2)	22 (152)
21	5005-0, H12, H14, H16, H18 H22, H24, H26, H32, H34, H36, H38 H112, F	All	Up thru 3.000 (76.2)	14 (97)
21	5050-0, H22, H24, H26, H32, H34, H36, H38, H112, F	All	Up thru 3.000 (76.2)	18 (124)
22	5052-0, H22, H24, H26 H28, H32, H34, H36, H38, H112, F	All	Up thru 3.000 (76.2)	25 (173)
25	5083-0, H111, H112,	Forgings	Up thru 4.000 (102)	38 (262)
	5083-0, H111, H112, F	Extrusions	Up thru 5.000 (127)	39 (269)
	5083-0, H112, H116, H321, F	Sheet & Plate	0.051 - 1.500 (1.3 - 38.1)	40 (276)
		Plate	1.501 - 3.000 (38.1 - 76.2)	39 (269)
	5083-0, F	Plate	3.001 - 5.000 (76.2 - 127)	38 (262)
		Plate	5.001 - 7.000 (127 - 178)	37 (255)
		Plate	7.001 - 8.000 (178 - 203)	36 (248)

(Continued)

Table 5.1 (Continued)

Material No.	Alloy and Temper(s)		Product-Thickness in in. (mm)	Minimum Tensile Strength in ksi (MPa)
25	5086-0, H32, H34, H36, H38, H111, H112, H116, F	All	Up thru 2.000 (50.8)	35 (242)
	5086-0, H111, H112, F	Extrusions Plate	2.001 – 5.000 (50.8 – 127) 2.001 – 3.000 (50.8 – 76.2)	35 (242) 34 (235)
22	5154-0, H22, H24, H26, H28 H32, H34, H36, H38, H112, F	All	Up thru 3.000 (76.2)	30 (207)
22	5254-0, H32, H34, H36, H38, H112, F	All	0.051 – 3.000 (1.3 – 76.2)	30 (207)
22	5454-0, H32, H34, H111, H112, F	All	Up thru 3.000 (76.2)	31 (214)
25	5456-0, H111, H112, F	Extrusions	Up thru 5.000 (127)	41 (283)
	5456-0, H112, H116, H321, F	Sheet & Plate Plate	0.051 – 1.500 (1.3 – 38.1) 1.501 – 3.000 (38.1 – 76.2)	42 (290) 41 (283)
	5456-0, H116, F	Plate	3.001 – 5.000 (76.2 – 127)	40 (276)
	5456-0, F	Plate Plate	5.001 – 7.000 (127 – 178) 7.001 – 8.000 (178 – 203)	39 (269) 38 (262)
22	5652-0, H22, H24, H32, H34, H112, F	All	Up thru 3.000 (76.2)	25 (173)
23	6005-T5	Extrusions	Up thru 1.000 (25.4)	24 (166)
23	6061-T4, T42, T451, T51, T6, T62, T651	All	Up thru 3.000 (76.2)	24 (166)
	6061-T6, T62, T651	Plate & Forgings	3.001 – 4.000 (76.2 – 102)	24 (166)
	6061-T62, T651	Plate	4.001 – 6.000 (102 – 152)	24 (166)
	6061-T6	Forgings	4.001 – 8.000 (102 – 203)	24 (166)
23	Alclad 6061-T4, T42, T451, T6, T62, T651	Sheet & Plate	Up thru 3.000 (76.2)	24 (166)
	Alclad 6061-T62, T651	Plate	3.001 – 5.000 (76.2 – 127)	24 (166)
23	6063-T4, T42, T5, T52, T6, T62, T83, T831, T832	Extrusions	Up thru 1.000 (25.4)	17 (117)
23	6351-T4, T5, T51, T53, T54, T6	Extrusions	Up thru 1.000 (25.4)	24 (166)
27	7005-T53	Extrusions	0.125 – 1.000 (3.2 – 25.4)	40 (276)

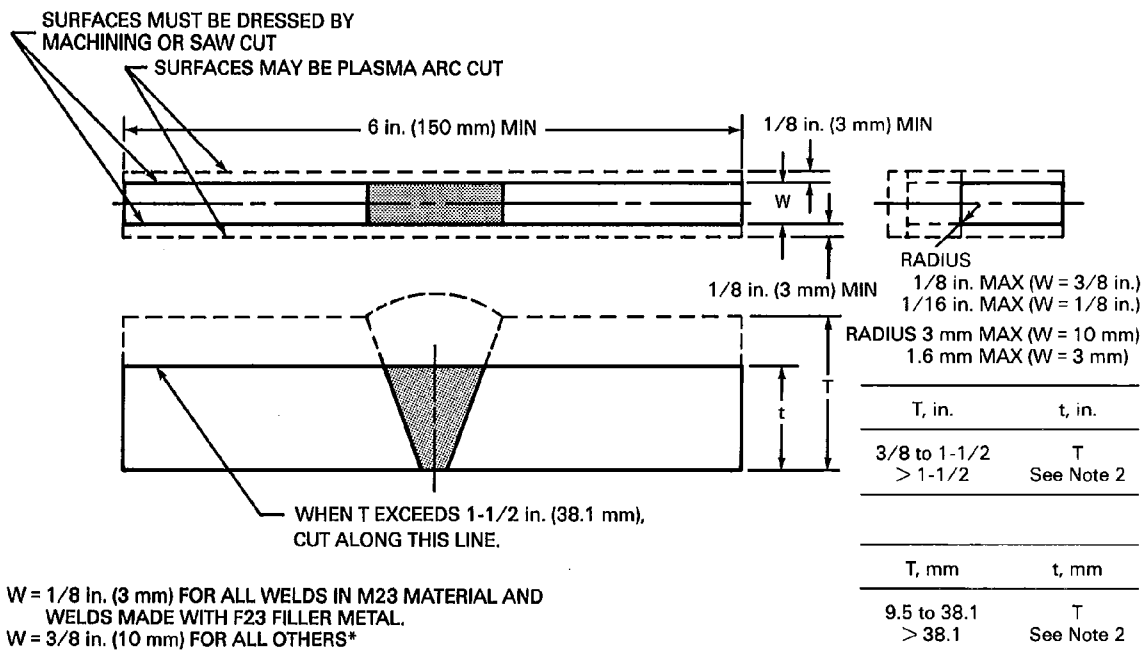
(Continued)

Table 5.1 (Continued)

Material No.	Alloy and Temper(s)	Product-Thickness in in. (mm)		Minimum Tensile Strength in ksi (MPa)
26	A201.0-T7	Castings	All	Note 1
26	354.0-T61, T62	Castings	All	Note 1
26	C355.0-T6, T61	Castings	All	Note 1
26	356.0-T6, T7, T71	Castings	All	23 (159)
26	A356.0-T6, T61	Castings	All	Note 1
26	357.0-T6, T7	Castings	All	Note 1
26	A357.0-T6, T61	Castings	All	Note 1
26	359.0-T61, T62	Castings	All	Note 1
26	443.0-F	Castings	All	17 (117)
26	514.0-F	Castings	All	22 (152)
26	535.0-F	Castings	All	35 (242)

Note:

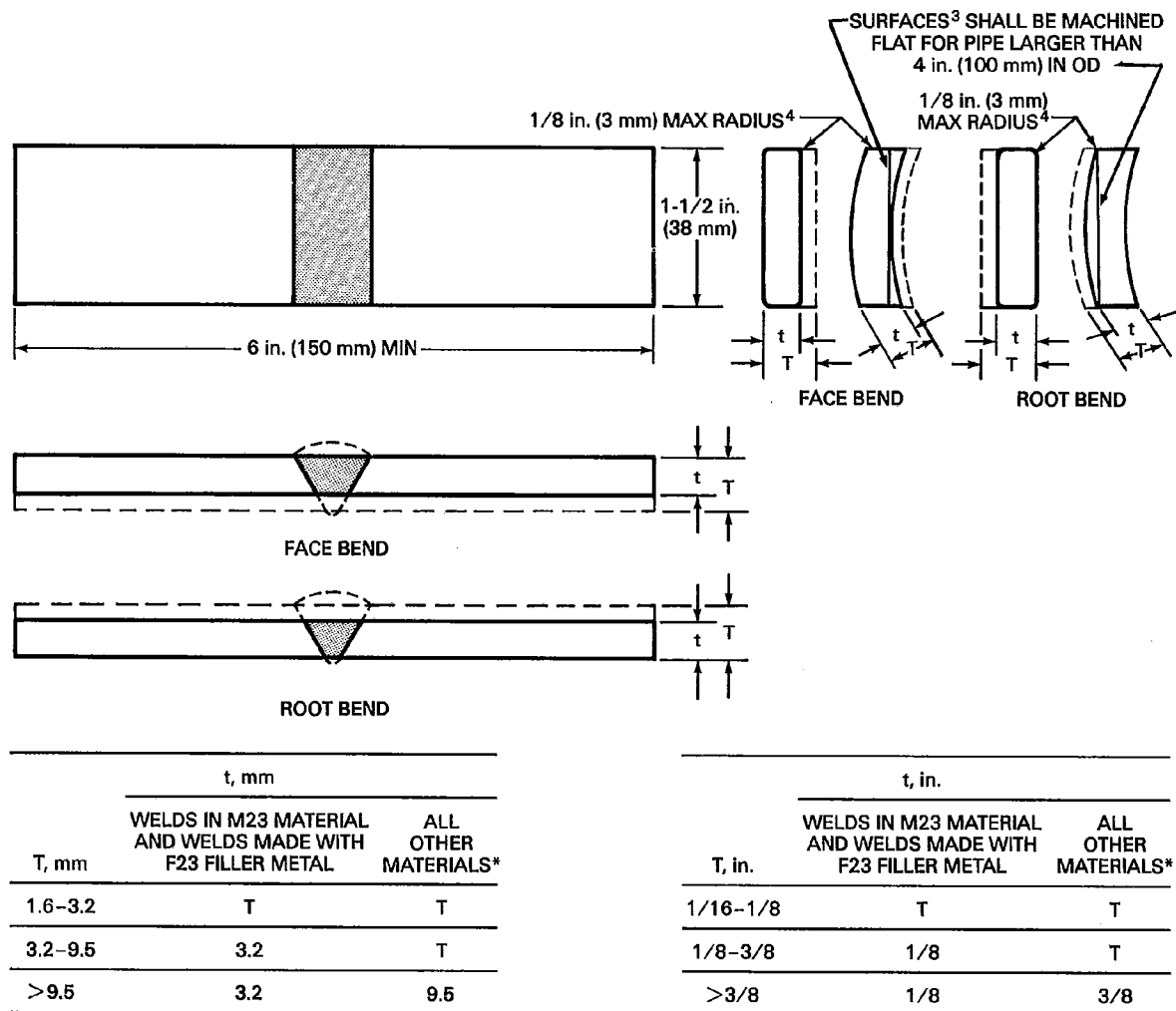
1. Minimum as-welded tensile strength has not been established for this alloy. The tensile properties must be established by procedure qualification and approved by the Engineer.

**Notes:**

1. Saw cut along line indicated.
2. For plates over 1-1/2 in. (38.1 mm) thick, cut the specimen into approximately equal strips with t between 3/4 and 1-1/2 in. and test each strip.
3. May be bent full width (see requirements on jig width, 5.10.2.3).

*If M23 materials are annealed before testing they shall be tested in this thickness category.

Figure 5.11 — Transverse Side Bend Specimens (see 5.10.1.1)



*IF M23 MATERIALS ARE ANNEALED BEFORE TESTING, THEY SHALL BE TESTED IN THE THICKNESS LISTED IN THIS CATEGORY.

Notes:

1. Weld reinforcement and backing strip or backing ring, if any, shall be removed flush with the surface of the specimen. If a recessed ring is used, this surface of the specimen may be machined to a depth not exceeding the depth of the recess to remove the ring, except that in such cases the thickness of the finished specimen shall be that specified above. Do not flame-cut nonferrous material.
2. If the pipe being tested is 4 in. (100 mm) outside diameter or less, the width of the bend specimen may be 3/4 in. (19 mm), measured around the outside surface. Alternatively, if the pipe being tested is less than 2 in. (51 mm) pipe size (2.375 in. (60.3 mm) outside diameter), the width of the bend specimens may be that obtained by cutting the pipe into quarter sections, less an allowance for saw cuts or machine cutting.
3. Surfaces shall be machined flat for pipe larger than 4 in. (100 mm) OD. Curvature shall remain where pipe is 4 in. (100 mm) or less OD.
4. $R = 1/2 t$ max for $t \leq 1/4$ in. (6.4 mm).
 $R = 1/8$ in. (3 mm) max for $t > 1/4$ in. (6.4 mm)

Figure 5.12 — Transverse Face- and Root-Bend Specimens (see 5.10.1.2 and 5.10.1.3)

5.10.1.4 Subsize Transverse Face and Root Bend Specimen. For pipe 4 in. (100 mm) or less in outside diameter, the width of the specimen may be 3/4 in. (19 mm), measured around the outside surface. Alternatively, for pipe less than 2-3/8 in. (60 mm) in outside diameter, the width of the specimen may be that obtained by cutting the pipe into quarter sections, less the allowance for cutting. The other dimensions shall be as shown in Figure 5.12.

5.10.1.5 Longitudinal Face Bend Specimen. The weld is parallel to the longitudinal axis of the specimen which is bent so that the face surface becomes the convex surface of the bent specimen. Longitudinal face bend test specimens shall conform to the dimensions shown in Figure 5.13.

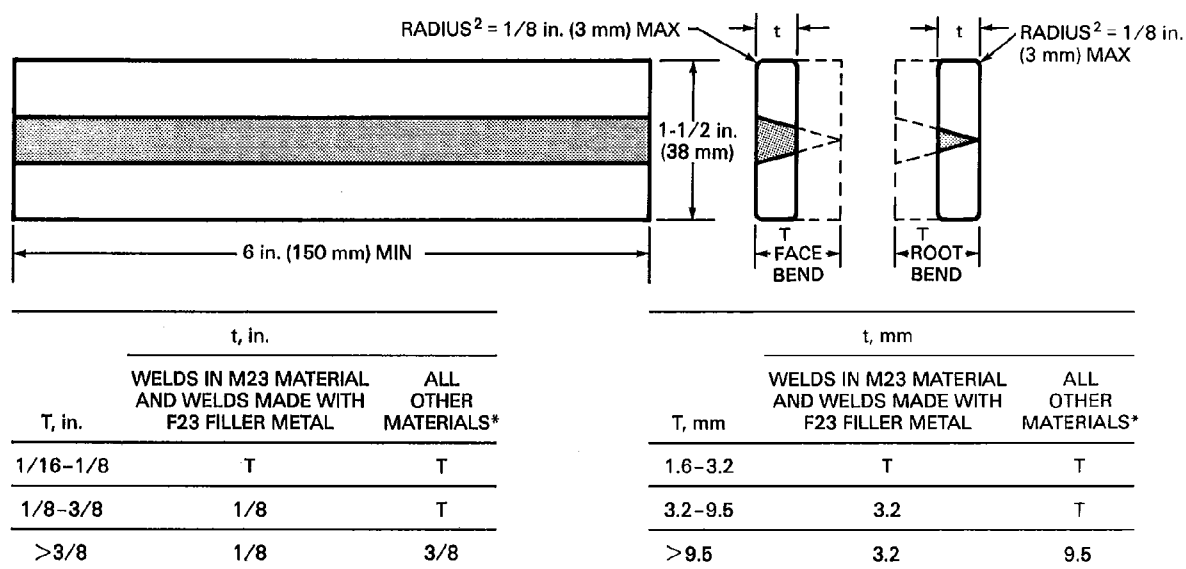
5.10.1.6 Longitudinal Root Bend Specimen. The weld is parallel to the longitudinal axis of the specimen which is bent so that the root surface becomes the convex surface of the bent specimen. Longitudinal root bend test specimens shall conform to the dimensions shown in Figure 5.13. In specimens taken from partial joint penetration welds, the root of the joint shall be the weld size,

and the weld assembly shall be cut to and tested at that plane.

5.10.2 Test Procedures — Bend Tests — Plate and Pipe. Bend test specimens cut from M23 and M24 materials may be annealed prior to testing.¹³ Bend test specimens shall be bent in a test jig that is in substantial accordance with Figure 5.14, 5.15 or 5.16.

5.10.2.1 When a plunger-type jig (Figure 5.14 or 5.15) is used, the face surface of the specimen shall be turned toward the gap of the jig for face bend tests, the root surface for root bend tests, and the side with the larger discontinuity, if any, for side bend tests. The specimen shall be centered on the jig and forced into the gap by applying a load to the plunger until, with jigs of the type in Figure 5.14, the position of the specimen is such that a 1/8 in. (3 mm) diameter wire cannot be inserted between the specimen and die, or with jigs of the type in Figure 5.15, the specimen is ejected from the bottom.

13. Annealing practice: Hold 2–3 hours at 775°F (410°C) and cool at 50°F/hr (28°C/hr) to 500°F (260°C). The rate of cooling below 500°F is unimportant.

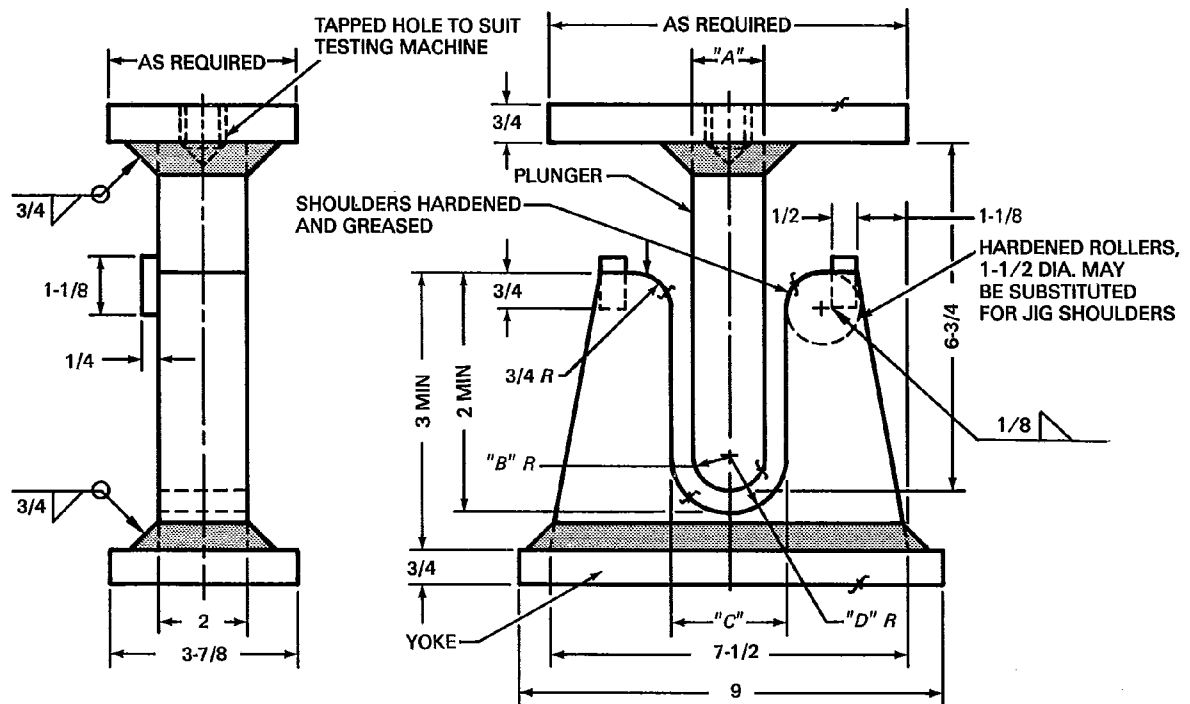


*IF M23 MATERIALS ARE ANNEALED BEFORE TESTING, THEY SHALL BE TESTED IN THE THICKNESS LISTED IN THIS CATEGORY.

Notes:

- Weld reinforcements and backing strip or backing ring, if any, shall be removed essentially flush with the undisturbed surface of the base material. If a recessed strip is used, this surface of the specimen may be machined to a depth not exceeding the depth of the recess to remove the strip, except that in such cases the thickness of the finished specimen shall be that specified above.
- $R = 1/2 t$ max for $t \leq 1/4$ in. (6.4 mm).
 $R = 1/8$ in. (3 mm) max for $t > 1/4$ in. (6.4 mm)

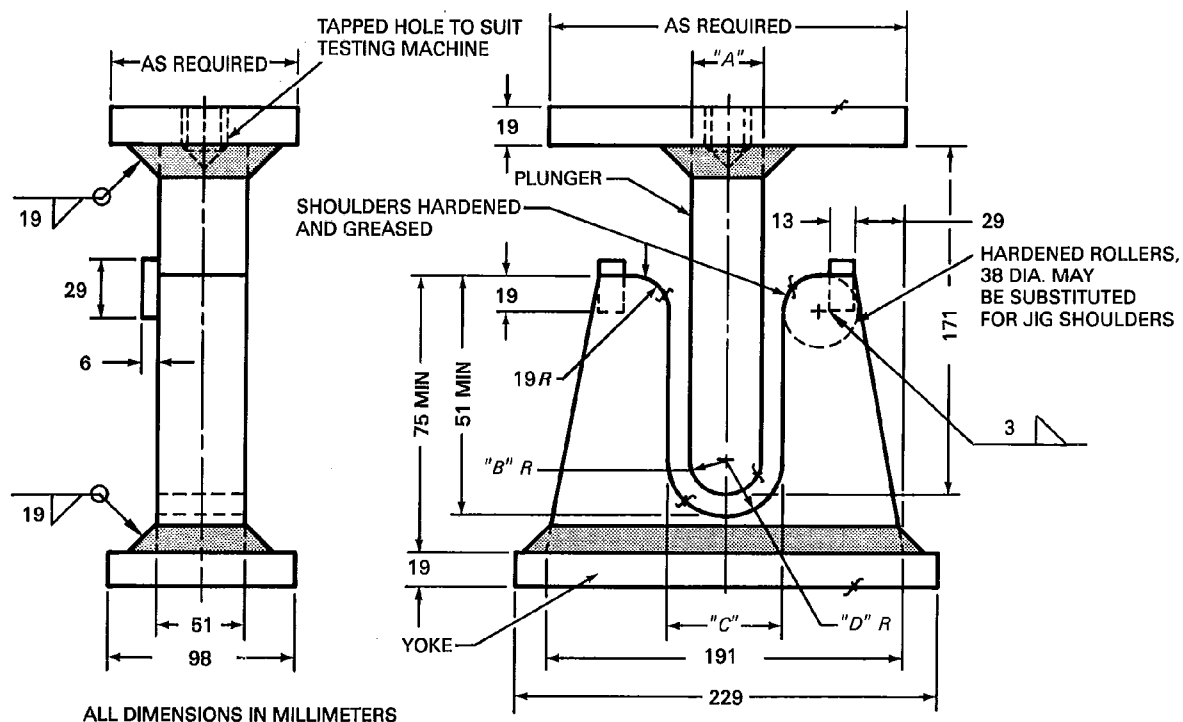
Figure 5.13 — Longitudinal Face- and Root-Bend Specimens (see 5.10.1.5 and 5.10.1.6)



THICKNESS OF SPECIMEN (in.)	A, in.	B, in.	C, in.	D, in.	MATERIALS ⁴
3/8 t	1-1/2 4t	3/4 2t	2-3/8 6t + 1/8	1-3/16 3t + 1/16	M21 and M22
1/8 t (< 1/8)	2-1/16 16-1/2t	1-1/32 8-1/4t	2-3/8 18-1/2t + 1/16	1-3/16 9-1/4t + 1/32	M23 and F23 Welds ¹
3/8 t	2-1/2 6-2/3t	1-1/4 3-1/3t	3-3/8 8-2/3t + 1/8	1-11/16 4-1/3t + 1/16	M25 ²
3/8 t	3 8t	1-1/2 4t	3-7/8 10t + 1/8	1-15/16 5t + 1/16	M24 ³ and M27

1. For any weldment made with F23 filler metal, the bend test specimen may be reduced to 1/8 in. in thickness, the corner radius "R" reduced to 1/16 in. maximum, and the specimen shall be bent as prescribed for as-welded M23 materials.
2. Includes annealed specimens of M23 materials.
3. M24 specimens are annealed prior to bend testing.
4. For M26 materials, See 5.17.1 or 5.25.1.

Figure 5.14 — Plunger-Type Guided Bend Jig (see 5.10.2.1)



THICKNESS OF SPECIMEN (mm)	A, mm	B, mm	C, mm	D, mm	MATERIALS ⁴
9.5 t	38 4t	19 2t	60 6t + 3	30 3t + 1.6	M21 and M22
3.2 t (< 3.2)	52 16-1/2t	26 8-1/4t	60 18-1/2t + 1.6	30 9-1/4t + 1	M23 and F23 Welds ¹
9.5 t	64 6-2/3t	32 3-1/3t	86 8-2/3t + 3	43 4-1/3t + 1.6	M25 ²
9.5 t	75 8t	38 4t	98 10t + 3	49 5t + 1.6	M24 ³ and M27

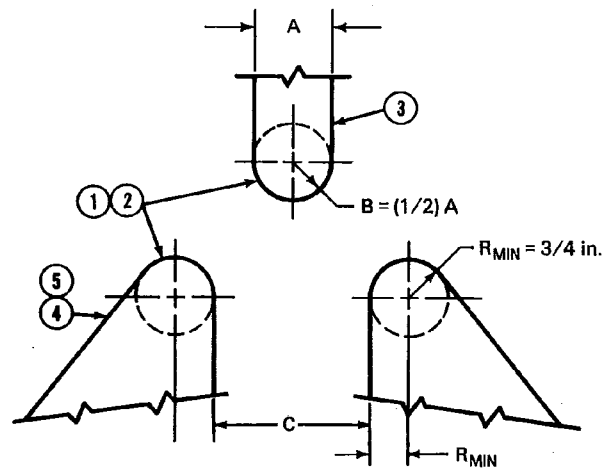
1. For any weldment made with F23 filler metal, the bend test specimen may be reduced to 3.2 mm in thickness, the corner radius "R" reduced to 1.6 mm maximum, and the specimen shall be bent as prescribed for as-welded M23 materials.

2. Includes annealed specimens of M23 materials.

3. M24 specimens are annealed prior to bend testing.

4. For M26 materials, See 5.17.1 or 5.25.1.

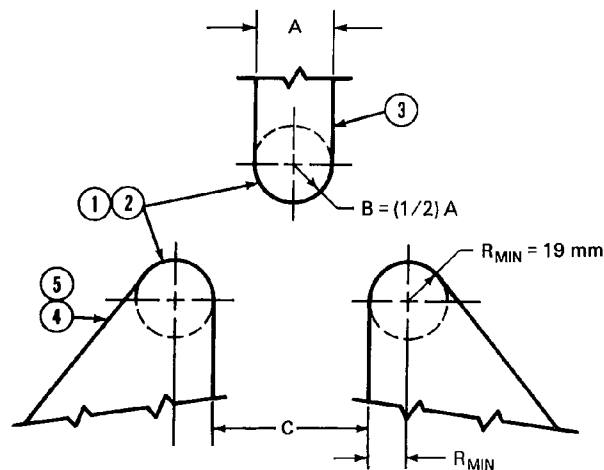
Figure 5.14 (continued) — Plunger-Type Guided Bend Jig (Metric Version) (see 5.10.2.1)



THICKNESS OF SPECIMEN (in.)	A, in.	B, in.	C, in.	MATERIALS ¹⁰
3/8 t	1-1/2 4t	3/4 2t	2-3/8 6t + 1/8	M21 and M22
1/8 t (< 1/8)	2-1/16 16-1/2t	1-1/32 8-1/4t	2-3/8 18-1/2t + 1/16	M23 and F23 Welds ⁷
3/8 t	2-1/2 6-2/3t	1-1/4 3-1/3t	3-3/8 8-2/3t + 1/8	M25 ⁸
3/8 t	3 8t	1-1/2 4t	3-7/8 10t + 1/8	M24 ⁹ and M27

1. Either hardened and greased shoulders, or hardened rollers free to rotate shall be used.
2. The shoulders or rollers shall have a minimum bearing surface of 2 in. for placement of the specimen. The rollers shall be high enough above the bottom of the jig so that the specimens will clear the rollers when the ram is in the low position.
3. The ram shall be fitted with an appropriate base and provision made for attachments to the testing machine, and shall be of a sufficiently rigid design to prevent deflection and misalignment while making the bend test. The body of the ram may be less than the dimensions shown in column A.
4. If desired, either the rollers or the roller supports may be made adjustable in the horizontal direction so that specimens of varied thickness may be tested on the same jig.
5. The roller supports shall be fitted with an appropriate base designed to safeguard against deflection or misalignment and equipped with means for maintaining the rollers centered, midpoint and aligned with respect to the ram.
6. The weld and heat-affected zone in the case of a transverse-weld bend specimen shall be completely within the bend portion of the specimen after testing.
7. For any weldment made with F23 filler metal, the bend test specimen may be reduced to 1/8 in. in thickness, the corner radius "R" reduced to 1/16 in. maximum, and the specimen shall be bent as prescribed for as-welded M23 materials.
8. Includes annealed specimens of M23 materials.
9. M24 material specimens are annealed prior to bend testing.
10. For M26 materials, see 5.17.1 or 5.25.1.

Figure 5.15 — Roller-Type Guided Bend Jig (see 5.10.2.1)

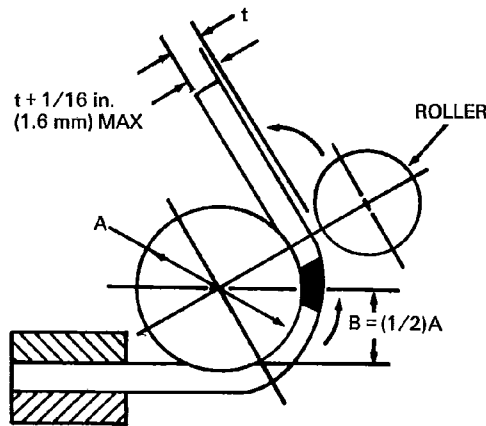


ALL DIMENSIONS IN MM

THICKNESS OF SPECIMEN (mm)	A, mm	B, mm	C, mm	MATERIALS ¹⁰
9.5 t	38 4t	19 2t	60 6t + 3	M21 and M22
3.2 t (< 3.2)	52 16-1/2t	26 8-1/4t	60 18-1/2t + 1.6	M23 and F23 Welds ⁷
9.5 t	64 6-2/3t	32 3-1/3t	86 8-2/3t + 3	M25 ⁸
9.5 t	75 8t	38 4t	98 10t + 3	M24 ⁹ and M27

1. Either hardened and greased shoulders, or hardened rollers free to rotate shall be used.
2. The shoulders or rollers shall have a minimum bearing surface of 51 mm for placement of the specimen. The rollers shall be high enough above the bottom of the jig so that the specimens will clear the rollers when the ram is in the low position.
3. The ram shall be fitted with an appropriate base and provision made for attachments to the testing machine, and shall be of a sufficiently rigid design to prevent deflection and misalignment while making the bend test. The body of the ram may be less than the dimensions shown in column A.
4. If desired, either the rollers or the roller supports may be made adjustable in the horizontal direction so that specimens of varied thickness may be tested on the same jig.
5. The roller supports shall be fitted with an appropriate base designed to safeguard against deflection or misalignment and equipped with means for maintaining the rollers centered, mid-point and aligned with respect to the ram.
6. The weld and heat-affected zone in the case of a transverse-weld bend specimen shall be completely within the bend portion of the specimen after testing.
7. For any weldment made with F23 filler metal, the bend test specimen may be reduced to 3.2 mm in thickness, the corner radius "R" reduced to 1.6 mm maximum, and the specimen shall be bent as prescribed for as-welded M23 materials.
8. Includes annealed specimens of M23 materials.
9. M24 material specimens are annealed prior to bend testing.
10. For M26 materials, see 5.17.1 or 5.25.1.

**Figure 5.15 (continued) — Roller-Type Guided Bend Jig
(Metric Version) (see 5.10.2.1)**



THICKNESS OF SPECIMEN (in.)	A, in.	B, in.	MATERIALS ⁷
$\frac{3}{8}$ t	$1\frac{1}{2}$ $4t$	$\frac{3}{4}$ $2t$	M21 and M22
$\frac{1}{8}$ $t (< 1/8)$	$2\frac{1}{16}$ $16\frac{1}{2}t$	$1\frac{1}{32}$ $8\frac{1}{4}t$	M23 and F23 Welds ⁴
$\frac{3}{8}$ t	$2\frac{1}{2}$ $6\frac{2}{3}t$	$1\frac{1}{4}$ $3\frac{1}{3}t$	M25 ⁵
$\frac{3}{8}$ t	3 $8t$	$1\frac{1}{2}$ $4t$	M24 ⁶ and M27

THICKNESS OF SPECIMEN (mm)	A, mm	B, mm	MATERIALS ⁷
9.5 t	38 $4t$	19 $2t$	M21 and M22
3.2 $t (< 3.2)$	52 $16\frac{1}{2}t$	26 $8\frac{1}{4}t$	M23 and F23 Welds ⁴
9.5 t	64 $6\frac{2}{3}t$	32 $3\frac{1}{3}t$	M25 ⁵
9.5 t	75 $8t$	38 $4t$	M24 ⁶ and M27

1. Dimensions not shown are the option of the designer. The essential consideration is to have adequate rigidity so that the jig parts will not spring.
2. The specimen shall be firmly clamped on one end so that there is no sliding of the specimen during the bending operation.
3. Test specimens shall be removed from the jig when the outer roll has been removed 180 degrees from the starting point.
4. For any weldment made with F23 filler metal, the bend test specimen may be reduced to 1/8 in. (3.2 mm) in thickness, the corner radius "R" reduced to 1/16 in. (1.6 mm) maximum, and the specimen shall be bent as prescribed for as-welded M23 materials.
5. Includes annealed specimens of M23 materials.
6. M24 material specimens are annealed prior to bend testing.
7. For M26 materials, see 5.17.1 or 5.25.1.

Figure 5.16 — Wrap-Around Guided Bend Jig (see 5.10.2.3)

5.10.2.2 When a jig of the wrap-around type (Figure 5.16) is used, the face surface of the specimen is turned toward the outer roller for face bend tests, the root surface for root bend tests, and the side with the larger discontinuity, if any, for side bend tests. The specimen shall be firmly clamped on one end so that there is no sliding of the specimen on the center roller during the bending operation. The specimen shall be wrapped around the center roller by a 180° movement of the outer roller.

5.10.2.3 Where specimens wider than 1.5 in. (38 mm) are to be bent, the test jig mandrel shall be at least 0.25 in. (6 mm) wider than the specimen.

5.10.3 Acceptance Criteria — Bend Tests — Pipe and Plate

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

5.10.3.2 The convex surface of the bend test specimen shall be visually examined for surface discontinuities. For acceptance, the surface shall contain no discontinuities exceeding the following dimensions:

(1) 1/8 in. (3 mm) measured in any direction on the surface.

(2) 3/8 in. (10 mm)—for the sum of the greatest dimensions of all discontinuities exceeding 1/32 in. (0.8 mm), but less than or equal to 1/8 in. (3 mm). This is based on a 1-1/2 in. (38 mm) specimen width. For other specimen widths, a proportional sum of the greatest dimensions shall apply.

(3) 1/4 in. (6 mm)—Maximum for a corner crack, except when that corner crack resulted from a visible inclusion or other fusion-type discontinuities, then the 1/8 in. (3 mm) maximum shall apply.

(4) Specimens with corner cracks exceeding 1/4 in. (6 mm) with no evidence of inclusions or other fusion type discontinuities may be disregarded and a replacement test specimen from the original weldment shall be tested.

5.11 Soundness Tests — Fillet Welds

5.11.1 Specimens

5.11.1.1 Option 1 — Fillet Weld Fracture Test — Pipe and Plate. The dimensions and preparation of fillet weld test weldments shall conform to the requirements shown in Figure 5.17 or 5.18. The test weldment for plate (Figure 5.17) shall be cut to provide two 4 in. (100 mm) center sections. The ends should be retained for macroetch specimens, if required. (See Table 5.5). The test weldment for pipe (Figure 5.18) shall be cut into four or more sections, transverse to the welds.

5.11.1.2 Option 2 — Fillet Weld Root Bend Test — Plate. The dimensions and preparation of the fillet weld test specimens shall conform to the requirements in Figure 5.19. The backing material and reinforcement shall be removed flush with the base metal.

All M23 materials and all materials welded with F23 filler metals shall have the face side removed to provide a 1/8 in. (3.2 mm) thick bend specimen as shown in Figure 5.12.

5.11.2 Fillet Weld Soundness — Test Procedures

5.11.2.1 Option 1 — Fracture Test — Pipe and Plate. The specimen load shall be increased steadily or applied by repeated blows until it breaks or folds flat on itself.

5.11.2.2 Option 2 — Root Bend Test — Plate. The specimen shall be loaded in such a way that the root of the weld becomes the convex surface of the bent specimen. The testing procedure for fillet weld root bend specimens shall be the same as for groove welds in 5.10.2.

5.11.3 Fillet Weld Soundness — Acceptance Criteria

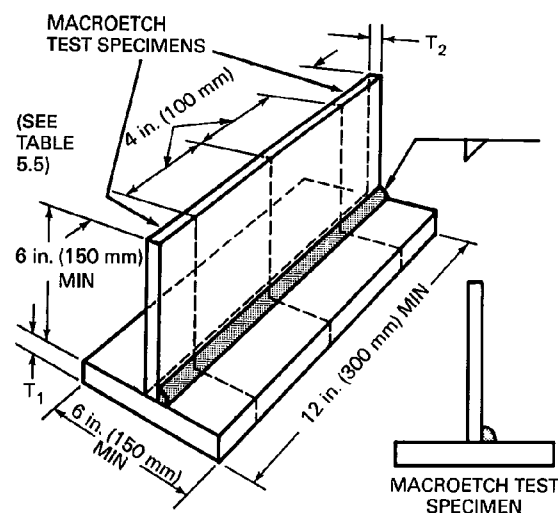
5.11.3.1 Option 1 — Fracture Test — Pipe and Plate.

If the specimen folds flat on itself, the specimen shall have satisfactorily passed the test. If the specimen fractures, the broken surface shall be examined visually. To pass, it shall show complete fusion to the root of the joint, and shall exhibit no inclusion or porosity larger than 3/32 in. (2 mm) in the greatest dimension. The sum of the greatest dimensions of all inclusions and porosity shall not exceed 3/4 in. (19 mm) in each 4 in. (100 mm) segment.

5.11.3.2 Option 2 — Root Bend Test — Plate. The specimen shall conform to the root bend criteria for groove welds.

5.12 Radiographic Examination

(Optional for performance qualification groove welds, plate)



INCHES			MILLIMETERS		
WELD SIZE	T ₁ MIN*	T ₂ MIN*	WELD SIZE	T ₁ MIN*	T ₂ MIN*
3/16	1/2	3/16	5	12.7	4.8
1/4	3/4	1/4	6	19.0	6.4
5/16	1	5/16	8	25.4	8.0
3/8	1	3/8	10	25.4	9.5
1/2	1	1/2	13	25.4	12.7
5/8	1	5/8	16	25.4	15.9
3/4	1	3/4	19	25.4	19.0
>3/4	1	1	>19	25.4	25.4

*Note: Where the maximum plate thickness used in production is less than the value shown in the table, the maximum thickness of the production pieces may be substituted for T₁ and T₂.

Figure 5.17 — Fillet Weld Soundness Test for Procedure Qualification — Option 1 — Plate (see 5.11.1.1)

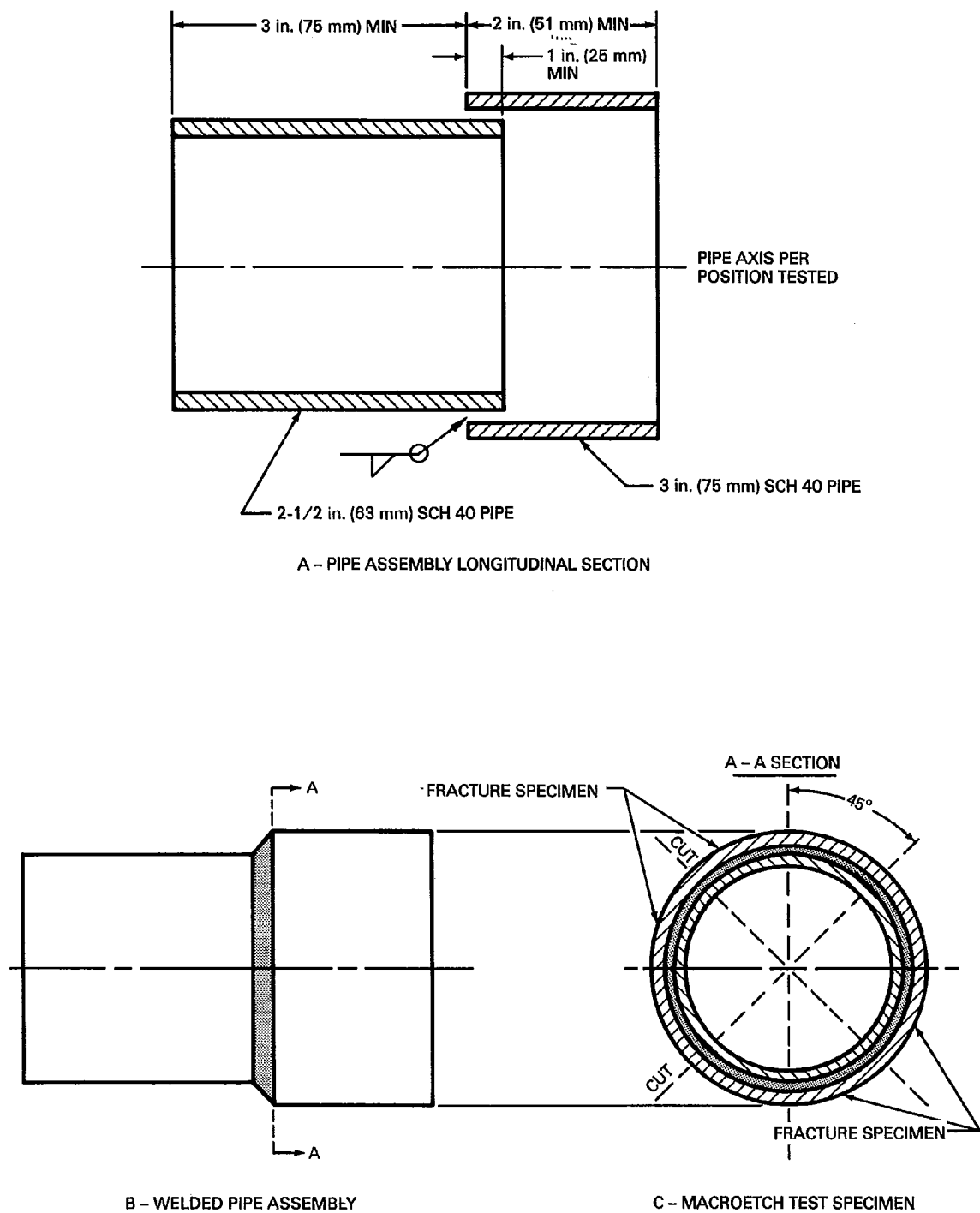


Figure 5.18 — Fillet Weld Soundness Test for Procedure Qualification — Option 1 — Pipe (see 5.11.1.1)

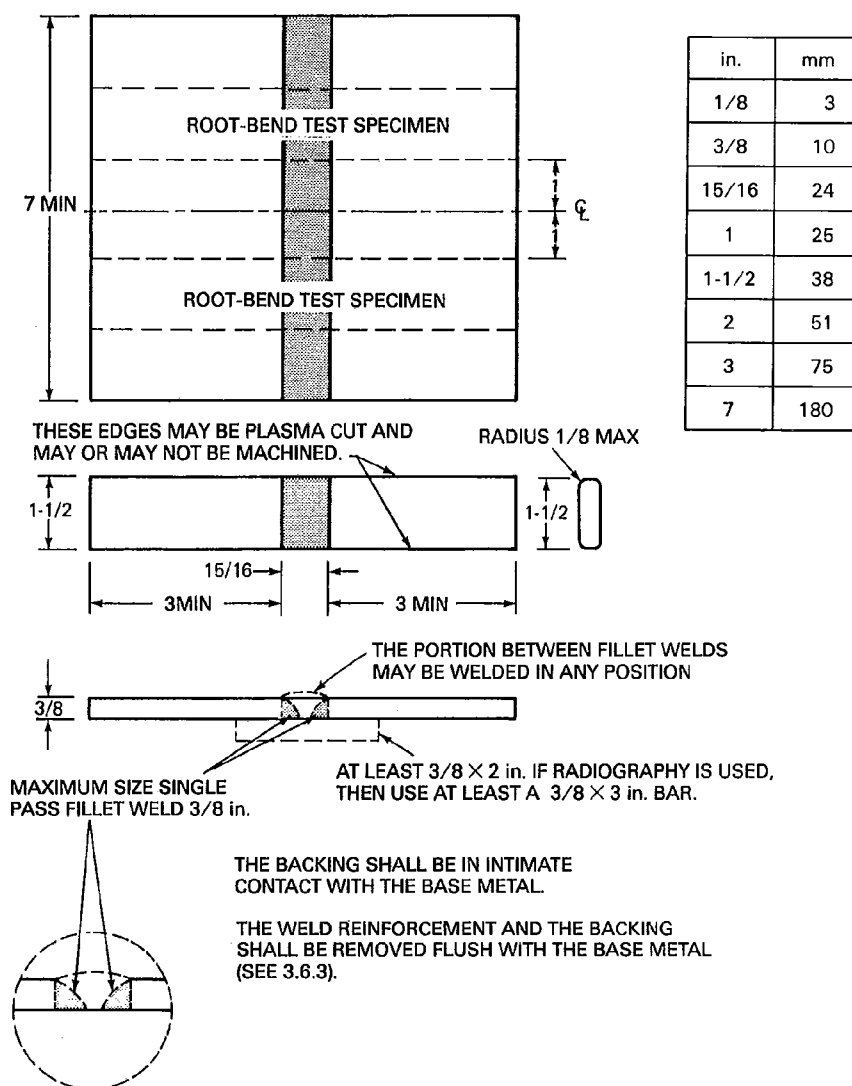


Figure 5.19 — Fillet Weld Soundness Test for Procedure Qualification — Option 2 — Root Bend Test — Plate (see 5.11.3.2)

5.12.1 Examination Procedure. The radiographic procedure and technique shall be in accordance with the requirements of Part B, section 6. Exclude 1-1/4 in. (32 mm) at each end of the weld from evaluation in the plate test. Welded test pipe or tubing 4 in. (100 mm) in diameter or larger shall be examined for a minimum of one-half of the weld perimeter selected to include a sample of all positions welded. (For example, a test pipe or tube welded in the 5G, 6G, or 6GR position shall be radiographed from the top centerline to the bottom centerline on either side.) Welded test pipe or tubing less than 4 in. in diameter shall require 100% radiography.

5.12.2 Radiographic Examination — Acceptance Criteria. When the radiographic option is used for performance qualification, the acceptability shall be based on the provisions of 8.8.2, 9.8.2, or 10.15.2, as applicable.

Part C **Procedure Qualification**

5.13 General

Procedure qualification shall be conducted by the contractor, fabricator or manufacturer. The procedure

qualification tests required in Part C are devised to determine the strength and degree of soundness of welds made by a specific welding procedure.

5.13.1 Contractor's, Fabricator's or Manufacturer's Responsibility. Each contractor, fabricator or manufacturer shall list in a document, known as the "welding procedure specification (WPS)," the conditions applicable to the welding that shall be performed under this Code. Each contractor, fabricator or manufacturer shall do the following:

- (1) Qualify the WPS by welding test weldments.
- (2) Test the specimens taken from the test weldments, as required in this section.
- (3) Record the welding data and test results in a document known as a "procedure qualification record (PQR)." See Appendix E, Form E(b). A WPS may require the support of more than one PQR.

5.13.2 Welding Procedure Specification (WPS). The welding procedure specification (WPS) shall list in detail the group numbers of the base metals to be joined, the filler metal(s) to be used, the range of preheat and post-weld heat treatments, thicknesses, and other variables associated with the welding process. Copies of the WPS shall be available for the guidance of the welders, welding operators, or tack welders and the authorized inspector(s). A recommended form for recording the WPS is given in Appendix E, Form E(a). Changes may be made in the nonessential variables to suit production requirements without qualification of the altered procedure, provided such changes are documented. The contractor, fabricator, or manufacturer shall certify that each welding procedure specification has been qualified by meeting the acceptance criteria of the procedure qualification test(s) and that the test results have been documented with the necessary Procedure Qualification Record(s) (PQR). A change in any essential variable outside the allowable limits shall require qualification of the altered procedure and associated PQR.

5.13.3 Procedure Qualification Record (PQR). The specific values of conditions involved in qualifying a WPS shall be recorded in a form called the Procedure Qualification Record (PQR). This form shall record the essential variables of the specific welding procedure and the test results. This document shall be certified by the contractor, fabricator, or manufacturer and shall be available for examination by the authorized inspector(s). A recommended form is given in Appendix E, Form E(b).

5.13.4 Combination of Welding Procedures. More than one procedure may be used in a single production joint, provided each procedure used is qualified either separately or in combination with the other procedure(s) within the thickness limits specified in Tables 5.3, 5.4, or 5.5, as applicable, for each of the procedures.

5.14 Limits of Qualified Positions for Procedures

To reduce the number of welding procedure qualifications that may be required, qualification under certain conditions also qualifies for other conditions as shown in Table 5.2 and enumerated in the following paragraphs.

5.14.1 Procedure qualification on pipe shall also qualify for plate, but not vice versa, except that qualification on plate in the 1G (flat) position or 2G (horizontal) position shall qualify for welding pipe over 24 in. (610 mm) in diameter in the 1G (flat) or 1G and 2G horizontal positions, respectively.

5.14.2 Procedure qualification of pipe in the 5G (pipe horizontal fixed) position qualifies the procedure for flat, vertical and overhead position groove and fillet welding of plate and pipe.

5.14.3 Procedure qualification of pipe in the 6G (inclined fixed) position qualifies the procedure for all position groove welding of plate and pipe, but does not qualify the procedure for groove and fillet welding of T-, Y- and K- connections.

5.14.4 Procedure qualification of T-, Y- and K-connections also qualifies the procedure for groove and fillet welding in all positions of plate and pipe.

5.15 Preparation of Test Weldment — Procedure Qualification

5.15.1 Base Metal and Filler Metal. The base metal(s) and filler metal(s) shall be as listed in the WPS. The dimensions of the test weldment shall be sufficient to provide the required test specimens. The base metals may be in the form of plate, pipe, tube, or other commercial product forms as listed in the WPS.

5.15.2 Joint Preparation. The edge preparation of the test weldment shall be as described in the WPS.

5.15.3 Cleaning Procedure. The test weldment shall be cleaned by means of the cleaning procedure(s) described in the WPS.

5.16 Limitation of Variables — Procedure Qualification

Changes greater than the limits set below or where no limits are given shall be considered essential changes in a WPS (see Appendix E) and shall require qualification of the altered procedure.

(1) A change in the base metal from one M-number group to another, as defined in 1.2.1

(2) A change in the filler metal from one F-number group to another, as defined in 1.2.2

Table 5.2
Procedure Qualification — Type and Position Limitations (see 5.14)

Qualification Test		Type of Weld and Position of Welding Qualified*			
		Plate		Pipe	
Weld	Plate or Pipe Positions**	Groove	Fillet	Groove	Fillet
Plate-groove Complete joint penetration	1G	1G	1F	1G (Note 1)	1F (Note 1)
	2G	1G, 2G	1F, 2F	1G, 2G (Note 1)	1F, 2F (Note 1)
	3G	1G, 3G	1F, 3F		
	4G	1G, 4G	1F, 4F		
Plate-groove Partial joint penetration	1G	1G	1F	1G (Note 1)	1F (Note 1)
	2G	2G	1F, 2F	1G, 2G (Note 1)	1F, 2F (Note 1)
	3G	3G	3F		
	4G	4G	4F		
Plate-fillet	1F		1F		1F (Note 1)
	2F		1F, 2F		1F, 2F (Note 1)
	3F		3F		5F (Note 1)
	4F		4F		4F (Note 1)
Pipe-groove Complete joint penetration	1G	1G	1F	1G	1F
	2G	1G, 2G	1F, 2F	1G, 2G	1F, 2F
	5G	1G, 3G, 4G	1F, 2F, 3F	1G, 2G, 5G	All
	6G	1G, 2G, 3G, 4G	All	1G, 2G, 5G, 6G	All
	6GR	All	All	All (Note 2)	All
Pipe-fillet	1F		1F		1F
	2F, 2FR		1F, 2F		1F, 2F
	4F		1F, 2F, 4F		1F, 2F, 4F
	5F		All		All

Notes:

1. Qualifies for welding pipe or tubing over 24 in. (610 mm) in diameter.
2. Qualifies for T-, Y-, and K-connections, and for complete joint penetration groove welds in all positions.

* Positions of welding: F = Flat, H = Horizontal, V = Vertical, OH = Overhead.

** See Figures 5.3, 5.4, 5.5 and 5.6.

- (3) A change in the welding process
- (4) A change in the nominal size of the diameter of the filler of more than 1/64 in. (0.4 mm)
- (5) A change of more than $\pm 15\%$ in the arc voltage or amperage
- (6) A change of more than 25% above or below the specified mean travel speed
- (7) For heat treatable alloys (M23, M24, M26, and M27), an increase of 100° F (55° C) in the specified pre-heat or specified maximum interpass temperature
- (8) The addition or deletion of filler metal
- (9) The addition or deletion of consumable inserts or a change in the method by which filler metal is added, such as preplacing wire or buttering
- (10) For a specified groove, a change of more than 25% in the number of passes. If the cross-sectional area of the groove is changed, it is permissible to change the number of passes in proportion to the area

(11) The addition of positions other than already qualified

(12) A change from vertical up to vertical down and vice versa

(13) A change of forehand to backhand technique. Note restrictions of 4.13.1.5.

(14) For a change in groove type:

(a) A change in the type of groove (a change from a V-groove to a U-groove, for example), except qualification of a complete joint penetration groove weld qualifies for any groove detail which complies with the requirements of Appendix B

(b) A change in the type of groove to a square groove or vice versa, or a decrease of 10° in the specified groove angle

(15) A change from a single shielding gas to any other gas or to a mixture of gases or a change of 10% or more in the specified percentage composition of the mixture

- (16) An increase of 50% or more or a decrease of 20% or more in the rate of flow of the shielding gas
- (17) A change from AC to DC or vice versa; in DC welding a change from electrode negative to electrode positive or vice versa
- (18) A change from conventional to pulsed type current welding power supply, or vice versa
- (19) For heat treatable alloys (M23, M24, M26, and M27), a change from the stringer-bead technique to a weave-bead technique, but not vice versa
- (20) A change in the type of initial and interpass cleaning (mechanical, chemical, etc.)
- (21) A change from single electrode to multiple electrode, or vice versa
- (22) A change in the spacing of multiple electrodes
- (23) The omission, but not inclusion, of backgouging
- (24) A change in thickness beyond the limitations of the "qualified range" as shown in Table 5.3, 5.4, or 5.5, as applicable
- (25) A change of more than 1/16 in. (1.6 mm) in the root opening when backing is not used
- (26) A change in backing material from aluminum to another material, but not vice versa

5.17 Tests — Procedure Qualification

5.17.1 The following are required tests for groove welds.

- (1) Visual examination for visual quality and dimensions
- (2) Macroetch test for soundness and weld size in partial joint penetration groove welds
- (3) Tension test for strength, except castings
- (4) Bend test for soundness and ductility, except castings.
- (5) When welding castings to other castings or wrought materials the bend test for soundness and ductility of groove welds and fillet welds shall be omitted; and a macroetch test for weld soundness shall be conducted.

5.17.2 The following are required tests for fillet welds.

- (1) Visual examination for appearance and dimensions
- (2) Macroetch test for penetration
- (3) Fracture test for soundness or root bend test for soundness, except castings

5.17.3 Test Specimens: Number, Type and Preparation

5.17.3.1 The type and number of specimens that shall be tested to qualify a welding procedure for complete joint penetration groove welds on plate; pipe, or tubing are shown in Table 5.3, together with the range of thickness qualified for use in construction. The range is based on the thickness of the plate, pipe or tubing used in making the qualification.

5.17.3.2 The type and number of specimens that shall be tested to qualify a welding procedure for partial joint penetration groove welds are shown in Table 5.4. A sample weld shall be made using the type of groove design and joint welding procedure to be used in construction, except the depth of groove need not exceed 1 in. (25 mm). If the partial joint penetration groove weld is to be used for corner or T-joints, the butt joint shall have a temporary restrictive plate in the plane of the square face to simulate the T-joint configuration.

5.17.3.3 When a joint welding procedure has been qualified for a complete joint penetration groove weld and is applied as the welding procedure for a partial joint penetration groove weld falling within the limitation of variables, three macroetch specimens are required.

5.17.3.4 The type and number of specimens that shall be tested to qualify a welding procedure for fillet welds are shown in Table 5.5.

5.17.4 Location of Removal of Test Specimens for Procedure Qualification. One sample weldment of sufficient size to obtain the number of test specimens required by Table 5.3, 5.4, or 5.5, as applicable, shall be prepared in accordance with the welding procedure specification.

5.17.4.1 Test Specimens — Groove Welds — Plate. The order of removal of test specimens shall conform to Figure 5.20(A), 5.20(B) or 5.20(C). Complete joint penetration groove welds made on plates 3/4 in. (19 mm) or greater in thickness which are welded using two-side welding techniques shall be tested using the test specimens in Figure 5.20(B). Partial joint penetration groove welds made on plates 3/8 in. (9.5 mm) or greater in thickness shall be tested with the unfused side machined off to the depth of the effective weld size. For base metals and combinations of base and filler metals which differ significantly in ductility, test specimen coupons as shown in Figure 5.20(C) shall be used.

5.17.4.2 Partial Joint Penetration Groove Welds — Plate or Pipe. The type and number of specimens that shall be tested to qualify a welding procedure are shown in Table 5.4. A sample weld shall be made using the type of groove design and joint welding procedure to be used in construction, except the depth of groove need not exceed 1 in. (25 mm).

If the partial joint penetration groove weld is to be used for corner or T-joints, the butt joints shall have a temporary restrictive plate in the plane of the square face to simulate the T-joint configuration. The sample weld shall be tested as follows:

- (1) When a joint welding procedure has been qualified for a complete joint penetration groove weld and is applied to the welding conditions of a partial joint penetration groove weld, three macroetch cross section test specimens are required.

Table 5.3
Number and Type of Test Specimens and Range of Thickness Qualified — Procedure
Qualification; Complete Joint Penetration Groove Welds (see 5.17.3.1)
(Dimensions in Inches)

1. Tests on Plate

Plate Thickness (T) Tested, in.	Number of Sample Welds per Position	Visual Inspection	Test Specimens Required				Plate Thickness Qualified, in.
			Reduced Section Tension (see Figure 5.7)	Root Bend (see Figures 5.12, 5.13)	Face Bend (see Figures 5.12, 5.13)	Side Bend (see Figure 5.11)	
$T < 1/8$	1 ⁽²⁾	Yes	2	2	2	—	T to 2T
$1/8 \leq T \leq 3/8$	1	Yes	2	2	2	—	T/2 to 2T
Over 3/8 and under 1	1	Yes	2	—	—	4	T/2 to 2T
1 and over	1	Yes	2	—	—	4	T/2 to unlimited

2. Tests on Pipe or Tubing — Class I Structures (see 10.1.2)

Weld Type	Pipe or Tube Size of Sample Weld		Number of Sample Welds per Position	Visual Inspection	Test Specimens Required				Pipe or Tubing Diameter Qualified, in.		Wall Thickness Qualified, in.	
					Macro-etch Test	Reduced Section Tension	Root Bend (see Figure 5.12)	Face Bend (see Figure 5.12)	Min	Max	Min	Max
	(see Figures 5.8, 5.9, 5.10)											
Wrought to Wrought	6 through 8	1/8 – 3/8	1	Yes	—	2	2	2	3/4	16	1/8	3/8
Cast to Wrought or Cast to Cast	3 through 5	3/16	1	Yes	2	—	—	—	2	16	1/8	1/2

3. Tests on Pipe or Tubing — Class II Structures (See 10.1.2)

Diam.	Pipe Size of Sample Weld Wall Thickness, T	Number of Sample Welds per Position	Visual Inspection	Test Specimens Required				Pipe or Tubing Diameter Qualified, in.	Wall Thickness Qualified, in.	
				Reduced Section Tension (see Figures 5.8, 5.9)	Root Bend (see Figure 5.12)	Face Bend (see Figure 5.12)	Side Bend (see Figure 5.11)		Diam.	Min
2 in. or 3 in.	Sch. 80	2	Yes	2	2	2	—	3/4 through 4	1/8	1/2
6 in. or 8 in.	Sch. 120	1	Yes	2	—	—	4	4 and over	0.187	Any
	Sch. 80									

(Continued)

Table 5.3 (Continued)**3. Tests on Pipe or Tubing — Class II Structures (See 10.1.2) (Continued)**

Diam.	Pipe Size of Sample Weld Wall Thickness, T	Number of Sample Welds per Position	Visual Inspection	Test Specimens Required				Pipe or Tubing Diameter Qualified, in. Diam.	Wall Thickness Qualified, in.	
				Reduced Section Tension (see Figures 5.8, 5.9, 5.10)	Root Bend (see Figure 5.12)	Face Bend (see Figure 5.12)	Side Bend (see Figure 5.11)		Min	Max
Job Size Pipe or Tubing										
< 24 in.	T < 1/8	1 ⁽²⁾	Yes	2	2	2	—	Test diam. & over	T	2T
	1/8 ≤ T ≤ 3/8 in.	1 ⁽²⁾	Yes	2	2	2	—	Test diam. & over	1/8	2T
	3/8 < T < 3/4 in.	1 ⁽²⁾	Yes	2	—	—	4	Test diam. & over	T/2	2T
	T ≥ 3/4 in.	1 ⁽²⁾	Yes	2	—	—	4	Test diam. & over	0.375	Any
≥ 24 in.	1/8 ≤ T ≤ 3/8 in.	1	Yes	2	2	2	—	Test diam. & over	1/8	2T
	3/8 < T < 3/4 in.	1	Yes	2	—	—	4	24 & over	T/2	2T
	T ≥ 3/4 in.	1	Yes	2	—	—	4	24 & over	0.375	Any

Notes:

1. All welded test pipes or tubing shall be visually inspected (see 5.8).
2. Adequate number of test welds per position must be made to obtain required test specimens.

(2) If a joint welding procedure is not covered by (1), then a sample joint shall be prepared and a macroetch test specimen made to determine the weld size. Then the excess material is machined off the bottom side of the joint to the thickness of the weld size.

Tension and bend specimens shall be prepared and tests performed, as required for complete joint penetration groove welds.

5.17.4.3 Test Specimens — Groove Welds — Pipe. The order of removal of test specimens shall conform to Figure 5.21, 5.22, 5.23 or 5.24.

5.17.4.4 Test Specimens — Fillet Welds. The number and type of test specimens that shall be tested to qualify a welding procedure are shown in Table 5.5. The location of test specimens shall conform to Figure 5.17, 5.18, or 5.19, and 5.11.1.

5.17.5 Preparation of Test Specimens. The test specimens shall be prepared in accordance with section 5, Part B.

5.17.6 Test Procedures. The required tests shall be conducted in accordance with section 5, Part B.

5.17.7 Acceptance Criteria — Groove Welds

5.17.7.1 Visual examination shall be in accordance with 5.8.2.

5.17.7.2 Tensile test results shall be within limits of 5.9.3 (castings excluded).

5.17.7.3 Bend test results shall be within limits of 5.10.3 (castings excluded).

5.17.7.4 Macroetch examination shall be conducted in accordance with 5.8.1.2. Partial penetration groove welds shall have the designated weld size. Complete joint penetration groove welds in cast alloy shall exhibit soundness throughout.

5.17.8 Acceptance Criteria — Fillet Welds

5.17.8.1 Visual examination shall be in accordance with 5.8.3.

5.17.8.2 Fracture test results shall be within the limits of 5.11.3, or fillet weld root bend test results shall be within the limits of 5.10.3, except castings.

5.17.8.3 Macroetch examination in accordance with 5.8.1.2 shall exhibit complete penetration to the root of the joint.

5.18 Retests

If any one specimen of all those tested fails to meet the test requirements for qualification, two retests of that particular type of test specimen may be performed with

Table 5.3
Number and Type of Test Specimens and Range of Thickness Qualified — Procedure
Qualification; Complete Joint Penetration Groove Welds (see 5.17.3.1)
(Dimensions in Millimeters)

1. Tests on Plate

Plate Thickness (T) Tested, mm	Number of Sample Welds per Position	Visual Inspection	Test Specimens Required				Plate Thickness Qualified, mm
			Reduced Section Tension (see Figure 5.7)	Root Bend (see Figures 5.12, 5.13)	Face Bend (see Figures 5.12, 5.13)	Side Bend (see Figure 5.11)	
T < 3.2	1 ⁽²⁾	Yes	2	2	2	—	T to 2T
3.2 ≤ T ≤ 9.5	1	Yes	2	2	2	—	T/2 to 2T
Over 9.5 and under 1	1	Yes	2	—	—	4	T/2 to 2T
1 and over	1	Yes	2	—	—	4	T/2 to unlimited

2. Tests on Pipe or Tubing — Class I Structures (see 10.1.2)

Weld Type	Pipe or Tube Size of Sample Weld		Number of Sample Welds per Position	Visual Inspection	Test Specimens Required				Pipe or Tubing Diameter Qualified, mm		Wall Thickness Qualified, mm	
	Diam., mm	Wall, t, of Wrought, mm			Macro-etch Test	Reduced Section Tension (see Figures 5.8, 5.9, 5.10)	Root Bend (see Figure 5.12)	Face Bend (see Figure 5.12)	Min	Max	Min	Max
Wrought to Wrought	150 through 200	3.2 – 9.5	1	Yes	—	2	2	2	19	410	3.2	9.5
Cast to Wrought or Cast to Cast	75 through 130	4.8	1	Yes	2	—	—	—	50	410	3.2	12.7

3. Tests on Pipe or Tubing — Class II Structures (See 10.1.2)

Diam.	Pipe Size of Sample Weld	Number of Sample Welds per Position	Visual Inspection	Test Specimens Required				Pipe or Tubing Diameter Qualified, mm	Wall Thickness Qualified, mm	
				Reduced Section Tension (see Figures 5.8, 5.9)	Root Bend (see Figure 5.12)	Face Bend (see Figure 5.12)	Side Bend (see Figure 5.11)		Diam.	Min
	Wall Thickness, T									
50 or 75	Sch. 80	2	Yes	2	2	2	—	19 through 100	3.2	12.7
	Sch. 40									
150 or 200	Sch. 120	1	Yes	2	—	—	4	100 and over	4.8	Any
	Sch. 80									

(Continued)

Table 5.3 (Continued) [Metric Version]**3. Tests on Pipe or Tubing — Class II Structures (See 10.1.2) (Continued)**

Diam.	Pipe Size of Sample Weld	Number of Sample Welds per Position	Visual Inspection	Test Specimens Required				Pipe or Tubing Diameter Qualified, mm	Wall Thickness Qualified, mm	
	Reduced Section Tension			Root Bend	Face Bend	Side Bend	Diam.		Min	Max
	(see Figures 5.8, 5.9, 5.10)			(see Figure 5.12)	(see Figure 5.12)	(see Figure 5.11)				
Job Size Pipe or Tubing										
< 610 mm	T < 3.2 mm	1 ⁽²⁾	Yes	2	2	2	—	Test diam. & over	T	2T
	3.2 ≤ T ≤ 9.5 mm	1 ⁽²⁾	Yes	2	2	2	—	Test diam. & over	3.2	2T
	9.5 < T < 19.0 mm	1 ⁽²⁾	Yes	2	—	—	4	Test diam. & over	T/2	2T
	T ≥ 19.0 mm	1 ⁽²⁾	Yes	2	—	—	4	Test diam. & over	9.5	Any
≥ 610 mm	3.2 ≤ T ≤ 9.5 mm	1	Yes	2	2	2	—	Test diam. & over	3.2	2T
	9.5 < T < 19.0 mm	1	Yes	2	—	—	4	610 & over	T/2	2T
	T ≥ 19.0 mm	1	Yes	2	—	—	4	610 & over	9.5	Any

Notes:

1. All welded test pipes or tubing shall be visually inspected (see 5.8).
2. Adequate number of test welds per position must be made to obtain required test specimens.

Table 5.4
Number and Type of Test Specimens and Range of Thickness Qualified — Procedure Qualification; Partial Joint Penetration Groove Welds (see 5.17.3.2)

Groove Type	Groove Depth, Max	Number of Sample Welds	Test Specimens Required ¹			Plate Thickness Qualified, Max
			Macroetch for Weld Size (E)	Tension and Bend Test		
				Reduced Section Tension (see Figures 5.7, 5.8)	Side Bend (see Figure 5.11)	
Same as used in construction ²	1 in. (25 mm)	1	3	2	4	Unlimited

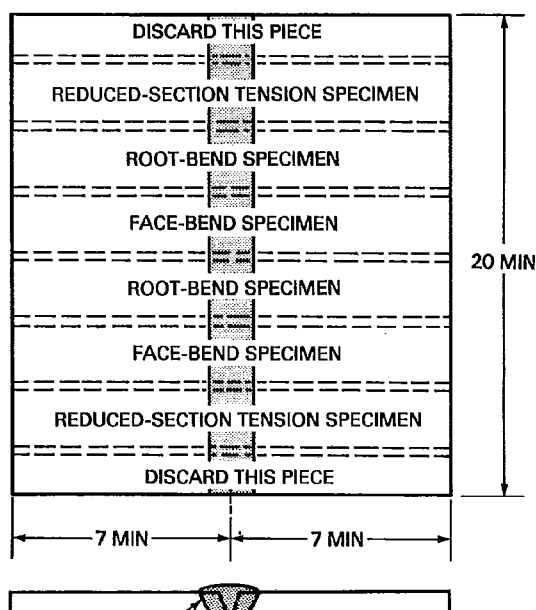
Notes:

1. All welded test plates shall be visually inspected.
2. If a partial joint penetration bevel- or J-groove weld is to be used for T-joints or a double-bevel- or double-J-groove weld is to be used for corner joints, the butt joint shall have a temporary restrictive plate in the plane of the square face to simulate a T-joint configuration.

Table 5.5
Number and Type of Test Specimens and Range of Thickness Qualified — Procedure
Qualification; Fillet Welds (see 5.17.4.4)

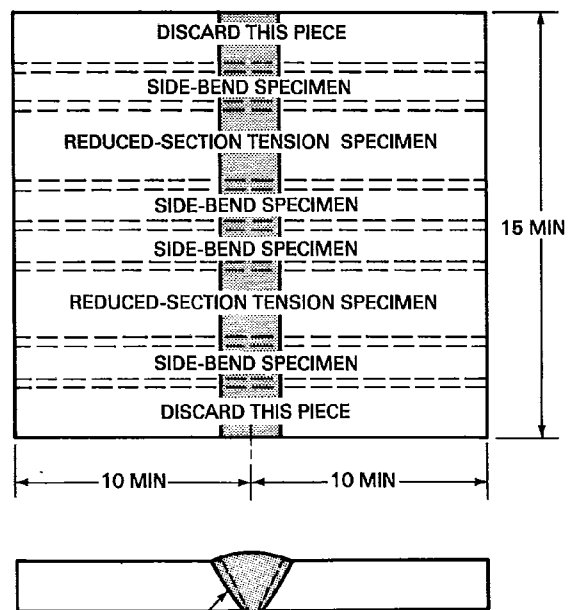
Test Specimen	Fillet Size	Number of Welds per Procedure	Test Specimens Required			Sizes Qualified	
			Macroetch	Fracture Test (see Figures 5.17, 5.18)	Root Bend (see Figure 5.12)	Plate Thickness	Fillet Size
1. Tests on Plate							
Fillet Weld Test Option 1 (see Figure 5.17)	Single pass, max size to be used in construction	1 in each position to be used	2 faces	2	—	Unlimited	Max tested single pass and smaller
	Multiple pass, min size to be used in construction	1 in each position to be used	2 faces	2	—	Unlimited	Min tested multiple pass and larger
Fillet Weld Test Option 2 (see Figure 5.19)	Max size to be used in construction	1 in each position to be used	—	—	2	Unlimited	All
2. Tests on Pipe and Tubing							
Fillet Weld Test — Pipe Option 1 (see Figure 5.18)	Single pass, max size to be used in construction	1 in each position to be used	2	4 or more	—	Unlimited	Max tested single pass and smaller
	Multiple pass, min size to be used in construction	1 in each position to be used	2	4 or more	—	Unlimited	Min tested multiple pass and larger

Note: All welded test specimens shall be visually inspected (see 5.8).



THE GROOVE CONFIGURATION SHOWN IS FOR ILLUSTRATION ONLY. THE GROOVE SHAPE USED SHALL CONFORM TO THAT BEING QUALIFIED.

(A) PLATES THROUGH 3/8 in.—PROCEDURE QUALIFICATION



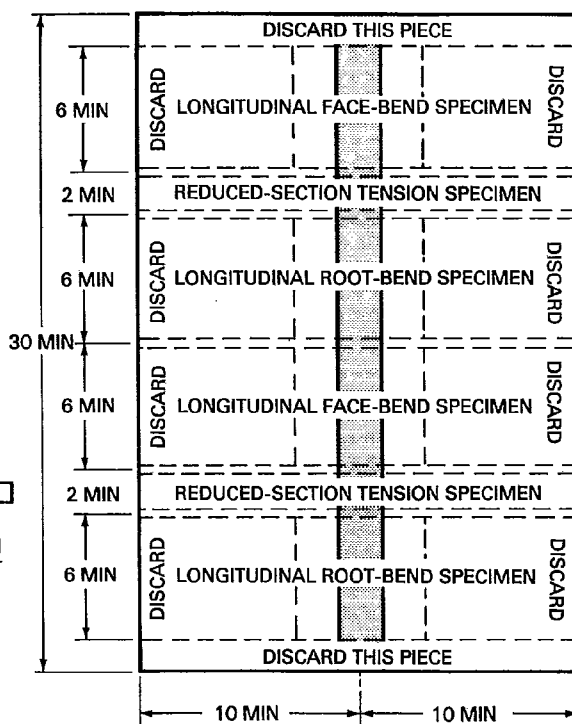
THE GROOVE CONFIGURATION SHOWN IS FOR ILLUSTRATION ONLY. THE GROOVE SHAPE USED SHALL CONFORM TO THAT BEING QUALIFIED.

(B) PLATES OVER 3/8 in.—PROCEDURE QUALIFICATION

in.	mm
3/8	9.5
2	50
6	150
7	180
10	255
15	380
20	510
30	760



THE GROOVE CONFIGURATION SHOWN IS FOR ILLUSTRATION ONLY. THE GROOVE SHAPE USED SHALL CONFORM TO THAT BEING QUALIFIED.



(C) PLATES — LONGITUDINAL BEND TEST SPECIMENS

Figure 5.20 — Location of Test Specimens for Procedure Qualification — Plate (see 5.17.4.1)

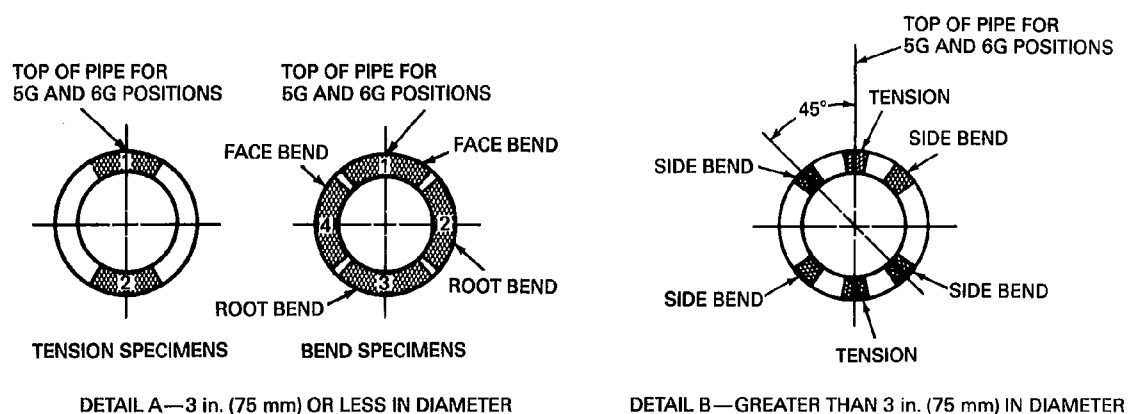


Figure 5.21 — Location of Test Specimens on Welded Test Pipe (see 5.17.4.3)

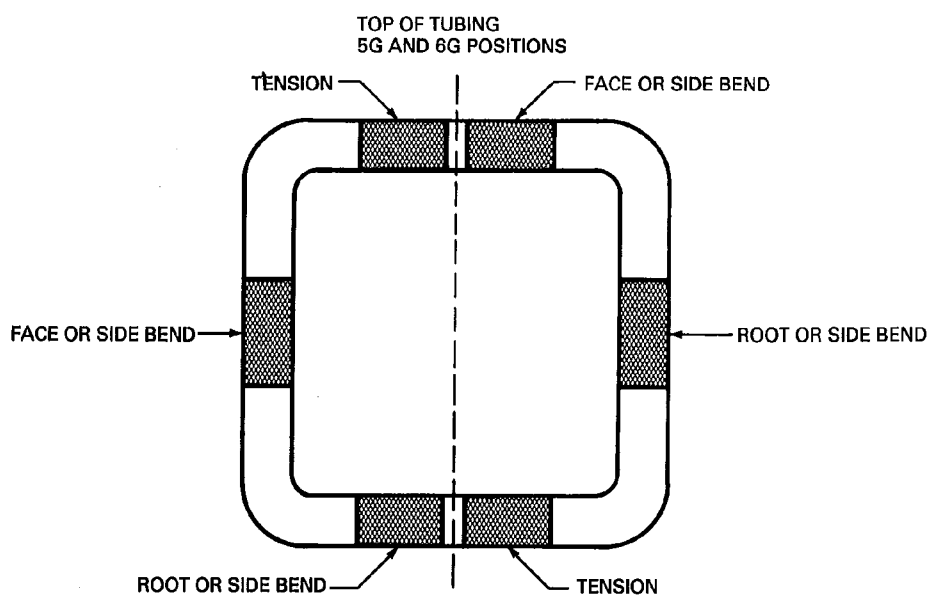
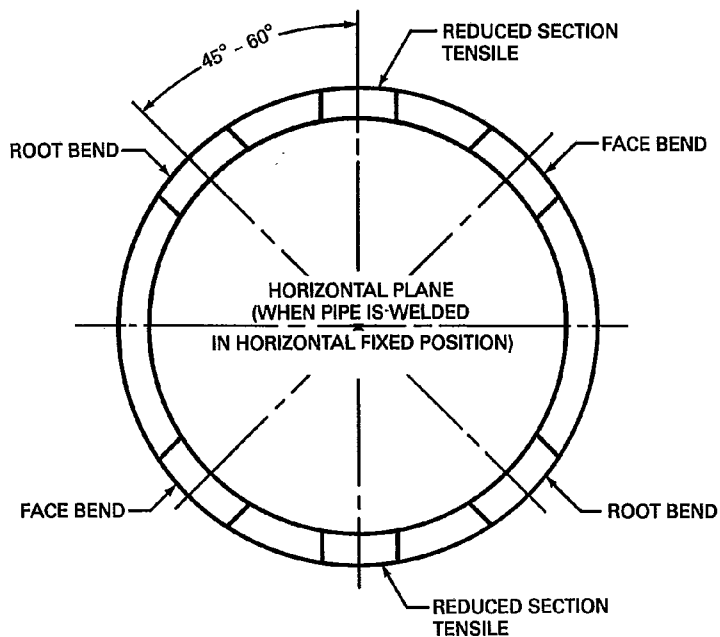
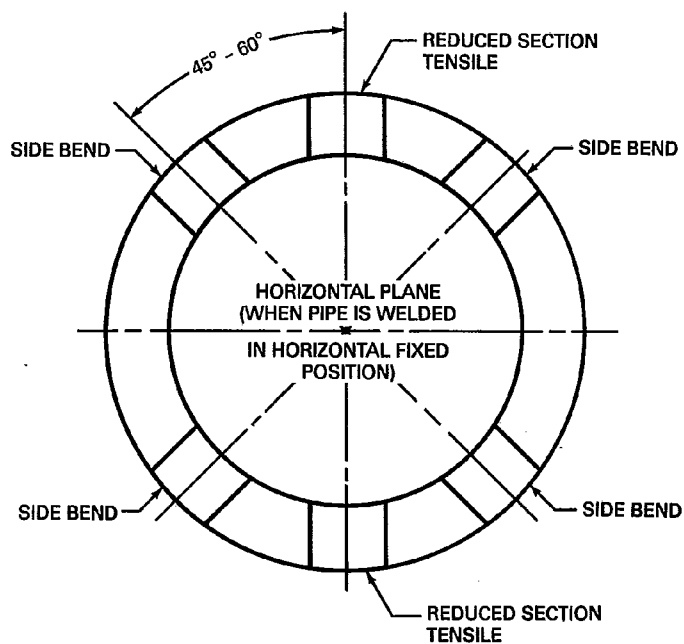


Figure 5.22 — Location of Test Specimens for Square and Rectangular Tubing (see 5.17.4.3)



**Figure 5.23 — Location of Test Specimens for Job Size Pipe or Tubing
1/16 in. (1.6 mm) through 3/8 in. (9.5 mm) Wall Thickness (see 5.17.4.3)**



**Figure 5.24 — Location of Test Specimens for Job Size Pipe or Tubing
Over 3/8 in. (9.5 mm) Wall Thickness (see 5.17.4.3)**

specimens cut from the same test weldment, or from an additional weldment made from the procedure qualification, material, and WPS. Both of the retest specimens shall meet the test requirements for the procedure to be qualified.

Part D

Performance Qualification

5.19 General

Note: Welders, welding operators, and tack welders should demonstrate a knowledge of safe practices and the particular hazards of the welding process and the procedures to be used in construction.

The qualification tests described in Part D are specially devised to determine the ability of a welder, welding operator, or tack welder to produce sound welds in accordance with the specified welding procedure. These qualification tests are not intended as a guide for selecting the procedure to be used for welding during construction. The test welds shall be made in accordance with the requirements for the Welding Procedure Specification.

5.19.1 Definitions. For purposes of this code the following shall apply:

(1) A welder is a person who uses a manual or semi-automatic process.

(2) A welding operator is a person who operates automated equipment, but has a degree of control over setting the values of the welding conditions. The welding operator may also provide manual guidance to the equipment along a weld joint.

(3) A tack welder is a person who, under the direction of a fitter, or as a fitter, tack welds an assembly in order to hold the parts together until the final welds are made.

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

5.19.3 Record of Tests. The essential variables of the weld procedure specification (WPS) and the test results obtained by each welder, welding operator, or tack welder shall be recorded on a Record of Performance Qualification Tests. A suggested form for these records is given in Appendix E, Form E(c).

5.19.4 Special Positions. A contractor, fabricator, or manufacturer who does production welding in a special orientation may make the tests for performance qualification in this specific orientation. Such qualifications are valid only for the positions actually tested, except that an angular deviation of $\pm 15^\circ$ is permitted in the inclination

of the weld axis and the rotation of the weld face, as defined in Figure 5.1 or 5.2.

5.19.5 A welder, welding operator, or tack welder who satisfactorily completes a test weldment that meets the criteria for Procedure Qualification in Part C of this section shall be considered qualified to weld joints within the type and position limitations for the qualification test weld set forth in Table 5.2 and subject to the limitation of variables for welders, welding operators, or tack welders in 5.22, 5.23, or 5.24, as applicable.

5.20 Limits of Qualified Positions for Performance

5.20.1 To reduce the number of welding performance qualifications that may be required, qualification under certain conditions also qualifies for other conditions as shown in Table 5.6 and enumerated in the following paragraphs:

5.20.2 Groove Welds — Plate

5.20.2.1 Qualification in the 1G (flat) position qualifies for flat position groove welding of plate, flat position and horizontal position fillet welding of plate, horizontal rotated (1G) position groove welding of pipe, and inclined rotated (1F) position and horizontal rotated (2FR) position fillet welding of pipe.

5.20.2.2 Qualification in the 2G (horizontal) position qualifies for flat position and horizontal position groove welding of plate, flat position and horizontal position fillet welding of plate, horizontal rotated position groove welding of pipe, and inclined rotated (1F) position and horizontal rotated (2FR) position fillet welding of pipe.

5.20.2.3 Qualification in the 3G (vertical) position qualifies for flat position and vertical position groove welding of plate; flat position, horizontal position and vertical position fillet welding of plate; horizontal rotated position groove welding of pipe; and inclined rotated (1F) position and horizontal rotated (2FR) position fillet welding of pipe.

5.20.2.4 Qualification in the 4G (overhead) position qualifies for flat position and overhead position groove welding of plate; flat position, horizontal position and overhead position fillet welding of plate; horizontal rotated position groove welding of pipe; and inclined rotated (1F) position and horizontal rotated (2FR) position fillet welding of pipe.

5.20.2.5 Qualification in both the 3G (vertical) and 4G (overhead) positions qualifies for all position groove welding of plate, all position fillet welding of plate, horizontal rotated position groove welding of pipe, and

Table 5.6
Welder Performance Qualification—Type of Weld and Position Limitations (see 5.20.1)

Qualification Test		Type of Weld and Position of Welding Qualified			
		Plate		Pipe	
Weld	Plate or Pipe Positions*	Groove	Fillet	Groove	Fillet
Plate-groove	1G	1G	1F, 2F	1G	1F, 2FR
	2G	1G, 2G	1F, 2F	1G	1F, 2FR
	3G	1G, 3G	1F, 2F, 3F	1G	1F, 2FR
	4G	1G, 4G	1F, 2F, 4F	1G	1F, 2FR
	3G and 4G	All	All	1G	1F, 2FR
Plate-fillet	1F		1F		1F
	2F		1F, 2F		1F, 2FR
	3F		1F, 2F, 3F		1F, 2FR
	4F		1F, 2F, 4F		1F, 2FR
	3F and 4F		All		1F, 2FR
Pipe-groove	1G	1G	1F, 2F	1G	1F, 2FR
	2G	1G, 2G	1F, 2F	1G, 2G	1F, 2F, 2FR
	5G	1G, 2G, 4G	(Note 1)	1G, 5G	(Note 1)
	6G	(Note 1)	(Note 1)	(Note 1)	(Note 1)
	2G and 5G	(Note 1)	(Note 1)	(Note 1)	(Note 1)
	6GR	All	All	All	All
Pipe-fillet	1F		1F		1F
	2F		1F, 2F		1F, 2F, 2FR
	2FR		1F, 2F		1F, 2FR
	4F		1F, 2F, 4F		1F, 2F, 4F, 2FR
	5F		All		All

Note 1. Qualifies all positions except for T-, Y-, and K-connections.

*See Figures 5.1, 5.2, 5.3, 5.4, 5.5, and 5.6.

inclined rotated (1F) position and horizontal rotated (2FR) position fillet welding of pipe.

5.20.2.6 Qualification on a groove weld test plate in the 1G (flat) or 2G (horizontal) position shall also qualify for groove welding pipe with a backing in the same position qualified.

5.20.3 Fillet Welds—Plate

5.20.3.1 Qualification in the 1F (flat) position qualifies for flat position fillet welding of plate, and inclined rotated (1F) position fillet welding of pipe.

5.20.3.2 Qualification in the 2F (horizontal) position qualifies for flat position and horizontal position fillet welding of plate, and inclined rotated (1F) position and horizontal rotated position fillet welding of pipe.

5.20.3.3 Qualification in the 3F (vertical) position qualifies for flat position, horizontal position and vertical position fillet welding of plate, and inclined rotated (1F) position and horizontal rotated (2FR) position fillet welding of pipe.

5.20.3.4 Qualification in the 4F (overhead) position qualifies for flat position, horizontal position, and overhead position fillet welding of plate, and inclined rotated (1F) position and horizontal rotated (2FR) position fillet welding of pipe.

5.20.3.5 Qualification in both the 3F (vertical) and 4F (overhead) positions qualifies for all position fillet welding of plate, and inclined rotated (1F) position and horizontal rotated (2FR) position fillet welding of pipe.

5.20.4 Groove Welds—Pipe

5.20.4.1 Qualification in the 1G (pipe axis horizontal, rotated) position qualifies for flat position groove welding of plate, flat position and horizontal position fillet welding of plate, horizontal rotated (1G) position groove welding of pipe, and inclined rotated (1F) position and horizontal rotated (2FR) position fillet welding of pipe.

5.20.4.2 Qualification in the 2G (pipe axis vertical, fixed) position qualifies for flat position and horizontal position groove welding of plate, flat position and horizontal position fillet welding of plate, horizontal rotated

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(1G) position and vertical fixed (2G) position groove welding of pipe, and inclined rotated (1F) position, horizontal fixed (2F) position, and horizontal rotated (2FR) position fillet welding of pipe.

5.20.4.3 Qualification in the 5G (pipe axis horizontal, fixed) position qualifies for flat position, vertical position and overhead position groove welding of plate; all positions fillet welding of plate; horizontal rotated (1G) position and horizontal fixed (5G) position groove welding of pipe; and all position fillet welding of pipe.

5.20.4.4 Qualification in the 6G (pipe axis inclined, fixed) position qualifies for all position fillet welding of plate and pipe and all position groove welding of plate and pipe, except for T-, Y-, and K-connections.

5.20.4.5 Qualification in the 6GR (restricted, pipe axis inclined, fixed) position qualifies for groove welding of T-, Y-, and K-connections and groove and fillet welding of plate and pipe in all positions.

5.20.4.6 Qualification on the groove weld pipe test shall also qualify for groove welding square or rectangular tubes equal to or less than the thickness of the test pipe welded.

5.20.5 Fillet Welds — Pipe

5.20.5.1 Qualification in the 1F (pipe axis inclined, rotated) position qualifies for flat position fillet welding of plate and inclined rotated (1F) position fillet welding of pipe.

5.20.5.2 Qualification in the 2F (pipe axis vertical, fixed) position qualifies for flat position and horizontal position fillet welding of plate, and inclined rotated (1F) position, horizontal fixed (2F) position, and horizontal rotated (2FR) position fillet welding of pipe.

5.20.5.3 Qualification in the 2FR (pipe axis horizontal, rotated) position qualifies for flat position and horizontal position fillet welding of plate, and inclined rotated (2F) position and horizontal rotated (2FR) position fillet welding of pipe.

5.20.5.4 Qualification in the 4F (pipe axis vertical, fixed) position qualifies for flat position, horizontal position, and overhead position fillet welding of plate; and inclined rotated (1F) position, horizontal fixed (2F) position, horizontal rotated (2FR) position, and overhead fixed (4F) position fillet welding of pipe.

5.20.5.5 Qualification in the 5F (pipe axis horizontal, fixed) position qualifies for all position fillet welding of plate, pipe, and tubing.

5.21 Preparation of Test Weldments — Performance Qualification

When performance qualification is done in accordance with a WPS that requires postweld heat treatment,

the postweld heat treatment may be omitted. Each welder, welding operator, or tack welder who welds under the rules of this Code shall have passed one or more tests as follows:

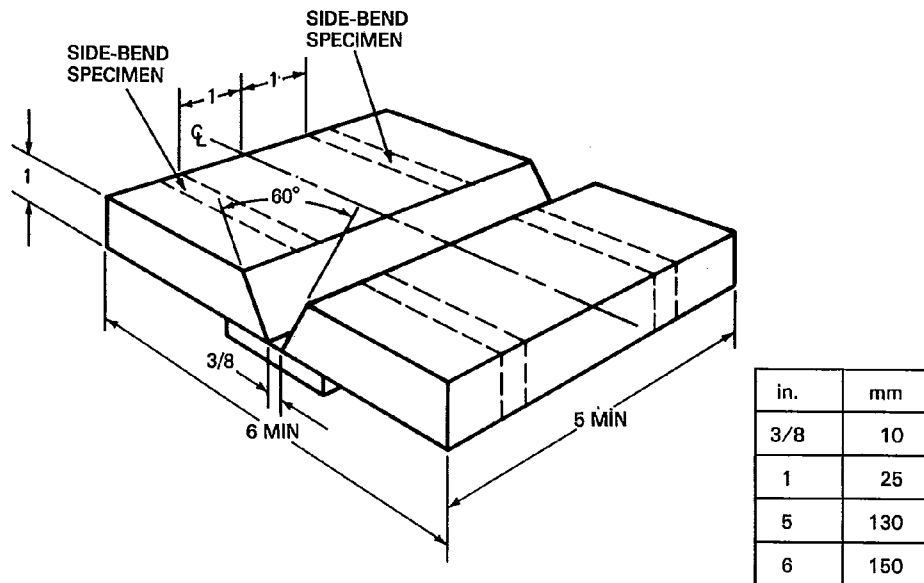
5.21.1 Groove Weld Qualification Test for Plate of Unlimited Thickness. For qualification (Option 1) in any position, the joint detail shall be as follows: 1 in. (25.4 mm) plate, single V-groove, 60° included angle, 3/8 in. (10 mm) root opening with backing (see Figure 5.25). For horizontal position qualification only (Option 2), the joint detail may, at the contractor's option, be as follows: single-bevel groove, 60° groove angle, 3/8 in. (10 mm) root opening with backing (see Figure 5.26). Backing shall be at least 3/8 in. (9.5 mm) by 2 in. (50 mm). Minimum length of welding groove shall be 5 in. (130 mm).

5.21.2 Groove Weld Plate Qualification Test for Plate of Limited Thickness. For qualification (Option 1) in any position, the joint detail shall be as follows: 3/8 in. (9.5 mm) plate, single V-groove, 60° included angle, 3/8 in. (10 mm) root opening with backing (see Figure 5.27). For horizontal position qualification only (Option 2), the joint detail may, at the contractor's option, be as follows: single-bevel groove, 60° groove angle, 3/8 in. (10 mm) root opening with backing (see Figure 5.28). Backing shall be at least 3/8 in. by 2 in. (9.5 mm × 50 mm). Minimum length of welding groove shall be 5 in. (130 mm).

5.21.3 Groove Weld Qualification Test for Pipe. The joint detail shall be (1) that shown in the qualified welding procedure specification for a single-welded pipe groove weld, or (2) pipe diameter and wall thickness as required, single V-groove, 60° included angle, 1/16 in. (1.6 mm) maximum root face and root opening without backing strip (see Figure 5.29 or 5.30), or (3) single V-groove, 60° included angle and suitable root face and root opening with backing (see Figure 5.31).

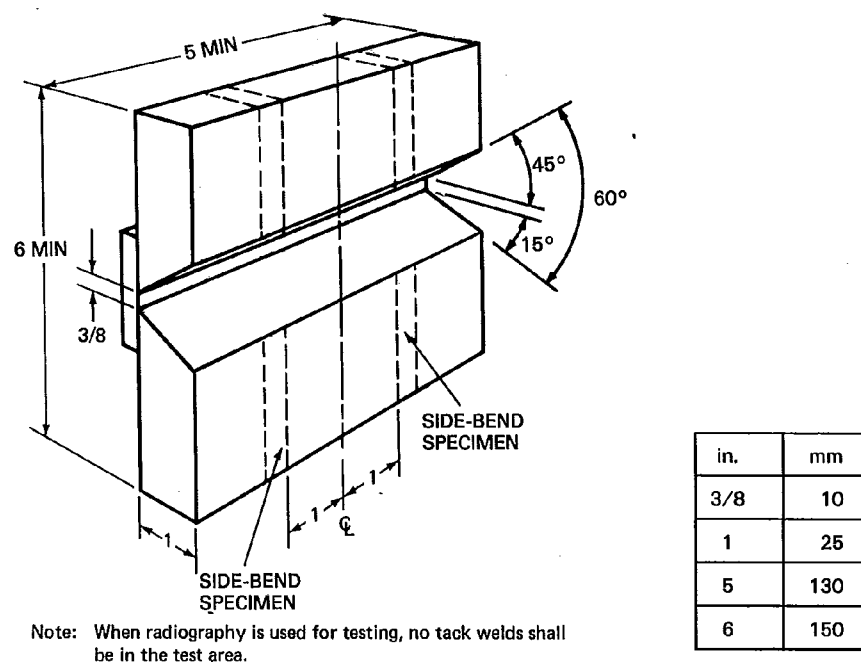
5.21.4 Groove Weld Qualification Test for T-, K-, or Y-Connections on Pipe or Tube. The joint detail (see Figure 5.32) shall be as follows: single-bevel, 60° minimum groove angle with bevel on pipe or tube at least 1/4 in. (6.4 mm) in thickness; the square edge pipe or tube shall be at least 3/16 in. (4.8 mm) thicker than the beveled pipe; 1/16 in. (1.6 mm) maximum root face and 1/16 in. root opening. A restriction ring shall be placed on the thicker material, within 1/2 in. (13 mm) of the joint and shall extend at least 6 in. (150 mm) beyond the surface of the pipe.

5.21.5 Fillet Weld Qualification Test for Plate and Pipe Only or Tack Welder Qualification. For fillet weld qualification only: (1) for fillet welds between parts having a dihedral angle (Ψ) of 75° or less, the welder shall weld a groove weld test plate as required by 5.21.1 or 5.21.2, and



Note: When radiography is used for testing, no tack welds shall be in the test area.

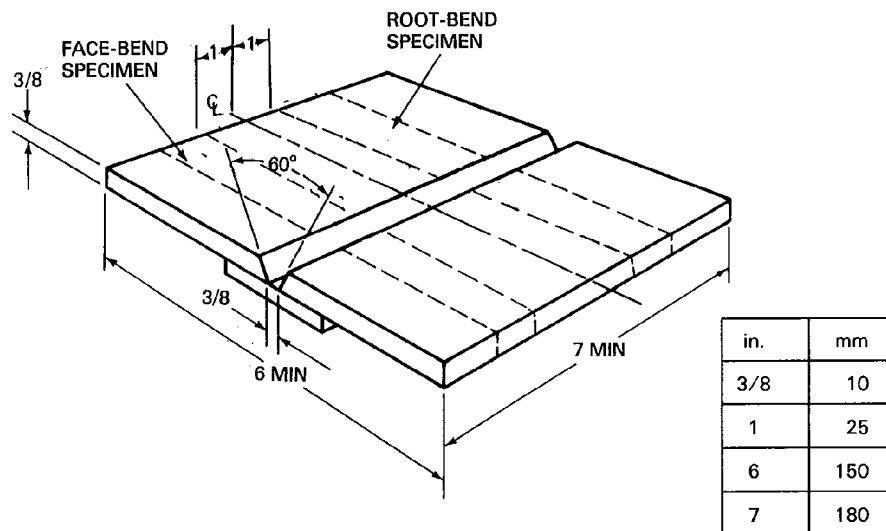
Figure 5.25 — Test Plate for Unlimited Thickness — Performance Qualification — Option 1 — All Positions (see 5.21.1)



Note: When radiography is used for testing, no tack welds shall be in the test area.

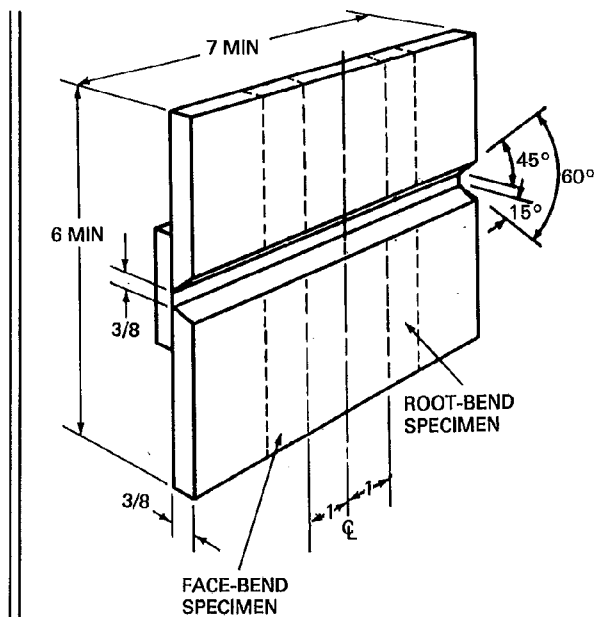
Figure 5.26 — Test Plate for Unlimited Thickness — Option 2 — Horizontal Position Only (see 5.21.1.1)

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Note: When radiography is used for testing, no tack welds shall be in the test area.

Figure 5.27 — Test Plate for Limited Thickness — All Positions — Performance Qualification (see 5.21.2)



Note: When radiography is used for testing, no tack welds shall be in the test area.

Figure 5.28 — Optional Test Plate for Limited Thickness — Horizontal Position — Performance Qualification (see 5.21.2)

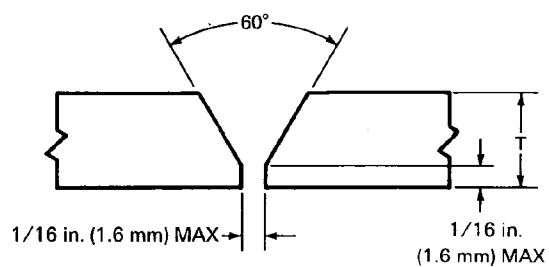


Figure 5.29 — Tubular Groove Weld — Performance Qualification — Without Backing (see 5.21.3)

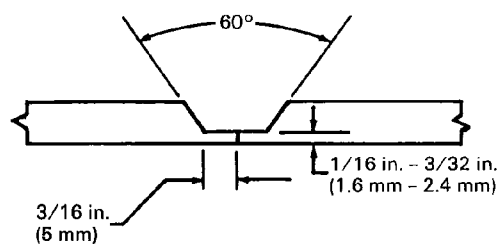


Figure 5.30 — Tubular Groove Weld — Performance Qualification — Without Backing (Alternative to Figure 5.29) (see 5.21.3)

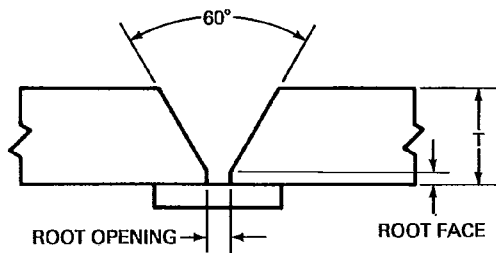


Figure 5.31 — Tubular Groove Weld — Performance Qualification With Backing (see 5.21.3)

(2) for joints having a dihedral angle (Ψ) greater than 75° , but not exceeding 135° , the welder shall prepare a weldment according to Option 1 or Option 2 depending on the contractor's choice, as follows:

5.21.5.1 Option 1. Plate and Pipe—Weld a fillet weld soundness test weldment in accordance with Figure 5.33.

5.21.5.2 Option 2. Plate Only—Weld a soundness test plate in accordance with Figure 5.19.

5.22 Limitation of Variables — Welder Performance Qualification

For the qualification of a welder, the following rules shall apply:

5.22.1 Qualification established with any one of the aluminum alloys permitted by this code shall be considered as qualification to weld or tack weld any of the other aluminum alloys with the process used in the qualification test.

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

5.22.3 Qualification established with an approved filler metal and shielding gas combination shall be considered as qualification to weld or tack weld with any other approved filler metal with the shielding gas and the process used in the qualification test.

5.22.4 A change in the position in which welding is performed as defined in 5.6 and outside the limitations of Table 5.6 shall require requalification.

5.22.5 A change from one diameter-wall pipe grouping shown in Table 5.7 to another shall require requalification.

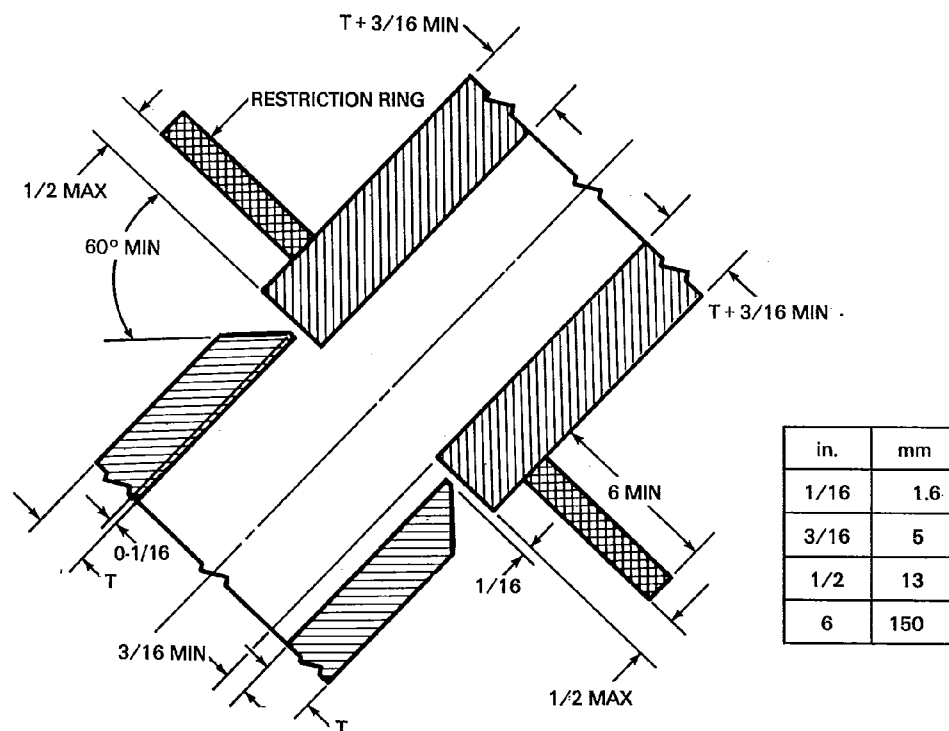
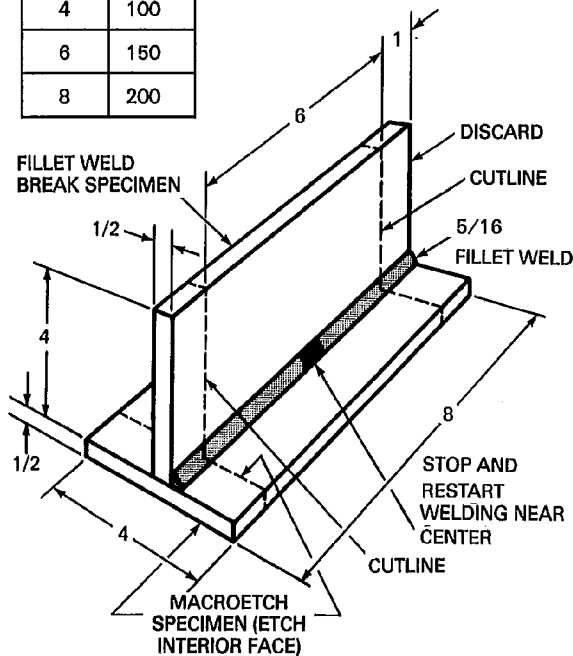


Figure 5.32 — Test Joint for T-, Y-, and K-Connections on Pipe or Square or Rectangular Tubing — Performance Qualification (see 5.21.4)

in.	mm
5/16	8
1/2	12.7
1	25
4	100
6	150
8	200



Note: Plate thickness and dimensions are minimum.

Figure 5.33 — Test Weldment for Fillet Welds Only — Performance Qualification — Option 1 (see 5.21.5.1)

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

5.22.7 The omission of backing material in complete joint penetration welds welded from one side shall require requalification.

5.23 Limitation of Variables — Welding Operator Performance Qualification

For the qualification of a welding operator, the following rules shall apply:

5.23.1 Qualification established with any one of the aluminum alloys permitted by this Code shall be considered as qualification to weld any of the other aluminum alloys with the process used in the qualification test.

5.23.2 Qualification established with an approved filler metal and shielding gas combination shall be considered qualification to weld with any other approved filler metal and shielding gas combination with the process used in the qualification test.

5.23.3 A welding operator qualified to weld with multiple electrodes is considered qualified to weld with a single electrode, but not vice versa.

5.23.4 A change in the position in which welding is performed, as defined in 5.6, shall require requalification.

5.23.5 A welding operator shall be qualified for each process used.

5.24 Limitation of Variables — Tack Welder Performance Qualification

For the qualification of a tack welder, the following rules shall apply:

5.24.1 Qualification established with any one of the aluminum alloys permitted by this code shall be considered as qualification to tack weld any of the other aluminum alloys with the process used in the qualification test.

5.24.2 Qualification as a tack welder shall qualify as a welder of fillet welds in the position qualified as defined in 5.3.

5.24.3 Qualification established with an approved filler metal and shielding gas combination shall be considered qualification to tack weld with any other approved filler metal and shielding gas combination for the process used in the qualification test.

5.24.4 A tack welder shall be qualified for each process used.

5.24.5 A change in the position in which tack welding is performed, as defined in 5.6, shall require requalification.

5.25 Tests — Performance Qualification

5.25.1 Required Tests — Groove Welds

(1) Visual examination for appearance and dimensions.

(2) Bend test for soundness and ductility (except castings), or radiographic examination.

(3) When welding a casting to other castings or wrought materials, the bend test for soundness and ductility of groove welds and fillet welds shall be omitted, and a macroetch test for soundness shall be conducted.

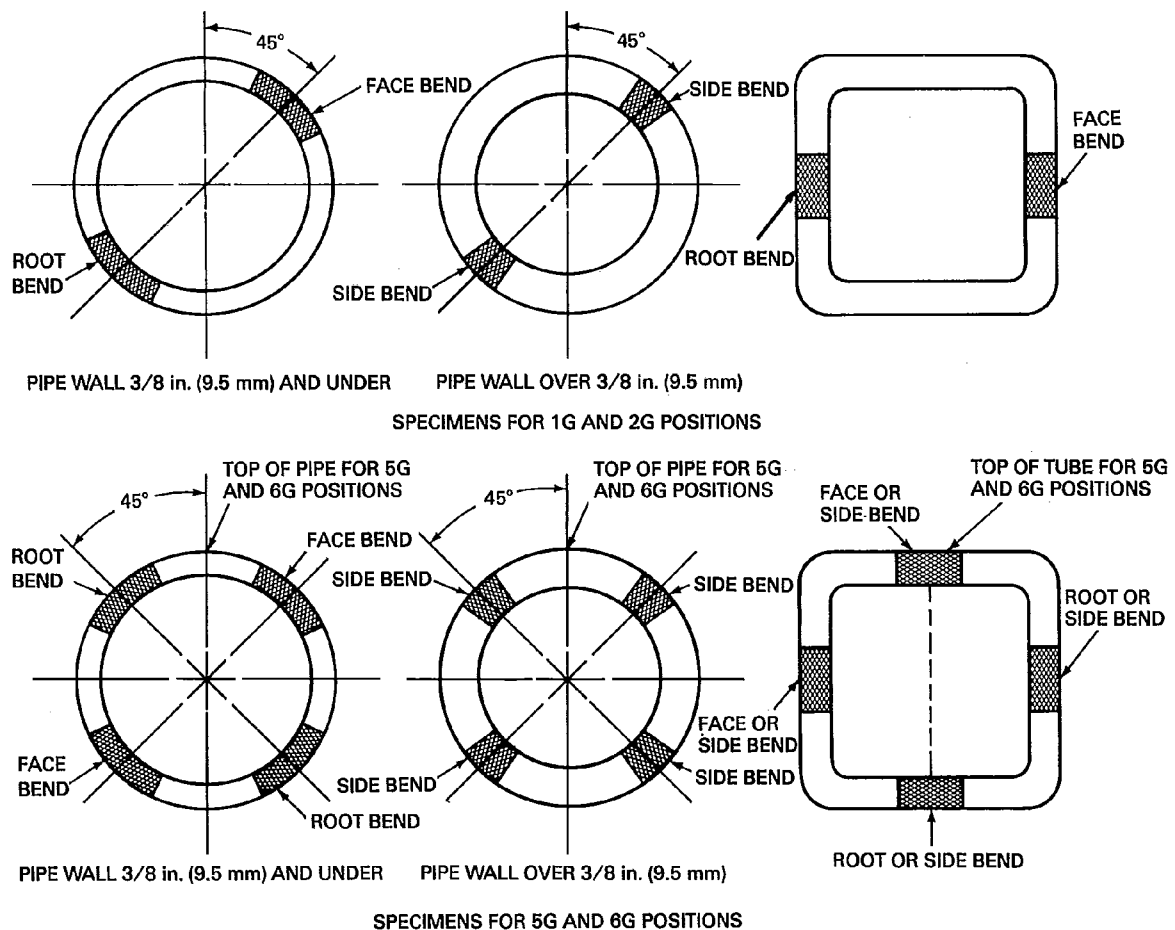


Figure 5.34 — Location of Test Specimen on Welded Test Pipe and Square and Rectangular Tubing — Performance Qualification (see 5.25.4)

5.25.2 Required Tests — Fillet Welds

- (1) Visual examination for appearance and dimensions and macroetch test.
- (2) Fracture test (Option 1) for soundness (see Figure 5.33), or root bend test (Option 2) for soundness (see Figure 5.19).
- (3) Macroetch test for soundness of welded castings.

5.25.3 Test Specimens: Number, Type, and Preparation. The type and number of test specimens that shall be tested to qualify a welder, welding operator, or tack welder are shown in Table 5.7 together with the range of material thicknesses that are qualified for use in construction in relation to the thickness of the test material used in making the qualification. Radiographic examination of the groove-weld test assembly may be used at the contractor's option in lieu of mechanical testing.

5.25.4 Location of Test Specimens for Performance Qualification. One sample weldment shall be made for the type of weld qualification being tested. Test size of the sample weldment and location of the test specimens to be removed shall be in accordance with the figures associated with the type of weldment being tested (see Figures 5.25 through 5.33). The removal of test specimens from pipe shall be as shown in Figure 5.34.

5.25.5 Preparation of Test Specimens. The test specimens shall be prepared in accordance with section 5, Part B.

5.25.6 Test Procedures

5.25.6.1 Bend tests shall be made as described in 5.10.2.

5.25.6.2 Fillet Weld Fracture Test. The entire length of the fillet weld shall be examined visually; then the

Table 5.7
Number and Type of Test Specimens and Range of Thickness Qualified —
Welder and Welding Operator Qualification (see 5.25.3)
(Dimensions in Inches)

1. Test on Plate

Type of Weld	Thickness (T) of Test Plate as Welded, in.	Visual Inspection	Number of Specimens					Plate Thickness Qualified, in.	
			Bend Tests* All Positions			Fillet Weld Fracture	Macroetch Test		
			Face	Root	Side			Min	Max ¹
Groove	< 3/8	Yes	1	1	—	—	—	T	2T
Groove	3/8	Yes	1	1	—	—	—	1/8	2T
Groove	Over 3/8 and under 1	Yes	—	—	2	—	—	1/8	2T
Groove	1 or over	Yes	—	—	2	—	—	1/8, unlimited	
Fillet Option 1 ¹	1/2	Yes	—	—	—	1	1	Unlimited	
Fillet Option 2 ²	3/8	Yes	—	2	—	—	—	Unlimited	

Notes:

1. See Figure 5.33.

2. See Figure 5.19.

3. Also qualifies for welding fillet welds on material of unlimited thickness.

*Radiographic examination of the welder or welding operator test plate may be made in lieu of the bend test. (See 5.7.3)

2. Tests on Pipe or Tubing — Class I Structures*

Material Type	Pipe or Tube Size of Sample Weld		Number of Sample Welds per Position	Visual Inspection	Test Specimens Required			Pipe or Tubing Diameter Qualified		Wall Thickness Qualified	
	Nominal Pipe Size, in.	Wall, t, of Wrought, in.			Macroetch Test	Root Bend (see Figure 5.12)	Face Bend (see Figure 5.12)	Min in.	Max in.	Min in.	Max in.
Wrought to Wrought	6 through 8	1/8 – 3/8	1	Yes	—	2	2	3/4	16	1/8	3/8
Cast to Wrought or Cast to Cast	3 through 5	3/16	1	Yes	2	—	—	2	16	1/8	1/2

*Class I structures: refer to 10.1.2 for definition of Class I structures.

(Continued)

Table 5.7 (Continued)
(Dimensions in Inches)**3. Tests on Pipe — Class II Structures***

Type of Weld	Pipe or Tubing Size as Welded		Visual Inspection	Number of Specimens						Pipe or Tube Size Qualified, in.	Pipe or Tube Wall Thickness Qualified, in.	
				All Positions Except 5G and 6G			5G and 6G Positions Only					
	Nominal Pipe Size	Wall Thickness		Face Bend	Root Bend	Side Bend	Face Bend	Root Bend	Side Bend		Min	Max ¹
Groove	2 in. or 3 in.	Sch. 80 Sch. 40	Yes	1	1	—	2	2	—	4 or smaller	0.063	0.674 ¹
Groove	6 in. or 8 in.	Sch. 120 Sch. 80	Yes	—	—	2	—	—	4	Larger than 4	0.187	Unlimited ¹
Groove	See Figure 5.32		Yes	—	—	—	—	—	4	All	Unlimited ¹	

*Class II structures: refer to 10.1.2 for definition of Class II structures.

4. Tests on Job Size Pipe or Tubing

Type of Weld	Pipe or Tubing Size as Welded		Visual Inspection	Number of Specimens (See Note)						Pipe or Tube Size Qualified, in.	Pipe or Tube Wall Thickness Qualified, in.	
	Nominal Pipe Size	Wall Thickness, T		All Positions Except 5G and 6G			5G and 6G Positions Only				Min	Max ¹
				Face Bend	Root Bend	Side Bend	Face Bend	Root Bend	Side Bend			
Groove	≤ 4 in.	Any	Yes	1	1	—	2	2	—	4 or smaller	0.063 ²	0.674 ¹
Groove	> 4 in.	Any	Yes	—	—	2	—	—	4	1/2 test diam. or 4 min ³ through unlimited (for maximum size qualified)	0.187	Unlimited
Fillet Option 1	2 in. or 3 in.	Sch. 120	Yes	Filled Weld Fracture Test			Macroetch Test			All	Unlimited ¹	
		Sch. 40		2			2					

Note: Radiographic examination of the welder or welding operator test pipe may be made in lieu of the bend test. (See 5.7.3)

1. Also qualifies for welding fillet welds on material of unlimited thickness.

2. If $T < 0.063$, minimum wall thickness qualified shall be T and maximum qualified shall be 2T.3. Minimum pipe size qualified shall not be less than 4 in. or $d/2$, whichever is greater, where d is diameter of test pipe.

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Table 5.7
Number and Type of Test Specimens and Range of Thickness Qualified —
Welder and Welding Operator Qualification (see 5.25.3)
(Dimensions in Millimeters)

1. Test on Plate

Type of Weld	Thickness (T) of Test Plate as Welded, mm	Visual Inspection	Number of Specimens					Plate Thickness Qualified, mm	
			Bend Tests* All Positions			Fillet Weld Fracture	Macroetch Test		
			Face	Root	Side			Min	Max ¹
Groove	< 9.5	Yes	1	1	—	—	—	T	2T
Groove	9.5	Yes	1	1	—	—	—	3.2	2T
Groove	Over 9.5 and under 25.4	Yes	—	—	2	—	—	3.2	2T
Groove	25.4 or over	Yes	—	—	2	—	—	3.2, unlimited	
Fillet Option 1 ¹	12.7	Yes	—	—	—	1	1	Unlimited	
Fillet Option 2 ²	9.5	Yes	—	2	—	—	—	Unlimited	

Notes:

1. See Figure 5.33.

2. See Figure 5.19.

3. Also qualifies for welding fillet welds on material of unlimited thickness.

*Radiographic examination of the welder or welding operator test plate may be made in lieu of the bend test. (See 5.7.3)

2. Tests on Pipe or Tubing — Class I Structures*

Material Type	Pipe or Tube Size of Sample Weld		Number of Sample Welds per Position	Visual Inspection	Test Specimens Required			Pipe or Tubing Diameter Qualified		Wall Thickness Qualified	
	Nominal Pipe Size, mm	Wall, t, of Wrought, mm			Macroetch Test	Root Bend (see Figure 5.12)	Face Bend (see Figure 5.12)	Min mm	Max mm	Min mm	Max mm
Wrought to Wrought	150 through 200	3.2 – 9.5	1	Yes	—	2	2	19	410	3.2	9.5
Cast to Wrought or Cast to Cast	75 through 130	4.8	1	Yes	2	—	—	50	410	3.2	12.7

*Class I structures: refer to 10.1.2 for definition of Class I structures.

(Continued)

Table 5.7 (Continued)
(Dimensions in Millimeters)**3. Tests on Pipe — Class II Structures***

Type of Weld	Pipe or Tubing Size as Welded		Visual Inspection	Number of Specimens						Pipe or Tube Size Qualified, mm	Pipe or Tube Wall Thickness Qualified, mm	
				All Positions Except 5G and 6G			5G and 6G Positions Only					
	Nominal Pipe Size	Thickness		Face Bend	Root Bend	Side Bend	Face Bend	Root Bend	Side Bend		Min	Max ¹
Groove	50 mm or 75 mm	5.5 mm	Yes	1	1	—	2	2	—	100 or smaller	1.6	17.1 ¹
Groove	150 mm or 200 mm	14.3 or 12.7	Yes	—	—	2	—	—	4	Larger than 100	4.8	Unlimited ¹
Groove	See Figure 5.32		Yes	—	—	—	—	—	4	All	Unlimited ¹	

*Class II structures: refer to 10.1.2 for definition of Class II structures.

4. Tests on Job Size Pipe or Tubing

Type of Weld	Pipe or Tubing Size as Welded		Visual Inspection	Number of Specimens (See Note)						Pipe or Tube Size Qualified, mm	Pipe or Tube Wall Thickness Qualified, mm	
	Nominal Pipe Size	Wall Thickness, T		All Positions Except 5G and 6G			5G and 6G Positions Only				Min	Max ¹
				Face Bend	Root Bend	Side Bend	Face Bend	Root Bend	Side Bend			
Groove	≤ 100 mm	Any	Yes	1	1	—	2	2	—	100 or smaller	1.6 ²	17.1 ¹
Groove	> 100 mm	Any	Yes	—	—	2	—	—	4	1/2 test diam. or 100 min ³ through unlimited (for maximum size qualified)	4.8	Unlimited
Fillet Option 1	50 mm or 75 mm	Sch. 120 or Sch. 40	Yes	Filled Weld Fracture Test			Macroetch Test			All	Unlimited ¹	
				2			2					

Note: Radiographic examination of the welder or welding operator test pipe may be made in lieu of the bend test. (See 5.7.1)

1. Also qualifies for welding fillet welds on material of unlimited thickness.

2. If $T < 1.6$ mm, minimum wall thickness qualified shall be T, and maximum qualified shall be 2T.3. Minimum pipe size qualified shall not be less than 100 mm or $d/2$, whichever is greater, where d is diameter of test pipe.

6 in. (150 mm) long specimen shall be tested as described in 5.25.2.2.

5.25.6.3 Radiographic test procedure shall be as described in section 6, Part B.

5.25.6.4 Macroetch test procedure is described in 5.8.1.2.

5.25.7 Acceptance Criteria — Groove Welds

5.25.7.1 Visual examination shall conform to 5.8.2.

5.25.7.2 Guided bend test results shall be within the limits of 5.10.3.

5.25.7.3 Radiographic evaluation shall be within the limits of 5.12.2.

5.25.8 Acceptance Criteria — Fillet Welds

5.25.8.1 Visual examination shall conform to 5.8.3.

5.25.8.2 Fracture test results shall be within the limits of 5.11.3.1.

5.25.8.3 Fillet weld root bend test results shall be within the limits of 5.10.3.

5.26 Retests

5.26.1 The performance test may be terminated at any stage of the testing procedure, whenever it becomes

apparent to the supervisor conducting the tests that the welder, welding operator, or tack welder does not have the required skill to produce satisfactory results.

5.26.2 In case a welder, welding operator or tack welder fails to meet the requirements of one or more weld tests, a retest may be allowed under the following conditions:

5.26.2.1 An immediate retest may be made consisting of two test specimens of each type on which the welder, welding operator, or tack welder failed. All retest specimens shall meet all the specified requirements.

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

5.27 Period of Effectiveness

The welder's, welding operator's, or tack welder's qualification, as specified in this code (section 5, Part D), shall be considered as remaining in effect indefinitely unless (1) the welder, welding operator, or tack welder is not engaged in a given process of welding for which the welder, welding operator, or tack welder is qualified for a period exceeding six months, or (2) there is some specific reason to question the welder's, welding operator's, or tack welder's ability.

6. Inspection

Part A *General Requirements*

6.1 General

6.1.1 For the purpose of this Code, fabrication/erection inspection and testing and verification inspection and testing are separate functions. Fabrication/erection inspection and testing shall be performed as necessary prior to assembly, during assembly, during welding, and after welding to ensure that materials and workmanship meet the requirements of the contract documents. Verification inspection and testing shall be performed in a timely manner to avoid delays in the work.

Fabrication/erection inspection and testing is the responsibility of the contractor, unless otherwise provided in the contract documents. Verification inspection and testing is the prerogative of the Engineer (owner) who may perform this function or, when provided in the contract, waive independent verification, or stipulate that both erection and verification inspections shall be performed by the contractor.

6.1.2 The fabrication/erection Inspector is the duly designated person who acts for, and on behalf of, the contractor on all inspection and quality matters within the scope of the contract documents. The verification Inspector is the duly designated person who acts for, and in behalf of, the owner or Engineer on all inspection and quality matters within the scope of the contract documents. When the term Inspector(s) is used without further qualification, it applies equally to erection and verification within the limits of responsibility designated in 6.1.1.

6.1.3 Inspector Qualification

6.1.3.1 Inspectors responsible for acceptance or rejection of material and workmanship shall be qualified. The basis of Inspector qualification shall be documented. If

the Engineer elects to specify the basis of inspector qualification, it shall be so stated in contract documents.

The following are acceptable qualification bases:

- (1) Current or previous certification as an AWS Certified Welding Inspector (CWI) in accordance with the provisions of AWS QC1, *Standard and Guide for Qualification and Certification of Welding Inspectors*, or
- (2) Current or previous qualification by the Canadian Welding Bureau (CWB) to the requirements of the Canadian Standard Association (CSA) Standard W178.2, *Certification of Welding Inspectors*, or
- (3) An Engineer or technician who, by training or experience, or both, in metals fabrication, inspection, and testing, is competent to perform inspection of the work.

6.1.3.2 The qualification of an Inspector shall remain in effect indefinitely, provided the Inspector remains active in inspection of welded aluminum fabrication, unless there is specific reason to question the Inspector's ability.

6.1.3.3 The Inspector may be supported by Assistant Inspectors who may perform specific inspection functions under the supervision of the Inspector. Assistant Inspectors shall be qualified by training and experience to perform the specific functions to which they are assigned. The work of Assistant Inspectors shall be regularly monitored by the Inspector, generally on a daily basis.

6.1.3.4 Inspectors and Assistant Inspectors shall have passed an eye examination with or without corrective lenses to prove: (1) near vision acuity of Snellen English, or equivalent, at 12 in. (305 mm), and (2) far vision acuity of 20/40, or better. An eye examination of all inspection personnel is required every three years or less, if necessary, to demonstrate adequacy.

6.1.3.5 The Engineer shall have authority to verify the qualification of Inspectors.

6.1.4 The Inspector shall ascertain that all fabrication and erection by welding is performed in accordance with the requirements of the contract documents.

6.1.5 The Inspector shall be furnished complete, detailed drawings showing the size, length, type, and location of all welds to be made. The Inspector shall be furnished the portion of the contract documents that describes material and quality requirements for the products to be fabricated or erected, or both.

6.1.6 The Inspector shall be notified in advance of the start of operations subject to inspection and verification.

6.2 Inspection of Materials

The Inspector shall make certain that only materials conforming to the requirements of this Code are used.

6.3 Inspection of Welding Procedure Qualification and Equipment

6.3.1 The Inspector shall make certain that all welding is in accordance with a welding procedure specification which has been qualified in accordance with 5.2 of this Code.

6.3.2 The Inspector shall inspect the welding equipment to be used for the work to make certain that it conforms to the requirements of 3.1.2.

6.4 Inspection of Welder, Welding Operator, and Tack Welder Qualifications

6.4.1 The Inspector shall permit welding to be performed only by welders, welding operators, and tack welders who are qualified in accordance with the requirements of 5.3 or shall make certain that all welders, welding operators, or tack welders have previously demonstrated their qualifications under other acceptable supervision.

6.4.2 When the quality of a welder's, welding operator's, or tack welder's work appears to be below the requirements of this Code, the Inspector may require that the welder, welding operator, or tack welder demonstrate an ability to produce sound welds by means of a simple test, such as the fillet weld break test or by requiring complete requalification in accordance with section 5, Part D.

6.4.3 The Inspector shall require requalification of any welder, welding operator, or tack welder who has not used each process to be used in the construction under consideration for a period exceeding six months.

6.5 Inspection of Work and Records

6.5.1 As part of the visual inspection, the Inspector shall make certain that the size, length, and location of all welds conform to the requirements of this Code, and to the detail drawings, and that no unspecified welds have been added without approval.

6.5.2 The Inspector shall make certain that only welding procedures which meet the provisions of 5.1 and 5.2 are employed.

6.5.3 The Inspector shall, at regular intervals, observe the technique and performance of each welder, welding operator, and tack welder to make certain that the applicable requirements of section 4 are met.

6.5.4 The Inspector shall examine the work to make certain that it meets the requirements of section 3 and subsections 8.8, 9.8, 10.10, or 10.15, as applicable. The size and contour of welds shall be measured with acceptable gages. Visual inspection for cracks in welds and base metal and other discontinuities should be aided by a strong light, magnifiers, or such other devices as may be found helpful.

6.5.5 The Inspector shall identify with a distinguishing mark all parts or joints that have been inspected and accepted.

6.5.6 The Inspector shall keep a record of qualifications of all welders, welding operators, and tack welders, all procedure qualifications or other tests that are made, and such other information as may be pertinent.

6.6 Obligations of the Contractor

6.6.1 In addition to the requirements of 6.1.1, the contractor shall be responsible for visual inspection and necessary correction of all deficiencies in materials and workmanship in accordance with the requirements of section 3 and subsection 8.8.1, 9.8.1, 10.10, or 10.15.1, as applicable.

6.6.2 The contractor shall comply with all requests of the Inspector to correct deficiencies in materials and workmanship as provided in the contract documents.

6.6.3 If faulty welding or its removal for rewelding damages the base metal so that in the judgement of the Engineer its retention is not in accordance with the intent of the contract documents, the contractor shall remove and replace the damaged base metal or shall compensate for the deficiency in a manner approved by the Engineer.

6.6.4 When nondestructive testing other than visual inspection is specified in the information furnished to bidders, it shall be the contractor's responsibility to ensure that all specified welds meet the quality requirements of 8.8, 9.8, 10.10, or 10.15, whichever is applicable.

6.6.5 If nondestructive testing other than visual inspection is not specified in the original contract agreement, but is subsequently requested by the owner, the contractor shall perform any requested testing or shall permit any testing to be performed in accordance with 6.7. The owner shall be responsible for all associated costs including handling, surface preparation, nondestructive testing, and repair of discontinuities other than those listed in 8.8.1, 9.8.1, 10.10, or 10.15.1, whichever is applicable, at rates mutually agreeable between owner and contractor. However, if such testing should disclose an attempt to defraud or disclose gross nonconformance to this code, repair work shall be done at the contractor's expense.

6.7 Nondestructive Testing

6.7.1 When nondestructive testing other than visual is to be required, it shall be so stated in the information furnished to the bidders. This information shall designate the categories of welds to be examined, the extent of examination of each category, and the method or methods of testing.

6.7.2 Welds tested nondestructively that do not meet the requirements of this Code shall be repaired by the methods permitted in 3.7.

6.7.3 When radiographic testing is used, the procedure and technique shall be in accordance with Part B of this section.

6.7.4 When ultrasonic testing is used, the procedure and technique shall be in accordance with Part C of this section.

6.7.5 For detecting discontinuities that are open to the surface, liquid penetrant inspection may be used. The methods set forth in ASTM E165, *Standard Recommended Practice for Liquid Penetrant Inspection Method*, shall be used and the standards of acceptance shall be in accordance with 8.8.1, 9.8.1, 10.10, or 10.15.1, whichever is applicable.

6.7.6 Personnel Qualification

6.7.6.1 Personnel performing nondestructive testing other than visual shall be qualified in accordance with the current edition of the American Society for Nondestructive Testing Recommended Practice No. SNT-TC-1A.¹⁴ Only individuals qualified for NDT Level I and working under the NDT Level II or individuals qualified for NDT Level II may perform nondestructive testing.

14. Available from the American Society for Nondestructive Testing, 4153 Arlingate Plaza, Columbus, Ohio 43228.

6.7.6.2 Certification of Level I and Level II individuals shall be performed by a Level III individual who has been certified by (1) The American Society for Nondestructive Testing, or (2) has the education, training, experience, and has successfully passed the written examination prescribed in SNT-TC-1A.

6.7.6.3 Personnel performing nondestructive tests under the provisions of 6.7.6 need not be qualified nor certified under the provisions of AWS QC1.

Part B Radiographic Testing of Groove Welds in Butt Joints

6.8 General

6.8.1 The procedures and standards set forth herein govern radiographic testing of welds when such inspection is required by the contract documents as provided in 6.7. The requirements listed herein are specifically for testing groove welds in butt joints in plates, shapes, and bars by X-ray or gamma-ray sources. The methodology shall conform to ASTM E94, *Standard Recommended Practice for Radiographic Testing*, and ASTM E142, *Standard Method for Controlling Quality of Radiographic Testing*, except as provided herein.

6.8.2 Variations in testing procedures, equipment, and acceptance standards may be used upon agreement between the contractor and the Engineer. Such variations include, but are not limited to, the following: radiographic testing of fillet, T, and corner welds; changes in source-to-film distance; unusual application of film; unusual penetrometer applications (including film side penetrometers and wire penetrometers); radiographic testing of thicknesses greater than 6 in. (150 mm); film types, densities, and variations in exposure, development, and view techniques.

6.9 Extent of Testing

6.9.1 The information furnished to bidders shall clearly identify the extent of radiographic testing.

6.9.2 Welds requiring radiography shall be tested for their full length, unless partial or spot testing is specified.

6.9.3 When partial testing is specified, the locations and lengths of welds or categories of welds to be tested shall be clearly designated in the contract documents.

6.9.4 When spot testing is specified, the number of spots in each designated category of welded joint to be radiographed in a stated length of weld shall be included in the information furnished to the bidders. Each spot radiograph shall show at least 4 in. (100 mm) of weld length.

When a spot radiograph shows discontinuities that require repair, two additional spots in the same segment of weld represented by the original spot shall be taken at locations away from the original spot. The location of the additional spots shall be agreed upon between the contractor and the verification inspector. When either of the two additional spots shows defects which require repair, the entire segment of the weld represented by the original spot shall be completely radiographed. If the weld involves more than one segment, two additional spot radiographs shall be taken at locations agreed upon by the contractor and the verification inspector, subject to the foregoing interpretation.

6.10 Radiographic Procedures

6.10.1 Radiographs shall be made using a single source of either X-ray or gamma radiation. The radiographic sensitivity shall be judged on the basis of the penetrameter images. The radiographic technique and equipment

shall provide sufficient sensitivity to clearly delineate the required penetrameters and the essential holes as described in 6.10.7, Table 6.1 and Figure 6.5. Identifying letters and numbers shall show clearly in the radiograph.

6.10.2 Radiography shall be performed in accordance with all applicable safety requirements. A summary of references for safe radiographic procedures is listed in Appendix J.

6.10.3 When the contract documents require the removal of weld reinforcement, the welds shall be prepared for radiography by grinding as described in 3.6.3. Other weld surfaces need not be ground or otherwise smoothed for purposes of radiographic testing unless surface irregularities between the weld and base metal obscure objectionable weld discontinuities.

6.10.3.1 Extension bars and run off plates shall be removed prior to radiographic inspection unless otherwise approved by the Engineer.

Table 6.1
Penetrameter Requirements (see 6.10.1)

Nominal Material Thickness Range (in.)	Penetrameter Identification	Penetrameter Thickness, in.	Essential Hole
Up to 0.25 incl.	10	0.010	4T
Over 0.25 to 0.375	12	0.012	4T
Over 0.375 to 0.50	15	0.015	4T
Over 0.50 to 0.625	15	0.015	4T
Over 0.625 to 0.75	17	0.017	4T
Over 0.75 to 0.875	20	0.020	4T
Over 0.875 to 1.00	20	0.020	4T
Over 1.00 to 1.25	25	0.025	4T
Over 1.25 to 1.50	30	0.030	2T
Over 1.50 to 2.00	35	0.035	2T
Over 2.00 to 2.50	40	0.040	2T
Over 2.50 to 3.00	45	0.045	2T
Over 3.00 to 4.00	50	0.050	2T
Over 4.00 to 6.00	60	0.060	2T

Nominal Material Thickness Range (mm)	Penetrameter Identification	Penetrameter Thickness, mm	Essential Hole
Up to 6.4 incl.	10	0.25	4T
Over 6.4 through 9.5	12	0.30	4T
Over 9.5 through 12.7	15	0.38	4T
Over 12.7 through 15.9	15	0.38	4T
Over 15.9 through 19.0	17	0.43	4T
Over 19.0 through 22.2	20	0.51	4T
Over 22.2 through 25.7	20	0.51	4T
Over 25.7 through 31.7	25	0.63	4T
Over 31.7 through 38.1	30	0.76	2T
Over 38.1 through 50.8	35	0.89	2T
Over 50.8 through 63.6	40	1.02	2T
Over 63.6 through 76.2	45	1.14	2T
Over 76.2 through 102	50	1.27	2T
Over 102 through 152	60	1.52	2T

6.10.3.2 When required by 4.8 or other provisions of the contract documents, backing shall be removed and the surface shall be finished flush by mechanical means prior to radiography. Weld finishing shall be as described in 3.6.3.

6.10.3.3 When weld reinforcement or backing, or both, are not removed, aluminum shims which extend at least 1/8 in. (3 mm) beyond three sides of the required penetrameter shall be placed under the penetrameter so that the total thickness of aluminum between the penetrameter and the film is approximately equal to the average thickness of the weld measured through its reinforcement and backing.

6.10.4 As described in ASTM E94 (see Appendix A), radiographic film shall be Type 1 or Type 2, and lead foil screens shall be used as needed. Fluorescent screens shall not be permitted.

6.10.5 Radiographs shall be made with a single source of radiation centered as near as practicable with respect to the length and width of that portion of the weld being examined.

6.10.5.1 Gamma ray sources, regardless of size, shall be capable of meeting the geometric unsharpness requirement of Article 2, Section V of *ASME Boiler and Pressure Vessel Code* (see Appendix A).

6.10.5.2 The source-to-subject distance shall not be less than the total length of film being exposed in a single

plane. This provision does not apply to panoramic exposures made under the provisions of 6.10.8.2.

6.10.5.3 The source-to-subject distance shall not be less than seven times the thickness of the weld plus reinforcement and backing, if any, nor shall the inspecting radiation penetrate any portion of the weld represented in the radiograph at an angle greater than 26.5° from a line normal to the weld surface.

6.10.6 X-ray units may be used as a source for all radiographic inspection, provided they have adequate penetrating ability. Maximum permissible voltage depends on material thickness, as shown by ASME Section V, Article 2. Iridium 192 shall only be used as a radiographic source when the aluminum being radiographed exceeds 2.5 in. (65 mm) in thickness.

6.10.7 For joints of approximately uniform thickness, at least two penetrameters shall show clearly on each radiograph 10 in. (255 mm) or greater in length, as shown in Figure 6.1. Radiographs of such joints less than 10 in. in length need show only one penetrameter, as shown in Figure 6.2.

When a transition in thickness occurs at a welded joint, each film shall clearly show two penetrameters on the thinner plate and one penetrameter on the thicker plate, as shown in Figure 6.3. When a radiograph representing a transition in weld thickness is less than 10 in. long, only one penetrameter need be applied to each thickness represented in the radiograph, as shown in

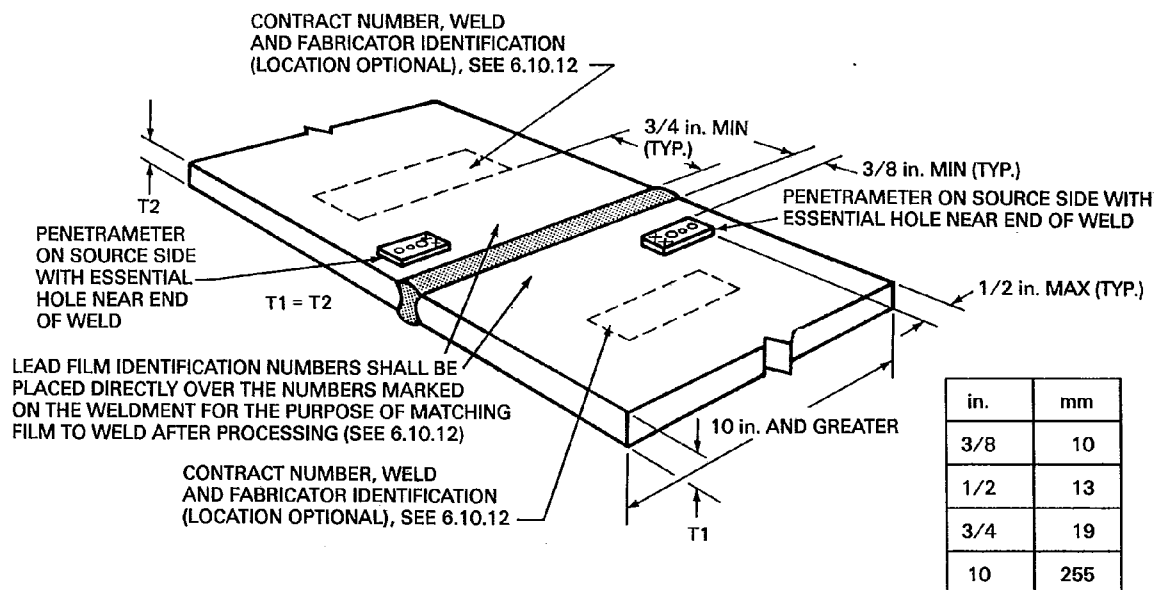


Figure 6.1 — Radiographic Identification and Penetrameter Locations on Approximately Equal Thickness Joints 10 in. (255 mm) and Greater in Length (see 6.10.7)

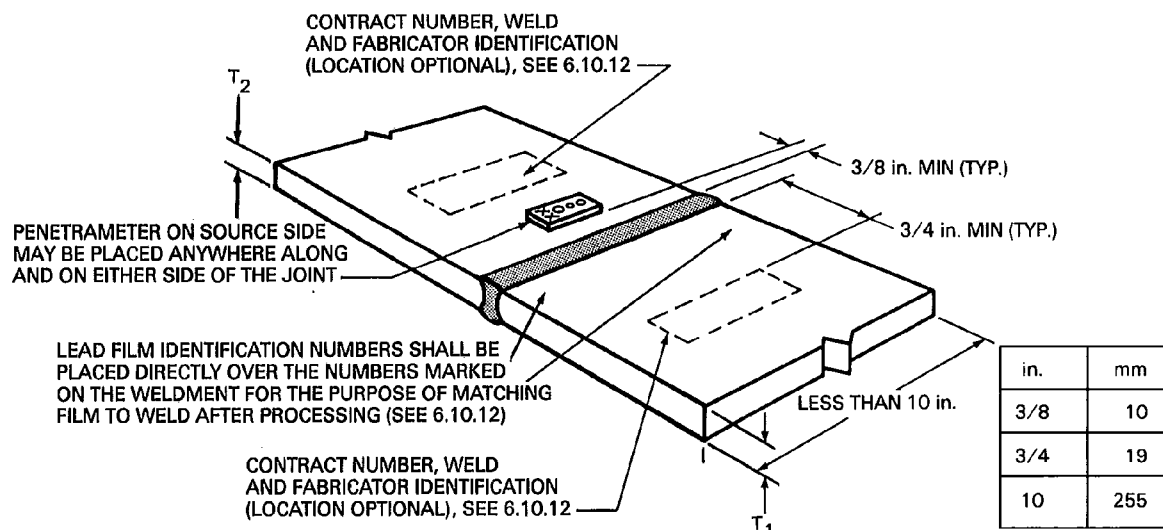


Figure 6.2 — Radiographic Identification and Penetrameter Locations on Approximately Equal Thickness Joints Less than 10 in. (255 mm) in Length (see 6.10.7)

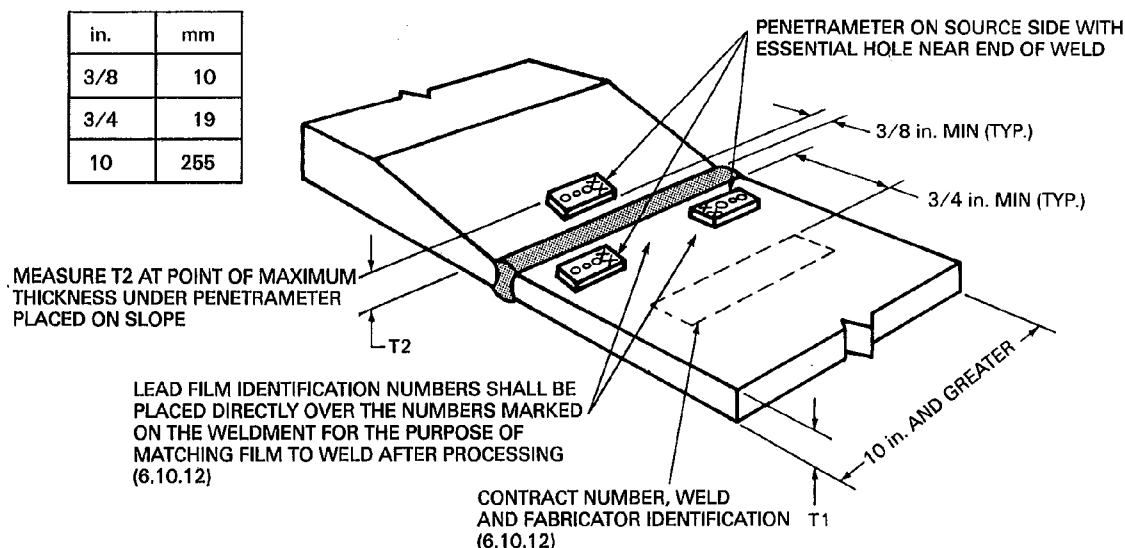


Figure 6.3 — Radiographic Identification and Penetrameter Locations on Transition Joints 10 in. (255 mm) and Greater in Length (see 6.10.7)

Figure 6.4. Penetrators shall be placed on the source side, parallel to the weld joint, with the essential holes at the outer end as detailed in Figures 6.1 and 6.3.

6.10.7.1 The thickness of the penetrator and the essential hole diameter shall be as specified in Table 6.1, except that a smaller essential hole or a thinner pene-

trator, or both, may be selected by the contractor, provided all other provisions for radiography are met.

The thickness of the weldment shall be measured as T1 or T2, or both, at the locations shown in Figures 6.1, 6.2, 6.3, or 6.4, and may be increased to provide for the thickness of allowable weld reinforcement, provided shims are used as specified in 6.10.3.3. Aluminum back-

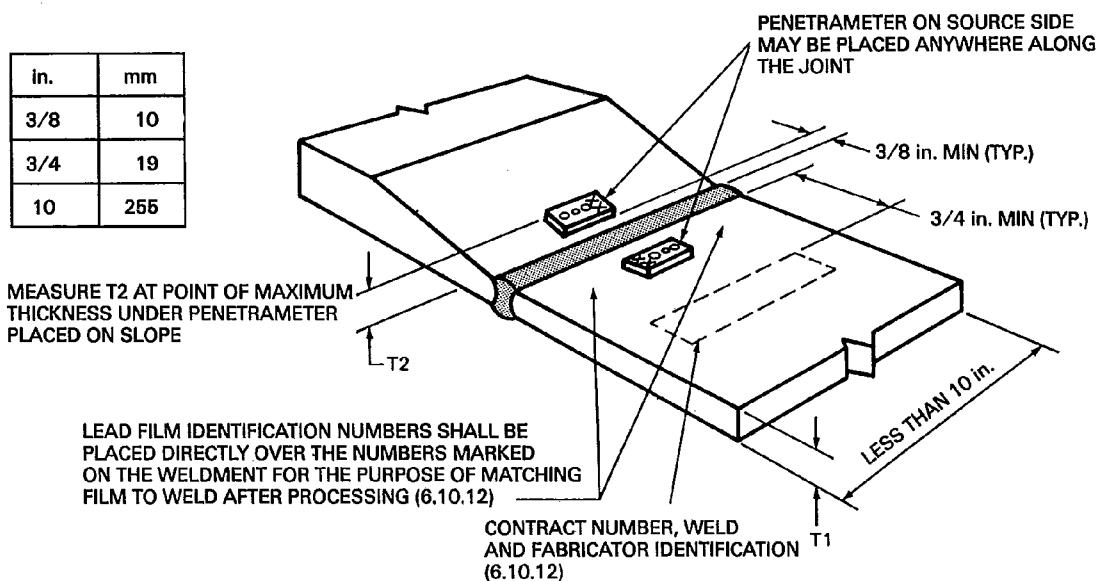


Figure 6.4 — Radiographic Identification and Locations on Transition Joints Less Than 10 in. (255 mm) in Length (see 6.10.7)

ing shall not be considered part of the weld or reinforcement in the penetrameter selection. The penetrameter representative of the maximum weld thickness may be placed on either the sloping surface within 1 in. (25 mm) of the fusion line, or on a shim of suitable thickness on the thinner side. On steeper slopes, tilting of the penetrameter may obscure the images of the holes.

6.10.7.2 Penetrameters for aluminum shall be manufactured from a radiographically similar aluminum alloy and shall conform to dimensions shown in Figure 6.5. For more detailed information, ASTM E142 should be consulted. Each penetrameter shall be manufactured with three holes, one of which shall be of a diameter equal to twice the penetrameter thickness (2T). The diameter of the two remaining holes shall be selected by the manufacturer. Penetrameter designations 10 through 25 shall contain a 4T hole.

6.10.8 Welded joints shall be radiographed and the film indexed by methods that will provide complete and continuous inspection of the joint within the limits specified to be examined. Joint limits shall show clearly in the radiographs. Short film, short screens (when required by the radiographic procedure), excessive undercut by scattered radiation, or any other process that obscures portions of the total weld length shall render the radiograph unacceptable.

6.10.8.1 Films shall have sufficient length and shall be placed to produce at least 1/2 in. (13 mm) of film, exposed to direct radiation from the source, beyond each free edge where the weld is terminated.

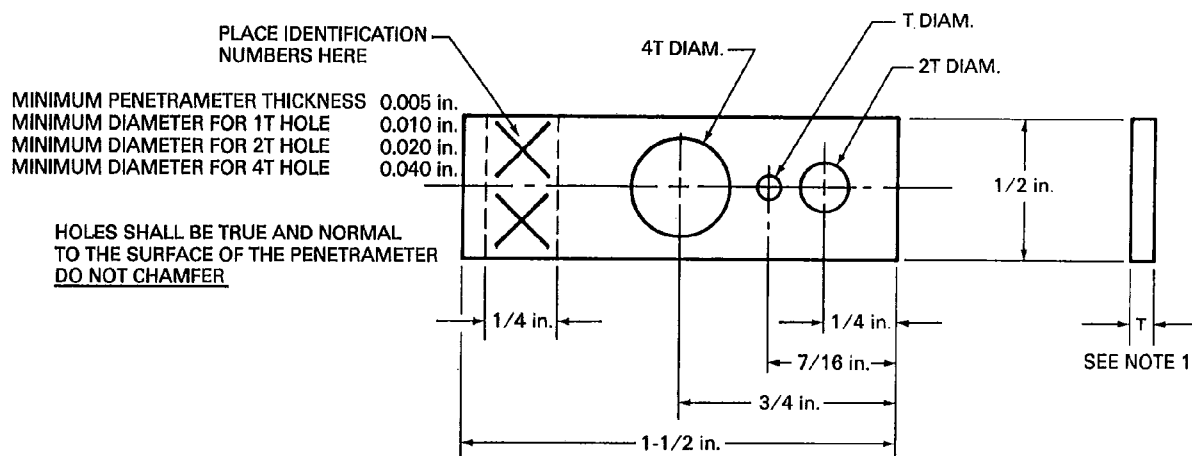
6.10.8.2 Welds longer than 14 in. (355 mm) may be radiographed by overlapping film cassettes and making a single exposure, or by using a single film cassette and making separate exposures. The provisions of 6.10.5 shall apply.

6.10.8.3 To check for backscattered radiation, a lead symbol "B", 1/2 in. (13 mm) high, 1/16 in. (1.6 mm) thick shall be attached to the back of each film cassette. If the "B" image appears on the radiograph, the radiograph shall be unacceptable.

6.10.9 Film widths shall be sufficient to depict all portions of the welded joint, including the heat-affected zones, and shall provide sufficient additional space for the required penetrameters and film identification without infringing upon the area of interest in the radiograph.

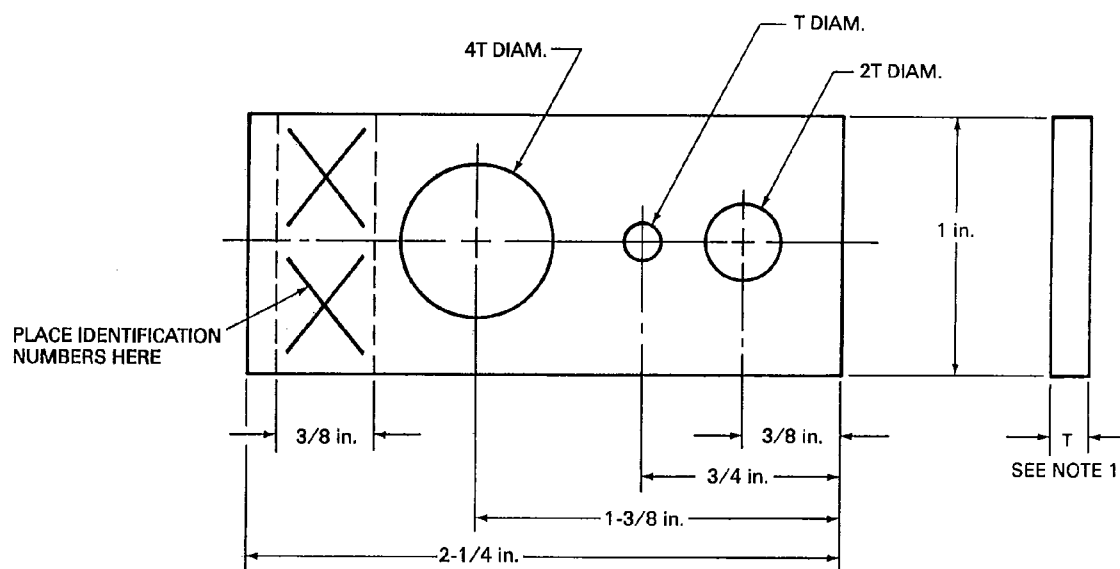
6.10.10 Quality of Radiographs. All radiographs shall be free from mechanical, chemical, or other blemishes to the extent that they might mask or be confused with the image of any discontinuity in the area of interest in the radiograph. Such blemishes include, but are not limited to the following:

- (1) fogging
- (2) processing defects such as streaks, water marks, or chemical stains
- (3) scratches, finger marks, crimps, dirt, static marks, smudges, or tears
- (4) loss of detail due to poor screen-to-film contact
- (5) false indications due to defective screens or internal faults



DESIGN FOR PENETRATOR THICKNESS FROM 0.005 in. AND INCLUDING 0.050 in.:
 FROM 0.005 in. THROUGH 0.023 in., SEE ASTM E142, TABLE 1
 OVER 0.012 in. THROUGH 0.020 in., MADE IN 0.0025 in. INCREMENTS
 OVER 0.020 in. THROUGH 0.050 in., MADE IN 0.005 in. INCREMENTS
 PENETRATOR THICKNESSES BETWEEN THE INCREMENTS INDICATED ARE PERMITTED,
 PROVIDED THEY DO NOT EXCEED THE MAXIMUM THICKNESS REQUIRED.

ALL DIMENSIONS IN in.

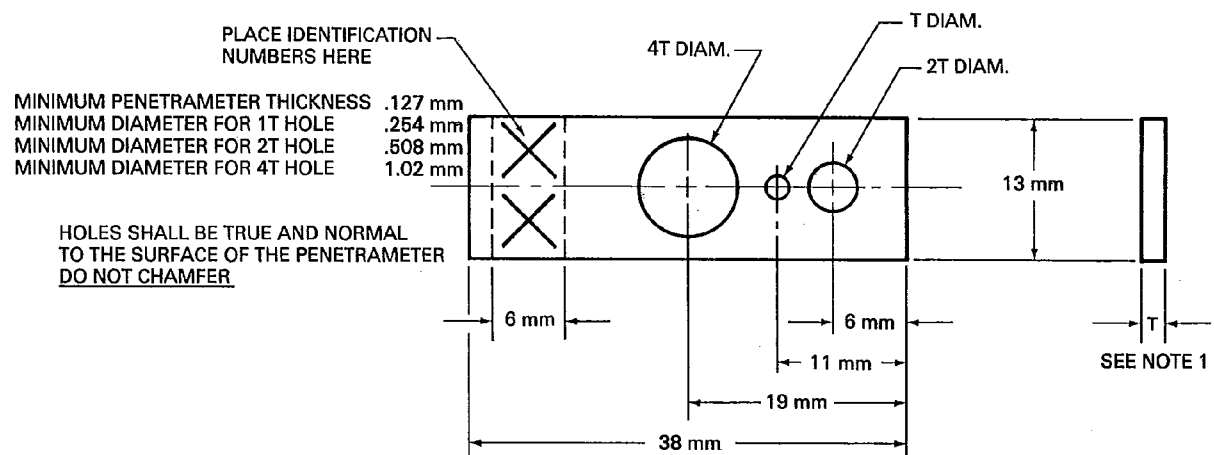


DESIGN FOR PENETRATOR THICKNESS FROM 0.060 in. to 0.160 in. INCLUSIVE
 MADE IN 0.010 in. INCREMENTS

Notes:

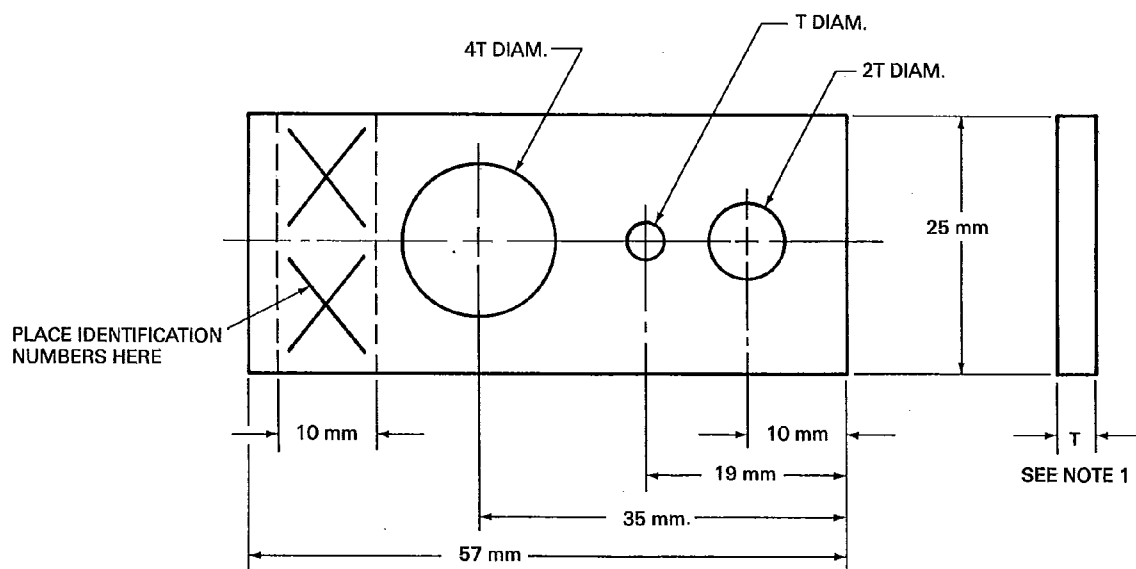
1. Tolerances on penetrator thickness and hole diameter shall be $\pm 10\%$ or one half of the thickness increment between penetrator sizes, whichever is smaller.
2. For the Essential Hole—See Table 6.1.

Figure 6.5 — Penetrator Design (see 6.10.7)



DESIGN FOR PENETRATOR THICKNESS FROM .127 mm AND INCLUDING 1.27 mm:
 FROM 1.127 mm THROUGH .305 mm, SEE ASTM E142, TABLE 1
 OVER .305 mm THROUGH .508 mm, MADE IN .0638 mm INCREMENTS
 OVER .508 mm THROUGH 1.27 mm, MADE IN .127 mm INCREMENTS
 PENETRATOR THICKNESSES BETWEEN THE INCREMENTS INDICATED ARE PERMITTED,
 PROVIDED THEY DO NOT EXCEED THE MAXIMUM THICKNESS REQUIRED.

ALL DIMENSIONS IN mm



DESIGN FOR PENETRATOR THICKNESS FROM 1.52 mm to 4.06 mm INCLUSIVE
 MADE IN .254 mm INCREMENTS

Notes:

1. Tolerances on penetrator thickness and hole diameter shall be $\pm 10\%$ or one half of the thickness increment between penetrator sizes, whichever is smaller.
2. For the Essential Hole—See Table 6.1.

Figure 6.5 (continued) — Penetrator Design (Metric Version) (see 6.10.7)

6.10.11 Density Limitations. The transmitted film density through the radiographic image of the body of the required penetrameter(s) and the area of interest shall be 1.8 minimum (preferably in the range from 2.5 to 3.5) for single film viewing for radiographs made with an X-ray source and 2.0 minimum for radiographs made with a gamma-ray source. For composite viewing of double film exposures, the minimum density shall be 2.6. Each radiograph of a composite set shall have a minimum density of 1.3. The maximum density shall be 4.0 for either single or composite viewing.

6.10.11.1 The film shall be processed to develop a film blackening measured by the H&D radiographic density expressed as:

$$D = \text{H\&D (radiographic) density} = \log_{10}(I_0/I)$$

where

I_0 = light intensity on the film, and

I = light transmitted through the film

6.10.11.2 When transitions in weld thickness are radiographed and the ratio of the thickness of the thicker section to the thickness of the thinner section is 3 or greater, radiographs should be exposed to produce single film densities of 3.0 to 4.0 in thinner sections. When this is done, the minimum density requirements of 6.10.11 shall be waived unless otherwise provided in the contract documents.

6.10.12 A radiograph identification mark and two location identification marks shall be placed on the weldment at each radiograph location, all of which shall show in the radiograph. The radiographic images shall be produced by placing lead numbers or letters, or any combination thereof, over each of the identical identification and location marks made on the weldment. The images provide the means for matching the developed radiograph with the weld.

Additional identification information may be pre-printed no less than 3/4 in. (19 mm) from the edge of the weld or produced on the radiograph by placing lead figures on the weldment.

Information required to show on the radiograph shall include the owner's contract identification, initial of the radiographic inspection company, initials of the fabricator, the fabricator shop order number, the radiographic identification mark, the date, and the weld repair number, if applicable.

6.11 Acceptability of Welds

Welds shown by radiographic testing to have discontinuities prohibited by 8.8.2, 9.8.2 or 10.15.2 shall be

discarded or corrected in accordance with 3.7. Tungsten inclusions shall be treated as porosity.

6.12 Examination, Report, and Disposition of Radiographs

6.12.1 The tester shall maintain a record of the welds or portions of welds subjected to radiographic inspection and include descriptions, pictures, or sketches of the discontinuity indications developed. See Appendix F for a suggested report form for radiographic inspections.

6.12.2 The contractor shall provide a variable intensity illuminator (viewer) with spot-review or masked spot-review capability. The viewer shall incorporate a means for adjusting the size of the spot under examination. The viewer shall have sufficient capacity to properly illuminate radiographs with an H&D density of 4.0. Film review shall be done in an area of subdued light.

6.12.3 Before a weld subject to radiographic testing by the contractor for the owner is accepted, all of its radiographs, including any that show unacceptable quality prior to repair, and a report interpreting them, shall be submitted to the verification Inspector.

6.12.4 A full set of radiographs of welds subject to radiographic testing by the contractor for the owner, including any that show unacceptable quality prior to repair, shall be delivered to the owner upon completion of the work. The contractor's obligation to retain radiographs shall cease: (1) upon delivery of this full set to the owner, or (2) one full year after the completion of the contractor's work, provided the owner is given prior written notice that the radiographs are scheduled for disposal.

Part C

Ultrasonic Testing of Groove Welds

6.13 General

6.13.1 When ultrasonic testing is required by the Contract Documents, the extent of testing, the procedure, and the acceptance criteria shall be specified therein.

6.13.2 The tester shall maintain a record of the welds or portions of welds subjected to ultrasonic testing. The contractor's obligation to retain these records shall cease: (1) upon delivery of a full set to the owner, or (2) one full year after completion of the contractor's work, provided the owner is given prior written notice that the records are scheduled for disposal.

7. Stud Welding

Part A *General Requirements*

7.1 General

Section 7 contains general requirements for arc stud welding and capacitor discharge stud welding of aluminum alloy studs to aluminum alloys and stipulates specific requirements for the following:

- (1) mechanical properties of aluminum alloy studs
- (2) workmanship, preproduction testing, qualification, and performance testing
- (3) inspection of stud welding during production.

Part B *Arc Stud Welding*

7.2 General Requirements

7.2.1 Studs shall be 1/4 in. (6.4 mm) up to and including 1/2 in. (12.7 mm) diameter and designed for arc welding to aluminum members with the use of automatically timed stud welding equipment. The type, size, and lengths of the stud shall be as specified by the drawings, specifications, or special provisions.

7.2.2 A ferrule or arc shield of heat resistant ceramic or other suitable material shall be furnished with each stud.

7.2.3 The minimum base metal thickness for arc stud application shall not be less than 50% of the stud diameter.

7.3 Material Requirements

7.3.1 Studs shall be made from cold drawn or extruded stock of alloys shown below. Other alloys may be used with the approval of the Engineer.

Aluminum Alloys For Arc Stud Welding Applications
4043
5183
5356
5556

7.3.2 The stud shall not be anodized, painted, or coated with any foreign substance.

7.3.3 The contractor shall obtain the stud manufacturer's certification that the studs conform to the applicable requirements of 7.3.

7.3.4 Mechanical testing of aluminum stud alloys shall be in accordance with the applicable sections of ASTM B557, *Standard Methods of Tension Testing Wrought and Cast Aluminum- and Aluminum-Alloys and Magnesium-Alloy Products* or AWS B4.0, *Standard Methods for Mechanical Testing of Welds*.

7.4 Workmanship

7.4.1 Studs shall be free from oil, moisture, excessive oxide, or other deleterious matter that would adversely affect the welding operation.

7.4.2 Base metal to which studs are to be welded shall be free of anodic coatings, moisture, or other injurious material to assure obtaining sound welds. These areas may be cleaned by etching, brushing with a stainless steel bristle brush, scraping, or grinding.

7.4.3 Ferrules shall be clean and dry. Any ferrules which show signs of surface moisture shall be oven dried at 250°F (120°C) for a minimum of two hours before use.

7.4.4 Ferrule geometry shall conform to the contour of the base metal.

7.4.5 Ferrules shall be broken free from all studs after welding.

7.4.6 Welded studs shall meet the visual inspection requirements of 7.8.

7.5 Technique

7.5.1 Studs shall be welded with automatically timed stud welding equipment connected to a source of direct current (electrode positive) power. Welding current, time, shielding gas, and settings for lift and plunge should be set at optimum settings, based on past practice and recommendations of stud and equipment manufacturers (see exception noted in 7.5.4).

7.5.2 Welding grade shielding gas (argon, helium, or helium/argon mixtures) shall be used.

7.5.3 If two or more arc stud welding guns are to be operated from the same power source, they shall be interlocked so only one gun can operate at a time, and so the power source can fully recover from making one weld before another weld is started.

7.5.4 At the option of the contractor, and with the approval of the Engineer, aluminum studs may be applied by fillet welding by using the GTAW process described in section 4, provided the following conditions are met.

7.5.4.1 The welding procedure used is qualified in accordance with section 5, Qualification of Procedures and Personnel.

7.5.4.2 The welder is qualified in accordance with section 5, Qualification of Procedures and Personnel.

7.5.4.3 The minimum fillet size to be used shall be as shown in Table 7.1.

7.5.4.4 The stud base shall be shaped to fit firmly against the part to which it is to be attached.

7.5.4.5 Fillet welded studs shall be visually inspected as set forth in 8.8.1 (1), (2), (3), and (4).

Table 7.1
Minimum Fillet Weld Size for
Small Diameter Studs
(see 7.5.4.3)

Stud Diameter (d) in. (mm)	Minimum Fillet Weld Size in. (mm)	
1/4 (6.4) < d ≤ 3/8 (9.5)	3/16	5
3/8 (9.5) < d ≤ 1/2 (12.7)	1/4	6

7.6 Qualification Requirements

7.6.1 General. Prior to shop or field application stud welding, procedures shall be prepared and qualified according to the requirements of 7.6. The results of these tests shall be recorded on a stud procedure qualification record (PQR).

7.6.2 Responsibility for Tests. The contractor shall be responsible for the preparation and qualification of stud welding procedures. The Engineer should accept properly documented evidence of previous qualification of the stud welding procedures to be employed.

7.6.3 Welding Procedure Qualification

7.6.3.1 Preparation of Stud Welding Procedures. Stud welding procedures shall be established in accordance with the limitation of variables except that a procedure established for each of two thicknesses of base metal using the same machine settings and conditions specified in the procedure qualification record may be used for all intermediate thicknesses. A suggested PQR form is shown in Appendix E(d).

7.6.3.2 Welding Position. Qualification in one position qualifies for all positions.

7.6.4 Limitation of Variables. Any of the following changes shall require requalification of the stud welding procedure:

- (1) A change in the base metal M-number
- (2) A change in the F-number of the stud alloy
- (3) A change in the nominal size or shape of the stud base
- (4) A change of more than $\pm 25\%$ in the base metal thickness or thickness range qualified
- (5) A change from a single shielding gas to any other gas, or to a mixture of gases, or a change of 10% or more in the specified percentage composition of the mixture
- (6) A change of more than 10% in the flow rate of the shielding gas
- (7) A change in ferrule geometry
- (8) A change of timer range or amperage range greater than $\pm 5\%$
- (9) A change in make or model of welding machine
- (10) A change in base metal form from a flat surface to a pipe or tube surface having an outside diameter of 12 in. (305 mm) or less, but not the reverse

7.6.5 Preparation of Test Specimens. Ten consecutively welded stud test specimens are required to qualify each welding procedure. Essential welding information shall be recorded using a form similar to Appendix E(e).

7.6.6 Procedure Qualification Tests and Acceptance Criteria

7.6.6.1 The test welds shall have a well-formed circumferential flash over at least 75% of the periphery of

the welded stud.¹⁵ There shall be no undercutting of the stud above the welded joint.

7.6.6.2 Five test weld specimens shall be tested by bending each stud to an angle of at least 15° from the axis of the stud. The studs shall be left in the bent condition. A test jig as shown in Figure 7.1 or other suitable device shall be used for bending.

7.6.6.3 Acceptance Criteria—Bend Tests. To pass the bend test requirements, all five studs shall exhibit no visible separation or fracture in the stud weld or heat-affected zones of the base metal or stud.

7.6.6.4 Tension Test—Option 1. Five test specimens shall be tested using a torque testing arrangement that is substantially in accordance with Figure 7.2. Minimum torque values for F-22 alloy studs are shown in Table 7.2.

15. The expelled metal around the base of the stud is designated as flash in accordance with the definition of upset in ANSI/AWS A3.0, *Standard Welding Terms and Definitions*.

Minimum torque values for other F-number studs shall be determined by the Engineer.

Table 7.2
Minimum Required Torque Values and
Tension Loads for Arc Stud Welding
(F-22 Aluminum Alloy Studs) (See 7.6.6.4)

Stud Size	Tension Test: Option 1		Tension Test: Option 2	
	Minimum Torque Value		Minimum Tensile Load	
	in.-lbf	J	lbs	kg
10 – 24	10	1.1	770	350
1/4 – 20 UNC	40	4.5	1360	620
5/16 – 18 UNC	70	7.9	2300	1045
3/8 – 16 UNC	81	9.2	3250	1480
7/16 – 14 UNC	140	15.8	4400	2000
1/2 – 13 UNC	—	—	5950	2700

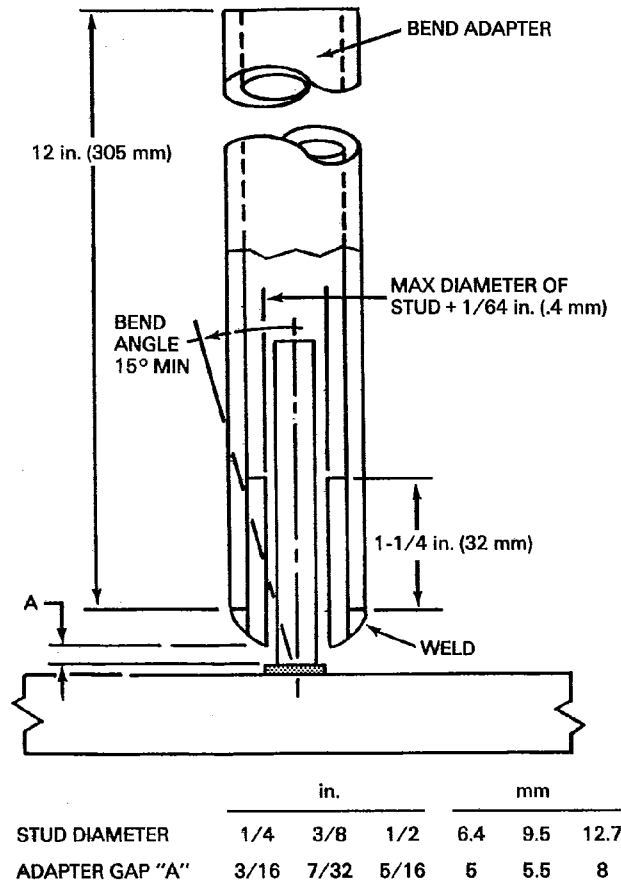
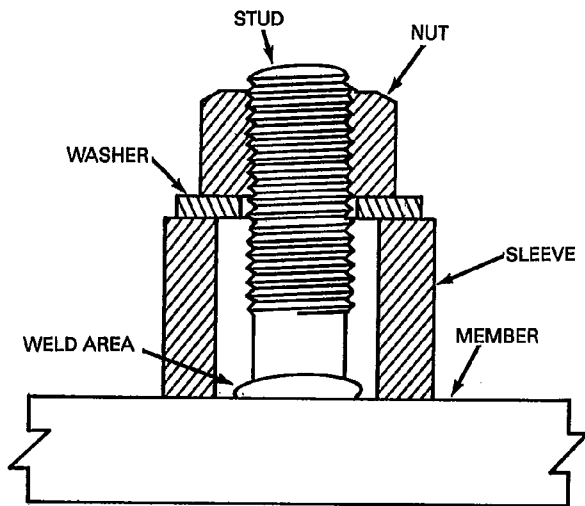


Figure 7.1 — Stud Weld Bend Jig (see 7.6.6.2)



Note: The dimensions shall be appropriate to the size of the stud. The threads of the stud shall be clean and lubricated.

Figure 7.2 — Torque Testing Arrangement For Stud Welds (see 7.6.6.4)

7.6.6.5 Tension Test — Option 2. Five test specimens shall be tested in tension using commercial tension testing equipment designed to properly grip the stud and base metal of the welded specimen. The load shall be applied axially until the stud fractures. The load at which the specimen fractures is the ultimate tensile load. Minimum tensile load values for F-22 alloy studs are shown in Table 7.2. Minimum tensile load values for other F-number studs shall be determined by the Engineer.

7.6.6.6 Acceptance Criteria — Tension Tests. To pass the tension test requirements, all five specimens (Option 1 or Option 2) shall meet the torque or tensile load values established for the stud alloy being qualified.

7.6.6.7 The contractor has the option to bend test the ten stud weld specimens in lieu of any tension testing.

7.6.7 A stud welding procedure shall be considered qualified if the test specimens meet the requirements of 7.6.6.1, 7.6.6.3 and 7.6.6.5, or 7.6.6.1 and 7.6.6.7.

7.6.8 Welding Procedure Specifications

7.6.8.1 A Welding Procedure Specification (WPS) shall be prepared for each stud welding application. The following information shall be included in the WPS:

- (1) Equipment used:
 - (a) Power supply
 - (b) Stud gun
 - (c) Timing equipment (controller)
 - (d) Size and length of cable
- (2) Stud material

(3) A sketch showing size and shape of studs and the section to be welded

- (4) Base metal and thickness or thickness limits
- (5) Gas shield type and flow
- (6) Ferrule identification (number or sketch)
- (7) Timer range setting
- (8) Current and polarity
- (9) Amperage range setting
- (10) Lift setting
- (11) Cleaning methods

7.6.8.2 Welding Procedure Specifications shall be available for examination by the owner or the owner's authorized representative. A suggested WPS Record form is shown in Appendix E(d).

7.7 Operator and Preproduction Qualification

7.7.1 Before production welding begins using a particular WPS, and at the beginning of each day's or shift's production, the first two studs shall be tested using material of similar thickness ($\pm 25\%$) and of the same material M-number as the production material.

7.7.2 After visual inspection to determine compliance with 7.6.6.1, the two studs shall be bent in accordance with 7.6.6.2.

7.7.3 Failure of either of the studs to meet the criteria specified in 7.7.2 shall cause the stud welding variables to be adjusted until two studs welded in accordance with the provisions of 7.7 pass the inspection requirements. If the changes to the procedure fall outside the limitation of variables in 7.6.4, a new Procedure Qualification Test and Welding Procedure Specification are required.

7.8 Acceptance Criteria — Production Welds

There shall be evidence of a well-formed circumferential flash over at least 75% of the periphery of the stud. There shall be no undercutting of the stud diameter above the welded joint. Welds failing to conform to these acceptance criteria shall be repaired in accordance with 7.10.

7.9 Mislocated Studs

7.9.1 When mislocated studs are required to be removed, they shall be completely removed by chiseling, rotary filing, thermal cutting or grinding using grinding wheels designated for use on aluminum.

7.9.2 The area where the mislocated stud was applied shall be thoroughly wire brushed, as stated in 7.4.2, and the surface contour of the base metal restored where required by applying weld filler metal by one of the welding processes allowed in section 4.

7.10 Repair of Misapplied Studs

During production welding, studs that do not exhibit flash for a full 75% of the periphery of the stud may be repaired by adding a fillet weld in the area of the missing flash. The fillet weld shall meet the requirements of 7.5.4 and extend beyond the area of missing flash. Studs not meeting the Code requirements of 7.8 other than deficient flash shall be removed and replaced in accordance with 7.9.

Part C *Capacitor Discharge Stud Welding*

7.11 General Requirements

7.11.1 Nonflanged studs shall be limited to a maximum base diameter of 1/4 in. (6.4 mm), and flanged stud base diameters shall be limited to a maximum of 5/16 in. (8 mm), unless otherwise qualified and approved by the Engineer.

7.11.2 For contact, gap, and drawn arc capacitor discharge stud welding, the size and shape of the stud tip or projection, or the weld-end geometry shall be designed to achieve sound welds. These characteristics and the shank shape or configuration shall be as specified in the drawings, specifications, or special provisions.

7.11.3 No ferrule is required.

7.11.4 Shielding gas is not required with the contact or gap capacitor discharge process. A suitable shielding gas shall be used with the drawn arc capacitor discharge process.

7.11.5 The minimum base metal thickness for capacitor discharge stud welding shall be no less than 25% of the base diameter of the stud.

7.12 Material Requirements

7.12.1 Studs shall be made from cold drawn or extruded stock of alloys shown below. Other alloys may be used with the approval of the Engineer.

Aluminum Alloys For Capacitor Discharge Stud Welding Applications

1100	5556
4043	6061
5183	6063
5356	

7.12.2 Studs shall not be anodized, painted, or coated with any foreign substance.

7.12.3 The contractor shall obtain the stud manufacturer's certification that the studs conform to the applicable requirements of 7.12.

7.12.4 Mechanical testing of aluminum stud alloys shall be in accordance with the applicable sections of ASTM B557, *Standard Methods of Tension Testing Wrought and Cast Aluminum and Aluminum-Alloy and Magnesium-Alloy Products*, or ANSI/AWS B4.0, *Standard Methods for Mechanical Testing of Welds*.

7.12.5 Stud bases for capacitor discharge welding studs may be flanged or nonflanged.

7.13 Workmanship

7.13.1 Studs shall be free from oil, moisture, excessive oxide, or other deleterious matter that would adversely affect the welding operation.

7.13.2 Base metal to which studs are to be welded shall be free of anodic coatings, moisture, or other injurious material to assure obtaining sound welds. These areas may be cleaned by etching, brushing with a stainless steel bristle brush, scraping, or grinding.

7.13.3 Welded studs shall meet the visual inspection requirements of 7.17.

7.14 Technique

7.14.1 Studs shall be welded with equipment that ensures the capacitors are fully charged to a preset value before the stud can be welded.

7.14.2 When required, welding grade shielding gas (argon, helium, or helium/argon mixtures) shall be used.

7.14.3 A wetting agent may be introduced in the weld area just prior to the weld being made.

7.15 Qualification Requirements

7.15.1 General. Prior to shop or field application, stud welding procedures shall be prepared and qualified according to the requirements of 7.15. The results of these tests shall be recorded on a stud procedure qualification record (PQR).

7.15.2 Responsibility for Tests. The contractor shall be responsible for the preparation and qualification of stud welding procedures. The Engineer should accept properly documented evidence of previous qualification of the stud welding procedures to be employed.

7.15.3 Welding Procedure Qualification

7.15.3.1 Preparation of Stud Welding Procedures. Stud welding procedures shall be established in accordance with the Limitation of Variables except that a procedure established for each of two thicknesses of base metal using the same machine settings and conditions specified in the procedure qualification record may be used for all intermediate thicknesses. A suggested PQR form is shown in Appendix E(e).

7.15.3.2 Welding Position. Qualification in one position qualifies for all positions.

7.15.4 Limitation of Variables. Any of the following changes shall require requalification of the stud welding procedure:

- (1) A change in the base metal M-number
- (2) A change in the F-number of the stud alloy or in the stud alloy, if the stud has no F-number
- (3) A change in the nominal size or shape of the stud base
- (4) A change of more than $\pm 25\%$ in the base metal thickness or thickness range qualified

Table 7.3
Minimum Required Torque Values and
Tension Loads for Capacitor Discharge
Stud Welding (F-22 Aluminum Alloy Studs)
(See 7.15.6.4)

Stud Size	Tension Test: Option 1		Tension Test: Option 2	
	Minimum Torque Value		Minimum Tensile Load	
	in.-lbf	J	lbs	kg
6 - 32	3.5	0.4	375	170
9 - 32	7.5	0.9	635	290
10 - 24	10	1.1	770	350
1/4 - 20 UNC	40	4.5	1360	620
5/16 - 18 UNC	70	7.9	2300	1045

(5) A change from a single shielding gas to any other gas, or to a mixture of gases, or a change of 10% or more in the specified percentage composition of the mixture

(6) A change of more than 10% in the flow rate of the shielding gas

(7) A change in capacitance (farads)

(8) A change in charging voltage

(9) A change in base metal form from a flat surface to a pipe or tube surface having an outside diameter of 12 in. (305 mm) or less, but not the reverse

(10) A change in make or model of welding machine

7.15.5 Preparation of Test Specimens. Ten consecutively welded stud weld test specimens are required to qualify each welding procedure. Essential welding information shall be recorded using a form similar to Appendix E(e).

7.15.6 Procedure Qualification Tests and Acceptance Criteria

7.15.6.1 The test welds shall have a well-formed circumferential flash over at least 75% of the periphery of the welded stud. There shall be no undercutting of the stud above the welded joint.

7.15.6.2 Five test weld specimens shall be tested by bending each stud to an angle of at least 15° from the axis of the stud. The studs shall be left in the bent condition. A test jig as shown in Figure 7.1 or other suitable device shall be used for bending.

7.15.6.3 Acceptance Criteria — Bend Tests. To pass the bend test requirements, all five studs shall exhibit no visible separation or fracture in the stud weld or heat-affected zones of the base metal or stud.

7.15.6.4 Tension Test — Option 1. Five test specimens shall be tested using a torque testing arrangement that is substantially in accordance with Figure 7.2. Minimum torque values for F-22 alloy studs are shown in Table 7.3. Minimum torque values for other F-number studs shall be determined by the Engineer.

7.15.6.5 Tension Test — Option 2. Five test specimens shall be tested in tension using commercial tension testing equipment designed to properly grip the stud and base metal of the welded specimen. The load shall be applied axially until the stud fractures. The load at which the specimen fractures is the ultimate tensile load. Minimum tensile load values for F-22 alloy studs are shown in Table 7.3. Minimum tensile load values for other F-number studs shall be determined by the Engineer.

7.15.6.6 Acceptance Criteria — Tension Tests. To pass the tension test requirements, all five specimens (Option 1 or Option 2) shall meet the torque or tensile load values established for the stud alloy being qualified.

7.15.6.7 The contractor has the option to bend test the ten stud weld specimens in lieu of any tension testing.

7.15.7 A stud welding procedure shall be considered qualified if the test specimens meet the requirements of 7.15.6.1, 7.15.6.3, and 7.15.6.6, or 7.15.6.1 and 7.15.6.7.

7.15.8 Welding Procedure Specifications

7.15.8.1 A Welding Procedure Specification (WPS) shall be prepared for each stud welding application. The following information shall be included in the welding procedure:

- (1) Equipment used:
 - (a) Power control
 - (b) Stud gun
 - (c) Size and length of cable
- (2) Stud material
- (3) A sketch showing size and shape of studs and the section to be welded
- (4) Base metal and thickness or thickness limits
- (5) Gas shield type and flow (if applicable)
- (6) Capacitance and charging voltage
- (7) Drop height
- (8) Capacitor discharge method
- (9) Cleaning method

7.15.8.2 Welding Procedure Specifications shall be available for examination by the owner or the owner's authorized representative. A suggested WPS Record form is shown in Appendix E(d).

7.16 Operator and Preproduction Qualification

7.16.1 Before production welding begins using a particular WPS, and at the beginning of each day's or shift's production, the first two studs shall be tested using material of similar thickness ($\pm 25\%$) and of the same material M-number as the production material.

7.16.2 After visual inspection to determine compliance with 7.15.6.1, the two studs shall be bent in accordance with 7.15.6.2.

7.16.3 Failure of either of the studs to meet the criteria specified in 7.16.2 shall cause the stud welding variable parameters to be adjusted until two studs welded in accordance with the provisions of 7.16 pass the inspection

requirements. If the changes to the procedure fall outside the limitation of variables in 7.15.4, a new Procedure Qualification Test and Welding Procedure Specification are required.

7.17 Acceptance Criteria — Production Welds

There shall be evidence of a well-formed circumferential flash over at least 75% of the periphery of the stud. There shall be no undercutting of the stud diameter above the welded joint. Welds failing to conform to these acceptance criteria shall be repaired in accordance with 7.19.

7.18 Mislocated Studs

7.18.1 When mislocated studs are required to be removed, they shall be completely removed by chiseling, rotary filing, thermal cutting or grinding using grinding wheels designated for use on aluminum.

7.18.2 The area where the mislocated stud was applied shall be thoroughly wire brushed, as stated in 7.13.2, and the surface contour of the base metal restored where required by applying weld filler metal by one of the welding processes allowed in section 4, Technique.

7.19 Repair of Misapplied Studs

During production welding, studs that do not exhibit flash for a full 75% of the periphery of the stud may be repaired by adding a fillet weld in the area of the missing flash. The fillet weld shall meet the requirements of 7.5.4 and extend beyond the area of missing flash. Studs not meeting the Code requirements of 7.17 other than deficient flash shall be removed and replaced in accordance with 7.18.

8. Nontubular Statically Loaded Structures

Part A *General Requirements*

8.1 Application

This section supplements sections 1 through 6 and is to be used in conjunction with and as a supplement to the applicable building code and the associated structural design specification as specified in the contract documents.¹⁶

8.2 Base Metal

8.2.1 Base metal to be welded under this Code shall be one listed in Table 1.1 and conform to the requirements of the latest edition of the applicable specifications listed below, except as noted in 8.2.3.

- (1) ASTM B26, Standard Specification for Aluminum-Alloy Sand Castings
- (2) ASTM B108, Standard Specification for Aluminum-Alloy Permanent-Mold Castings
- (3) ASTM B209, Standard Specification for Aluminum-Alloy Sheet and Plate
- (4) ASTM B211, Standard Specification for Aluminum-Alloy Bar, Rod, and Wire

16. The term *building code*, as used herein, refers to the building law or specifications adopted by the legal jurisdiction in which the building is to be constructed. The term, *associated structural design specification* refers to the rules and specifications under which the plans for the work were prepared. In the absence of a locally applicable building code or other construction regulations, it is recommended that the design and construction be made to comply with a specification adopted by a recognized engineering society, a recognized Trade Association, or a recognized governmental agency, for example, The Construction Manual Series of the Aluminum Association, Section 1, *Specifications for Aluminum Structures*.

(5) ASTM B221, Standard Specification for Aluminum-Alloy Extruded Bar, Rod, Wire, Shapes, and Tubes

(6) ASTM B247, Standard Specification for Aluminum-Alloy Die and Hand Forgings

(7) ASTM B308, Standard Specification for Aluminum-Alloy Standard Structural Shapes, Rolled or Extruded

(8) ASTM B361, Standard Specification for Factory-Made Wrought Aluminum and Aluminum-Alloy Welding Fittings

8.2.2 Combinations of base metals may be welded together, provided that due design attention is given to the possible differences in properties, and the intended welding procedure is qualified in accordance with 5.2.

8.2.3 When an alloy not listed in Table 1.1 is approved under the provisions of the associated design specifications and is considered for use, the procedure to be used for welding shall be qualified by the contractor in accordance with the qualification requirements of sections 1 through 5 and such other requirements as may be prescribed by the Engineer.

8.2.4 When an alloy not listed in Table 1.1 is proposed as a substitute material, the contractor shall determine the weldability and perform any additional tests required by the Engineer. The contractor shall assume the financial responsibility for all such tests only if the contractor has the opportunity to include these costs in the bid proposal. However, when a proposal for use of a substitute material not listed in Table 1.1 is made after the contract documents have been signed, the financial responsibility for the costs of all additional testing shall be assumed by the party which makes such substitute material proposals.

8.2.5 Extension bars, run-off plates, and permanent backing shall be of the same M-number as that of the base metal. Filler plates shall be of the same alloy as the base metal. Temporary backing shall meet the requirements of 4.9.5.

8.3 Filler Metal

The filler metal shall be selected from Table 1.2 for the base metal or metals used in construction.

Part B Allowable Stresses

8.4 Allowable Stresses

For allowable stresses¹⁷ see *Specifications for Aluminum Structures* of the Aluminum Association's Construction Manual or other specification as given in the contract documents.

Part C Workmanship

8.5 Dimensional Tolerances

The dimensions of structural members shall be within the tolerances specified in 3.5, and the following additional requirements:

8.5.1 Departures from flatness of girder webs shall be determined by measuring offsets from a straight edge whose length is not less than the least clear dimension of the panel, and placed in that location which shows the maximum departure from the straight edge, and with the ends of the straight edge adjacent to opposite boundaries of the panel.

8.5.2 Except as allowed by 8.5.3, departures from flatness of girder webs in panels having a depth, D , and a thickness, t , in panels bounded by stiffeners or flanges, or both, and whose least panel dimension is d , shall not exceed the following:

Placement of Stiffeners on Web	Proportions of Panel	
	$D/t = \text{Depth}/$ Thickness	Maximum Departure
both sides	< 150	$d/100$
	≥ 150	$d/80$
one side	< 100	$d/100$
	≥ 100	$d/67$
none	—	$D/150$

8.5.3 In girders which have been subpunched and reamed for a bolted field splice or connection, departures

¹⁷ Allowable stresses in heat-treated and work-hardened structural alloys vary with the alloy and the extent of the heat-affected zone.

of two times those allowed in 8.5.2 shall be acceptable, provided that, when the bolted splice or connection is completed, the final assembly is in accordance with 8.5.2.

8.5.4 If architectural considerations or the associated structural design specification place more severe restrictions than imposed by 8.5.2, specific reference shall be included in the contract documents.

8.6 Temporary Welds

8.6.1 Temporary welds shall be subject to the same welding procedure and quality requirements as final welds (see 3.3.7.2). Their possible effects on the material properties shall be considered in the design process.

8.6.2 In main stress carrying members of M23, M24, M25, M26, and M27 base metal, temporary welds, not incorporated in the final weld, shall be identified on the shop drawings and approved by the Engineer.

8.7 Weld Termination

Weld terminations shall be subject to the provisions of 4.8. Peening of the weld crater or exposed weld surfaces is permitted to relieve localized shrinkage stresses.

8.8 Quality of Welds

8.8.1 Visual Inspection. All welds shall be visually inspected. A weld shall be acceptable by visual inspection if it shows the following:

- (1) The weld has no cracks.
- (2) Thorough fusion exists between adjacent layers of weld metal, and between weld metal and base metal.
- (3) Weld profiles are in accordance with 3.6.
- (4) Except as provided herein, undercut shall not exceed the values shown in Figure 8.1 for primary stress direction category applicable to the area containing the undercut. The undercut may be twice the value permitted in Figure 8.1 (for the applicable stress category) for an accumulated length of 2 in. in any 12 in. (50 mm in 305 mm) length of weld, but in no case may undercut on one side be greater than 1/16 in. (1.6 mm). For weld lengths less than 12 in., the permitted length shall be proportional to the actual length.
- (5) A fillet weld in any single continuous weld may be less than the nominal fillet weld size required by 1/16 in. (1.6 mm) without correction, provided that the undersized portion of the weld does not exceed 10% of the length of the weld. On web-to-flange welds in girders, no undersized fillets are permitted at the ends for a length equal to twice the width of the flange.
- (6) Shrinkage contained entirely within the crater area of an intermittent fillet weld shall be permitted.

8.8.2 Radiographic Inspection. Welds that are subject to radiographic testing in addition to visual inspection shall have no cracks and shall be unacceptable if the radiograph shows any of the types of discontinuities given in 8.8.2.1, 8.8.2.2 and 8.8.2.3.

8.8.2.1 Individual discontinuities, having the greatest dimension of $3/32$ in. (2 mm) or greater, shall not have the following:

- (1) A discontinuity with greatest dimension larger than $2/3$ of the weld size, or $3/4$ in. (19 mm), or
- (2) A discontinuity closer than three times its greatest dimension to the end of a groove weld subject to primary tensile stress

8.8.2.2 A group of in-line discontinuities, some having a dimension of $3/32$ in. (2.4 mm) or greater, shall not have the following:

- (1) The sum of the greatest dimensions of all discontinuities within a length equal to six times the weld size greater than the weld size (when the length of weld being

examined is less than six times the weld size, the permissible sum of the greatest dimensions shall be proportionally less than the weld size), or

- (2) A space between two adjacent discontinuities is less than three times the greatest dimension of the larger of the discontinuities in the pair under consideration

8.8.2.3 The sum of the greatest dimensions of a group of in-line relevant discontinuities smaller than $3/32$ in. (2.4 mm) in any linear inch of weld shall not exceed $3/8$ in. (10 mm). Only that porosity whose major dimension exceeds $1/32$ in. (0.8 mm), shall be considered in evaluating the radiographic soundness criteria.

8.8.3 Ultrasonic Testing. When ultrasonic testing is required by the contract documents, the testing procedure and acceptance criteria shall be specified therein.

8.8.4 Liquid Penetrant Inspection. Welds that are subject to liquid penetrant inspection shall be unacceptable if the inspection confirms the presence of surface cracks which render the weld unacceptable on the basis of the requirements for visual inspection.

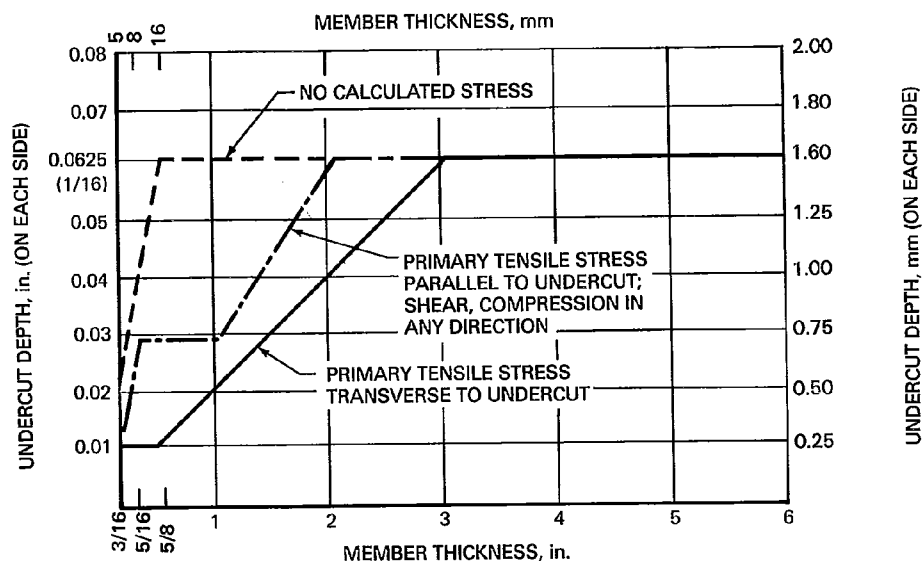


Figure 8.1 — Permissible Undercut Values for Nontubular Statically Loaded Structures (see 8.8.1)

9. Nontubular Dynamically Loaded Structures

Part A *General Requirements*

9.1 Application

This section supplements sections 1 through 6 and is to be used in conjunction with and as a supplement to the associated structural design specification for the design and construction of nontubular dynamically loaded structures, as specified in the bid proposal and contract documents.¹⁸

9.2 Base Metal

9.2.1 The base metal to be welded under this Code shall be one listed in Table 1.1 and shall conform to the requirements of the latest edition of the applicable specification listed below except as noted in 9.2.3:

- (1) ASTM B209, Standard Specification for Aluminum-Alloy Sheet and Plate
- (2) ASTM B211, Standard Specification for Aluminum-Alloy Bar, Rod, and Wire
- (3) ASTM B221, Standard Specification for Aluminum-Alloy Extruded Bar, Rod, Wire, Shapes, and Tubes
- (4) ASTM B247, Standard Specification for Aluminum-Alloy Die and Hand Forgings

18. The term, *associated structural design specification*, refers to the rules and specifications under which the plans for the work were prepared. In the absence of a locally applicable code or other construction regulations, it is recommended that the design and construction be made to comply with a specification developed and adopted by a recognized engineering society, a recognized trade association, or by a recognized governmental agency; for example the *Specifications for Structures of Aluminum Alloys* Papers Nos. 3341 and 3342, Reports of the Task Committee on Lightweight Alloys, Committee on Metals, Structural Division, American Society of Civil Engineers.

(5) ASTM B308, Standard Specification for Aluminum-Alloy Standard Structural Shapes, Rolled or Extruded

(6) ASTM B361, Standard Specification for Factory-Made Wrought Aluminum and Aluminum-Alloy Welding Fittings

9.2.2 Combinations of base metals may be welded together, provided the design process considers the possible differences in properties and the welding procedure is qualified in accordance with 5.2.

9.2.3 When an alloy not listed in Table 1.1 is approved under the provisions of the associated design specifications and is considered for use, the procedure to be used for welding shall be qualified by the contractor in accordance with the qualification requirements of sections 1 through 5 and such other requirements as may be prescribed by the Engineer.

9.2.4 When an alloy not listed in Table 1.1 is proposed as a substitute material, the contractor shall determine the weldability and perform any additional tests required by the Engineer. The contractor shall assume the financial responsibility for all such tests only if the contractor has the opportunity to include these costs in the bid proposal. However, when a proposal for use of a substitute material not listed in Table 1.1 is made after the contract documents have been signed, the financial responsibility for the cost of all additional testing shall be assumed by the party which makes such substitute material proposals.

9.2.5 Extension bars, run-off plates, and permanent backing shall be of the same M-number as that of the base metal. Filler plates shall be of the same alloy as the base metal. Temporary backing shall meet the requirements of 4.9.5.

9.3 Filler Metal

The filler metal shall be selected from Table 1.2 for the base metal or metals used in construction.

Part B **Allowable Stresses**

9.4 Allowable Stresses

For allowable stresses see *Specifications for Aluminum Structures*, of the Aluminum Association Construction Manual (see Appendix A) or other specification as given in the contract documents.¹⁹

Part C **Workmanship**

9.5 Dimensional Tolerances

The dimensions of structural members shall be within the tolerances specified in 3.5 and the following additional requirements:

9.5.1 Departures from flatness of girder webs shall be determined by measuring offsets from a straight edge whose length is not less than the least clear dimension of the panel and placed in that location which shows the maximum departure from the straight edge, and with the ends of the straight edge adjacent to opposite boundaries of the panel.

9.5.2 Except as allowed in 9.5.3, departures from flatness of webs having a depth, D , and a thickness, t , in panels bounded by stiffeners or flanges, or both, and whose least panel dimension is d , shall not exceed the following:

Placement of Stiffeners on Web	Proportions of Panel $D/t = \text{Depth}/$ Thickness	Maximum Departure	
		Interior Girders	Face Girders
both sides	< 150	$d/115$	$d/130$
	≥ 150	$d/92$	$d/105$
one side	< 100	$d/100$	$d/120$
	≥ 100	$d/67$	$d/80$
none	—	$D/150$	$D/150$

9.5.3 In girders which have been subpunched and reamed for a bolted field splice or connection, departures of two times those allowed in 9.5.2 shall be acceptable, provided that when the bolted splice or connection is completed, the web assumes an allowable departure.

¹⁹ Allowable stresses in heat-treated and work-hardened structural alloys vary with the alloy and the extent of the heat-affected zone.

9.5.4 If architectural considerations or the associated structural design specification place more severe restrictions than imposed in 9.5.2, specific reference shall be included in the bid documents and contract.

9.6 Temporary Welds

9.6.1 Temporary welds shall be subject to the same welding procedure and quality requirements as final welds. Their possible effects on the material properties shall be considered in the design process.

9.6.2 In main stress carrying members of M23, M24, M25, M26, or M27 materials, temporary welds not incorporated in the final weld shall be identified on the shop drawings and approved by the Engineer.

9.7 Weld Terminations

9.7.1 Weld terminations shall be subject to the provisions of 4.8. Peening of the weld crater on exposed weld surfaces is permitted to relieve localized shrinkage stresses.

9.7.2 Groove and fillet weld terminations in primary structures subject to fatigue loads shall require weld terminations made by the following techniques:

- (1) reversing the direction of travel for a minimum distance of 2 in. (50 mm), or
- (2) increasing travel speed to reduce crater size or
- (3) both (1) plus (2), or
- (4) providing buildup of metal, and removing the crater and buildup using mechanical means.

9.8 Quality of Welds

9.8.1 Visual Inspection. All welds shall be visually inspected. A weld shall be acceptable by visual inspection if it shows that:

- (1) The weld has no surface cracks.
- (2) Thorough fusion exists between adjacent layers of weld metal and between weld metal and base metal.
- (3) All craters are filled in accordance with 9.7.2.
- (4) Weld profiles are in accordance with 3.6.
- (5) Undercut shall not exceed the limits shown in Table 9.1.
- (6) A fillet weld in any single continuous weld may be less than the nominal fillet weld size required by 1/16 in. (1.6 mm) without correction, provided that the undersized portion of the weld does not exceed 10% of the length of the weld. On web-to-flange welds on girders, no undersized fillet weld is permitted at the ends for a length equal to twice the width of the flange.

Table 9.1
Permissible Undercut Values (see 9.8.1)

Thickness	Primary Stress Direction	Maximum Undercut	
		in.	mm
1/8 to 1 in., incl. (3.2 mm to 25.4 mm)	Transverse	0.01	0.25
Over 1 in. (25.4 mm)	Transverse	1/32	0.8
All thicknesses	Parallel or none	1/32	0.8

9.8.2 Radiographic Examination. The extent of radiographic examinations shall be as specified in the bid contract documents. Welds shall be unacceptable if the radiographs show any cracks or any of the types of discontinuities specified in 9.8.2.1 through 9.8.2.4.

9.8.2.1 Porosity—with sharp tails.

9.8.2.2 Porosity, (defined in Table 9.2, Notes 1 and 2). Maximum permissible porosity in radiographs per 3 in. (75 mm) length of weld is shown in Table 9.2 and defined in (1) through (5) as follows:

(1) Assorted porosity is acceptable, provided that the combination of the various sizes does not exceed the total area of indications permitted for a 3 in. (75 mm) length of weld.

(2) For welds of larger size than considered in Table 9.2, the total area of porosity as determined from the radiographic film shall not exceed $0.067E$ square inches in any 3 in. (75 mm) length of weld, where E is the weld size. If the weld is less than 3 in. long, the total allowable area of porosity shall be reduced in direct proportion.

(3) The maximum dimension of porosity shall be 27% of E , or 1/8 in. (3.2 mm), whichever is smaller except that an isolated indication separated from an adjacent large indication by 1-1/4 in. (32 mm) or more may be $E/3$, or 1/4 in. (6.4 mm), whichever is less.

(4) Aligned porosity shall be acceptable provided that the sum of the major dimensions of the indications is not more than $E/2$ in a length of $6E$, or 3 in. (75 mm), whichever is less. A sequence of four or more pores shall be considered to be aligned when they touch a line parallel to the length of the weld drawn through the center of the outer pores.

Table 9.2
Maximum Acceptable Porosity^{1,2} in Radiographs for Any 3 in. (75 mm)
Length of Weld (Nontubular and Dynamically Loaded) (see 9.8.2)

(E) Weld Size ³ (in.)	Total Area ⁴ Permitted (sq. in.)	Large Pores		Medium Pores		Fine Pores	
		Major Dimension (in.)	Max No.	Major Dimension (in.)	Max No.	Major Dimension (in.)	Max No.
1/8	0.008	0.033	9	0.025	16	0.018	31
1/4	0.017	0.067	4	0.032	21	0.020	54
3/8	0.024	0.100	3	0.037	23	0.022	65
1/2	0.033	0.125	2	0.041	25	0.026	62
5/8	0.042	0.125	3	0.043	28	0.029	63

(E) Weld Size ³ (mm)	Total Area ⁴ Permitted (sq. mm)	Large Pores		Medium Pores		Fine Pores	
		Major Dimension (mm)	Max No.	Major Dimension (mm)	Max No.	Major Dimension (mm)	Max No.
3.2	5	0.84	9	0.64	16	0.46	31
6.4	11	1.70	4	0.81	21	0.50	54
9.5	15.5	2.54	3	0.94	23	0.56	65
12.7	21	3.17	2	1.04	25	0.66	62
16	27	3.17	3	1.09	28	0.74	63

Notes:

1. Porosity may be circular, elliptical, conical, or irregular in shape. The major dimension shall be measured in determining the size of an indication. The porosity may be a void or a tungsten or non-metallic inclusion. Copper or ferrous inclusions shall not be permitted in the welds.
2. Only that porosity whose major dimension exceeds 1/64 in. (0.4 mm) shall be considered relevant in evaluating the radiographic soundness criteria.
3. Values for intermediate sizes shall be determined by interpolation.
4. The maximum number of pores allowed is determined by the total area permitted for the type of pore (large, medium, or fine) being counted.

9.8.2.3 Inadequate Joint Penetration. The length shall not exceed 20% of the length of the weld.

9.8.2.4 Incomplete Fusion. None shall be accepted, except in the fillet weld root area under the following condition: incomplete fusion in the fillet weld root area may be classified as inadequate joint penetration when it is less than 20% of the weld size, E.

9.8.3 Ultrasonic Testing. When ultrasonic testing is required by the contract documents, the testing procedure and acceptance criteria shall be specified therein.

9.8.4 Liquid Penetrant Inspection. Welds that are subject to liquid penetrant inspection shall be unacceptable if the inspection confirms the presence of surface cracks which render the weld unacceptable on the basis of the requirements for visual inspection.

10. Tubular Structures

Part A *General Requirements*

10.1 Application

10.1.1 This section supplements Sections 1 through 6 and shall be used in conjunction with an associated structural design specification for structures in which the loads are carried primarily by tubular members.²⁰ It is not intended to apply to pressure vessels or pressure piping, but may be applied to their supporting structures.

10.1.2 This section recognizes two classes of tubular structures with different workmanship requirements. Unless otherwise specified, structures of the type identified in Standard Specifications for Structural Supports for Highway Signs, Luminaires, and Traffic Signals, published by the American Association of State Highway and Transportation Officials (Appendix A) are Class I structures.²¹ All other structures are Class II structures. Many of the requirements (dimensional and weld quality) are more stringent for Class II structures.

10.1.3 Due to the generally anticipated smaller size of Class I members, the joint configurations shown in Figures 10.1, 10.2, and 10.3 shall apply to Class II structures only.

20. The term *associated structural design specification*, refers to the rules and specifications under which the plans for the structure were prepared. In the absence of a locally applicable building code or other construction regulations, it is recommended that the design and construction be made to comply with a specification adopted by a recognized engineering society, a recognized trade association, or a recognized governmental agency.

21. There are certain support structures in AASHTO specifications which should be given special consideration because of their configuration and loadings.

10.2 Base Metal

10.2.1 Base metal to be welded under this code shall be one listed in Table 1.1 and shall conform to the requirements of the latest edition of the applicable specification listed below, except as noted in 10.2.3:

- (1) ASTM B26, Standard Specification for Aluminum-Alloy Sand Castings
- (2) ASTM B108, Standard Specification for Aluminum Alloy Permanent Mold Castings
- (3) ASTM B209, Standard Specification for Aluminum and Aluminum Alloy Sheet and Plate
- (4) ASTM B210, Standard Specification for Aluminum Alloy Drawn Seamless Tubes
- (5) ASTM B211, Standard Specification for Aluminum-Alloy Bar, Rod, and Wire
- (6) ASTM B221, Standard Specification for Aluminum and Aluminum Alloy Extruded Bars, Rods, Wire, Shapes, and Tubes
- (7) ASTM B241, Standard Specification for Aluminum and Aluminum Alloy Seamless Pipe and Seamless Extruded Tube
- (8) ASTM B247, Standard Specification for Aluminum Alloy Die and Hand Forgings
- (9) ASTM B308, Standard Specification for Aluminum Alloy 6061-T6 Standard Structural Shapes, Rolled or Extruded
- (10) ASTM B313, Standard Specification for Aluminum and Aluminum Alloy Round Welded Tubes
- (11) ASTM B361, Standard Specification for Factory-Made Wrought Aluminum and Aluminum-Alloy Welding Fittings
- (12) ASTM B429 Standard Specification for Aluminum-Alloy Extruded Structural Pipe and Tube
- (13) ASTM B483, Standard Specification for Aluminum-Alloy Drawn Tubes for General Purpose Applications

10.2.2 Combinations of base metals may be welded, provided that design consideration is given to possible differences in properties, and the intended welding procedure is qualified in accordance with 5.2.

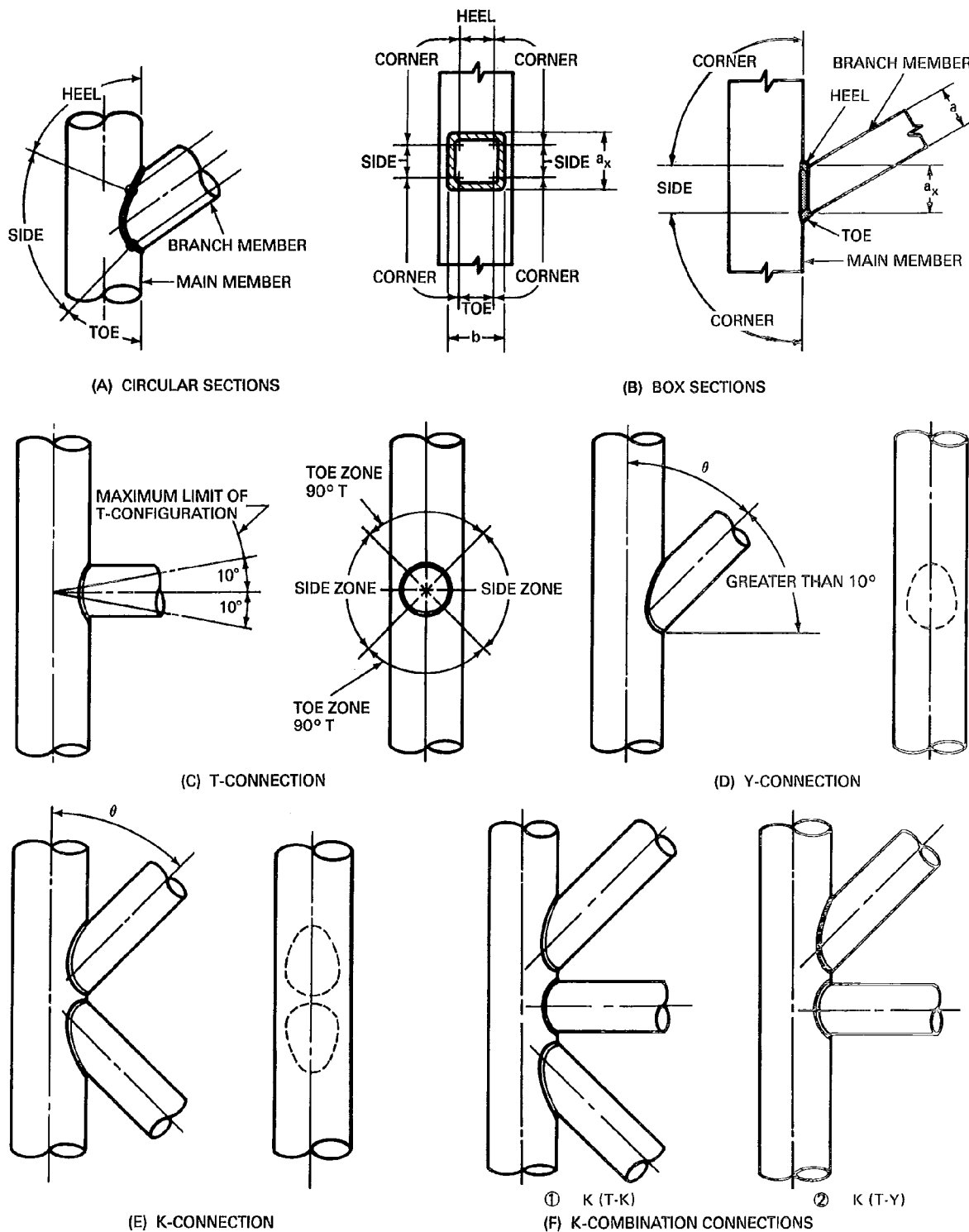
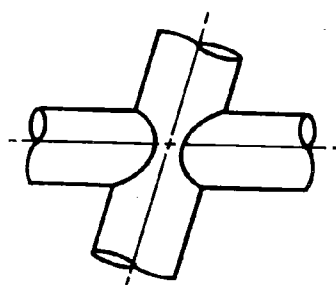
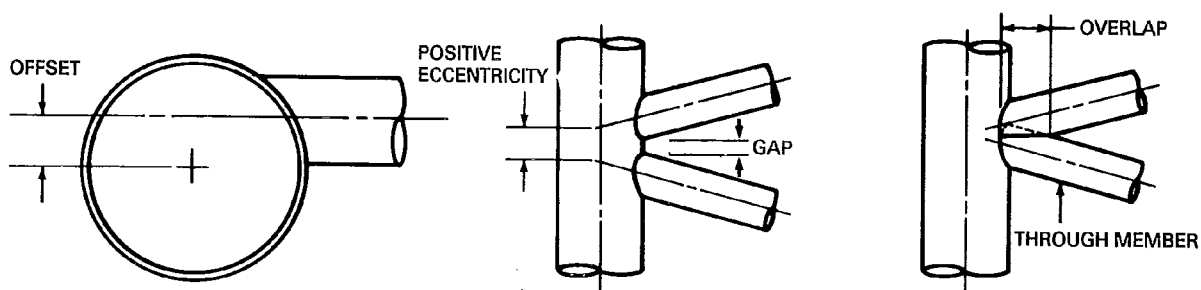


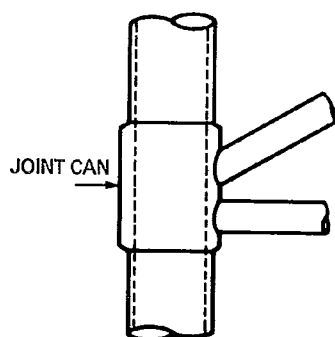
Figure 10.1 — Parts of Tubular Connections (see 10.5.1)



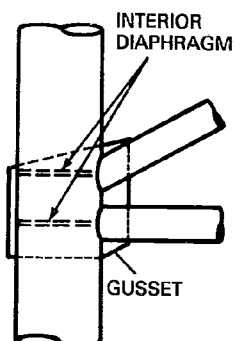
(G) CROSS CONNECTION



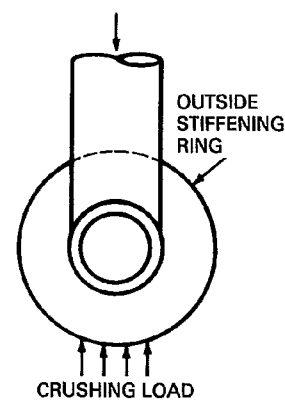
(H) DEVIATIONS FROM CONCENTRIC CONNECTIONS

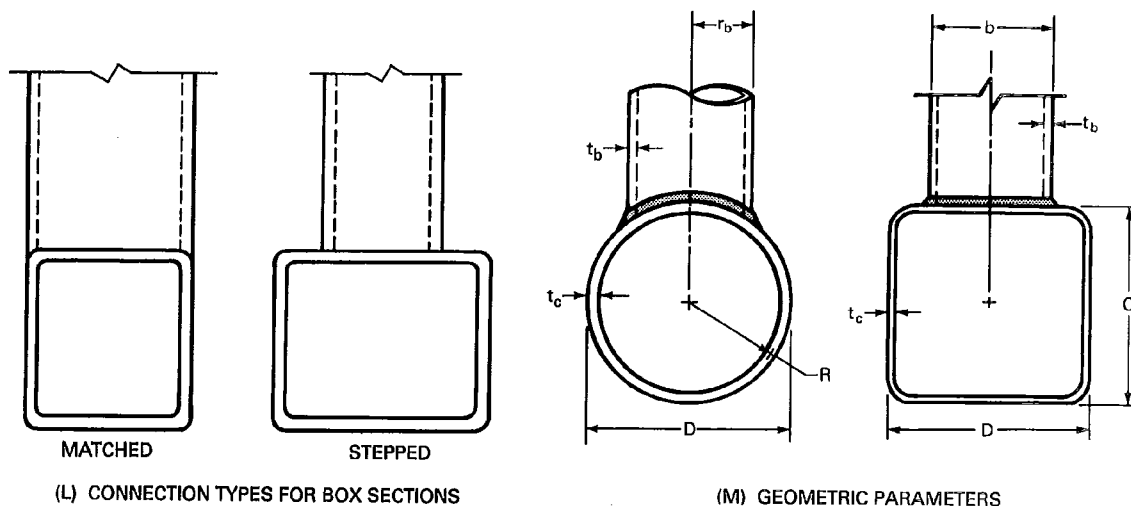
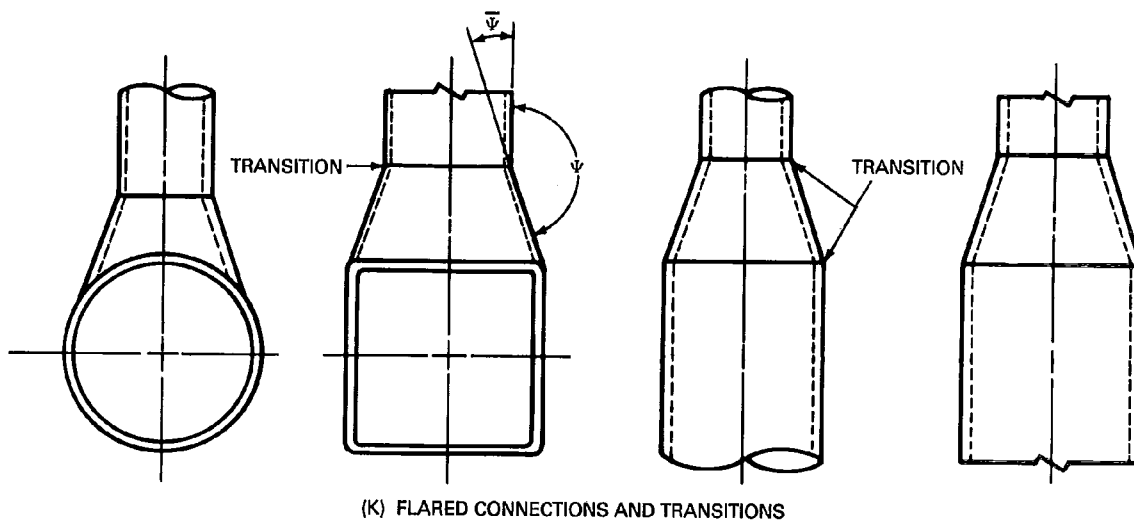


(I) SIMPLE TUBULAR CONNECTION



(J) EXAMPLES OF COMPLEX REINFORCED CONNECTIONS

**Figure 10.1 (continued) — Parts of Tubular Connections (see 10.5.1)**



Parameter	Circular sections	Box sections
β	r_b/R	b/D
η	—	a_x/D See Fig. 10.1 (B)
γ	R/t_c	$D/2t_c$
τ	t_b/t_c	t_b/t_c
θ	Angle between member center lines	
ψ	Local dihedral angle at given point on welded joint	

Figure 10.1 (continued)—Parts of Tubular Connections (see 10.5.1)

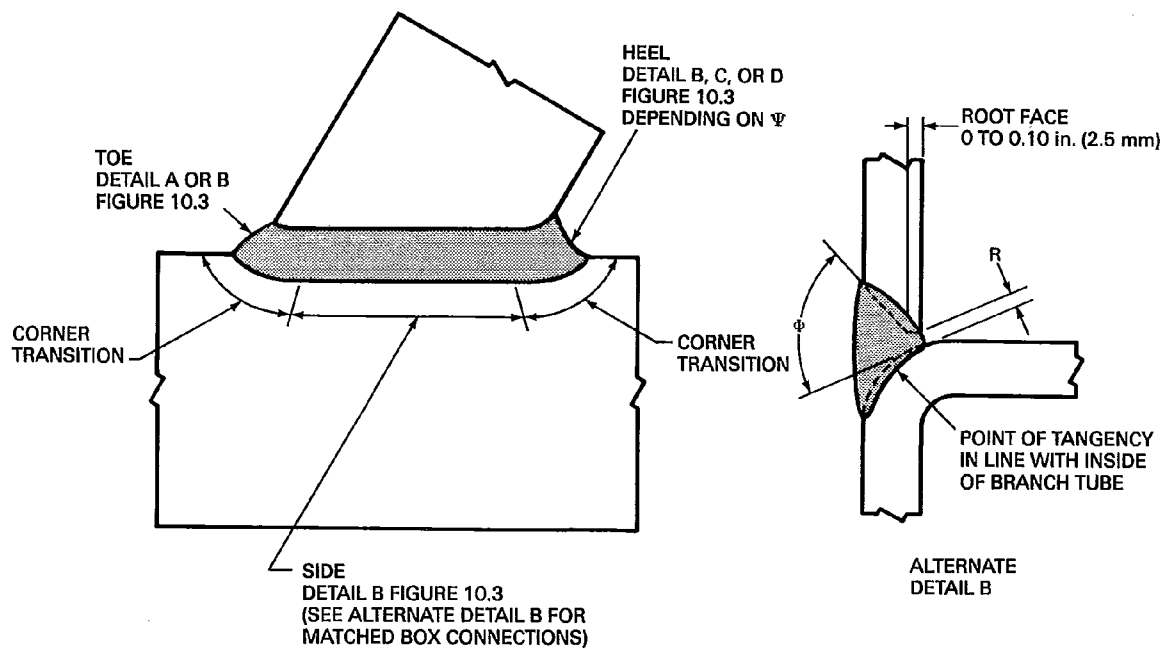


Figure 10.2 — Complete Joint Penetration Box Connections (see 10.5.2)

10.2.3 When an alloy not listed in Table 1.1 is approved under the provisions of the associated structural design specification and is considered for use, the procedure to be used for welding it shall be qualified by the fabricator or contractor in accordance with the qualification requirements of sections 1 through 5 and such other requirements as prescribed by the Engineer.

10.2.4 When an alloy not listed in Table 1.1 is proposed as a substitute material, the contractor shall determine the weldability and perform any additional tests required by the Engineer. The contractor shall assume the financial responsibility for all such tests only if the contractor has the opportunity to include these costs in the bid proposal. However, when a proposal for use of a substitute material not listed in Table 1.1 is made after the contract documents have been signed, the financial responsibility for the costs of all additional testing shall be assumed by the party that made such substitute material proposals.

10.3 Filler Metal

The filler metal shall be selected from Table 1.2 for the base metal or metals used in construction.

Part B Allowable Stresses

10.4 Allowable Stresses

Allowable stresses²² shall be as given in *Specifications for Aluminum Structures—Construction Manual Series*, Section 1 or other specifications as given in the Contract Documents.

Part C Details of T-, Y-, and K-Connections

10.5 Tubular Branch Connections

10.5.1 A branch connection (see Figure 10.1) shall be classified as follows:²³

22. Allowable stresses in heat-treated and work-hardened structural alloys vary with the alloy and the extent of the heat-affected zone.

23. The connections shown in Figures 10.1, 10.2, and 10.3 are applicable to Class II structures only.

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- T-connection angle between main and branch members is between 80° and 90°.
- Y-connection angle between main branch members is 80° or less.
- K-connection two branches in the same plane, on the same member, and the intersections of their axis with the axis of the main member are spaced less than three times the diameter or least face dimension of the main member. Angles of intersection of branch members need not be equal.
- cross connection two branches in the same plane, on opposite sides of the main member, where their axes are in a straight line.

Some variations of tubular connections are shown in Figure 10.1.

10.5.2 The regions of a branch connection shall be classified as shown in Figures 10.2 and 10.3 on the basis of the local dihedral angle between the surface generators of the main and branch members.

Part D **Workmanship Class I Structures**

10.6 Dimensional Tolerances

10.6.1 Dimensional tolerances for fillet welds shall be as stated in 10.12.2.

10.6.2 Dimensional tolerances for complete joint penetration groove welds shall be as stated in contract documents.

10.7 Finishing Cut Edges

When welding cast or wrought material to wrought material, plasma arc cuts need not have any machining performed on the cut edge of the wrought material prior to welding.

10.8 Temporary Welds

In Class I structures, temporary welds need not be made in accordance with a welding procedure. However, temporary welds shall be removed flush with the surrounding metal.

10.9 Weld Terminations

10.9.1 Weld terminations shall be subject to the provisions of 4.8. Peening of weld craters on exposed weld surfaces is permitted to relieve localized shrinkage stresses.

10.9.2 Weld terminations around the circumference of piping and tubing shall overlap the weld start by a minimum of 1/2 in. (13 mm) for circumferences through 18 in. (460 mm) and 1 in. (25 mm) for circumferences greater than 18 in.

10.9.3 Fillet weld craters shall be filled to the full cross section of the weld or repaired in accordance with 3.7.

10.10 Quality of Welds

Inspections shall be performed by visual examination with acceptance criteria as shown in Table 10.1. Any other requirements for inspection and commensurate acceptance levels shall be stated in the contract documents. See Figure 10.4.

10.11 Repair of Defective Base Metal and Defective Welds

Repairs shall be carried out in accordance with 3.7.

Part E **Workmanship Class II Structures**

10.12 Dimensional Tolerances

10.12.1 The ends of branch members which are to be welded with complete joint penetration welds shall be shaped by a machining operation to fit snugly with the main member at an angle within 5° of the intersection angle shown on the drawing. The edge shall be trimmed to produce a satisfactory welding edge as shown in Figures 10.2 and 10.3.

10.12.2 The parts to be joined by fillet welds shall be fitted as closely as practicable, and in no case be separated by more than 3/32 in. (2 mm). If the separation is 1/16 in. (1.6 mm) or more, the leg of the fillet weld shall be increased by the amount of the separation.

10.12.3 The separation between faying surfaces of lap joints or butt joints, or both, landing on a backing shall not exceed 1/16 in. (1.6 mm). Where irregularities in rolled or extruded shapes, after straightening, prevent contact within the above limit, the procedure to be used to bring the separation within the limiting value shall be approved by the Engineer. The use of filler plates is prohibited, unless specified on the drawing or approved by the Engineer and made in accordance with 2.4.

10.12.4 Abutting parts to be joined by girth welds shall be carefully aligned. Girth welds shall not be closer together than the smaller of the pipe diameter or 3 ft (0.9 m). There shall be no more than two girth welds in any 10 ft (3 m) interval of pipe, except as may be

	DETAIL A $\Psi = 180^\circ - 135^\circ$ (See Detail A Below)		DETAIL B $\Psi = 150^\circ - 50^\circ$ (See Detail B Below)		DETAIL C $\Psi = 75^\circ - 30^\circ$ (See Detail C Below)	DETAIL D $\Psi = 40^\circ - 15^\circ$ (See Detail D Below)
End preparation (ω)			90°*		*	
			10° or 45° for $\Psi > 105^\circ$		10°	
Fitup or root opening (R)	GTAW (1)	GMAW (1)	GTAW (1)	GMAW (1)	$\begin{matrix} \text{**} \\ W \text{ max.} & \phi \end{matrix}$ GTAW (1) (2) $\left\{ \begin{matrix} 1/8 \text{ in. (3 mm)} & 25^\circ - 40^\circ \\ 3/16 \text{ in. (5 mm)} & 15^\circ - 25^\circ \end{matrix} \right.$ GMAW (1) (2) $\left\{ \begin{matrix} 1/8 \text{ in. (3 mm)} & 30^\circ - 40^\circ \\ 1/4 \text{ in. (6 mm)} & 25^\circ - 30^\circ \\ 3/8 \text{ in. (10 mm)} & 20^\circ - 25^\circ \\ 1/2 \text{ in. (13 mm)} & 15^\circ - 20^\circ \end{matrix} \right.$	
	max min	3/16 in. (5 mm) 3/16 in. (5 mm) 1/16 in. (1.6 mm) No min for $\phi > 90^\circ$	3/16 in. (5 mm) 3/16 in. (5 mm) 1/16 in. (1.6 mm) No min for $\phi > 120^\circ$	1/4 in. (6 mm) 1/4 in. (6 mm) 1/16 in. (1.6 mm) 1/16 in. (1.6 mm)		
Joint included angle ϕ	90°		60° for $\Psi \leq 105^\circ$		40° if more use Detail B	
	45°		37-1/2° if less use Detail C		1/2 Ψ	
Completed weld	$\geq t_b$		$\geq t_b$ for $\Psi > 90^\circ$ $\geq t_b / \sin \Psi$ for $\Psi \leq 90^\circ$		$\geq t_b / \sin \Psi$ but need not exceed $1.75t_b$ Weld may be built up to meet this	$\geq 2t_b$
	t_w					
	L	$t_b / \sin \Psi$ but need not exceed $1.75t_b$				

* Otherwise as needed to obtain required ϕ

** Initial passes of back up weld discounted until width of groove (W) is sufficient to assure sound welding; the necessary width of weld groove (w) provided by back-up weld

Notes:

1. Detail for GTAW also applies to GMAW for which the root pass is made by GTAW. t_b = wall thickness of branch member
2. In details C and D back-up weld may be made by GTAW. t_w = weld size (effective throat)

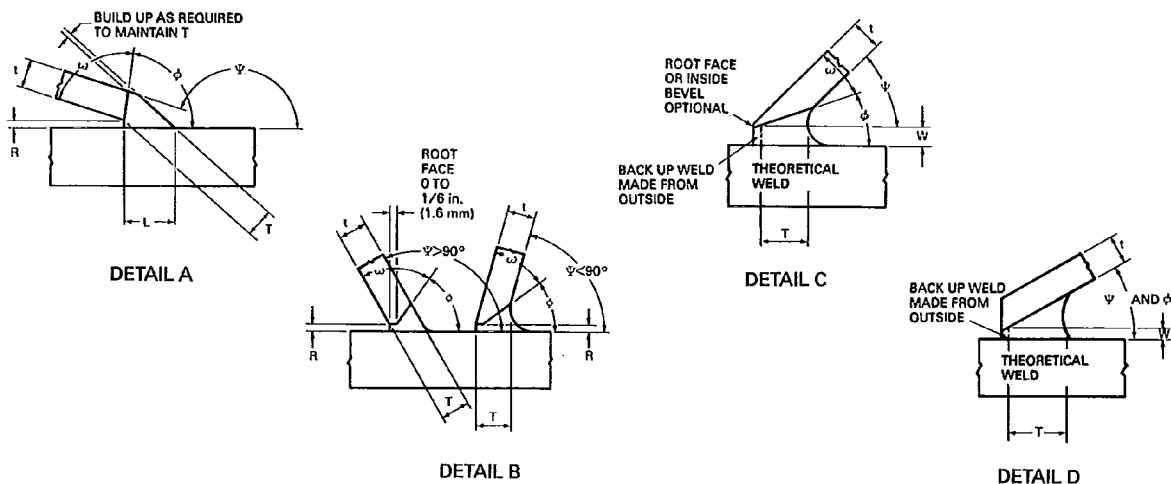


Figure 10.3 — Complete Joint Penetration Circular — Tubular Joints for T-, Y-, and K-Connections Made by Gas Tungsten Arc and Gas Metal Arc Welding (see 10.5.2)

Table 10.1
Acceptance Criteria — Class I Structures (see 10.10)

Description	Limit
Undercut	Regardless of length, undercut shall not exceed the value shown in Figure 10.4 for the primary stress direction category applicable to the area containing the undercut. Further, the undercut may be twice the value permitted by Figure 10.4 (for the applicable stress category) for an accumulated length of 2 in. in any 12 in. (50 mm in 305 mm) length of weld, but in no case may undercut on one side be greater than 1/16 in. (1.6 mm). For weld lengths less than 12 in. (305 mm), the permitted length should be proportional to the actual length.
Underfill of groove welds	None.
Reinforcement of groove welds	1/8 in. maximum (3.2 mm).
Scratch or burn marks	
Depth	Same as undercut.
Fillet weld throat	
Convexity	$0.15 S + 0.060$ in. (1.5 mm), where S = longest specified leg size
Concavity	Throat shall not be undersize. See Figure 3.2 for acceptable and unacceptable weld profiles.
Cracks	None shall be accepted.

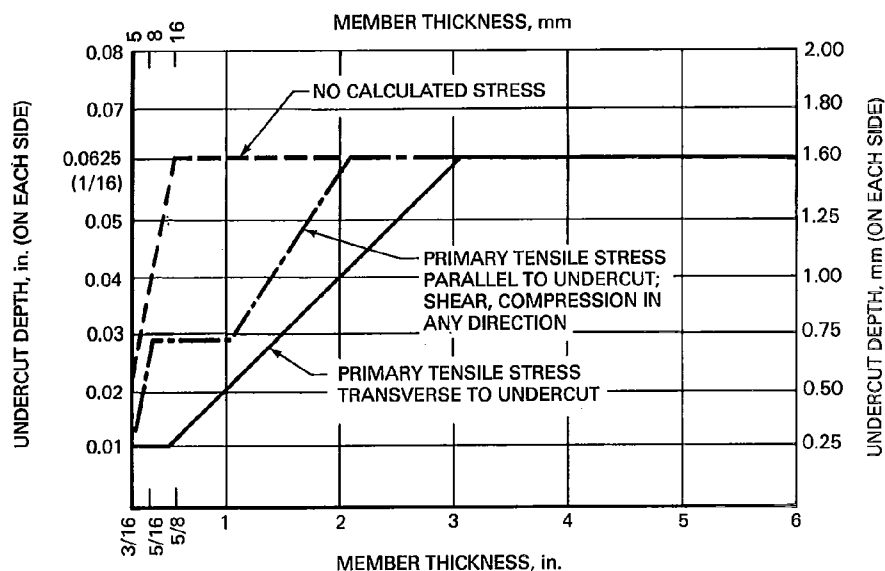


Figure 10.4 — Permissible Undercut Value for Total Length of Joint — Class I Tubular Structures (see 10.10)

approved by the Engineer. Radial offset of abutting edges at a girth weld shall not exceed 30% of the wall thickness or 1/4 in. (6 mm), whichever is smaller. If the offset exceeds 1/8 in. (3 mm), the joint shall be welded from both sides. For joints that cannot be welded from both sides, the radial offset shall not exceed 1/8 in. (3 mm).

10.12.5 Longitudinal weld seams of adjoining sections shall be staggered a minimum of 90° unless closer spacing is approved by the Engineer.

10.12.6 Variations in welding groove details from those shown on the detail drawings shall be in accordance with those shown in 3.3.2. In addition, variations from the joint detail for welds made from one side only without backing shall not exceed the following:

Root face of joint	$\pm 1/32$ in. (1 mm)
Root opening	$\pm 1/16$ in. (1.6 mm)
Groove angle	$\pm 5^\circ$

10.12.7 Tolerances for tubular members shall be those specified in 3.5 wherein the term *column* is interpreted as a tubular compression member which may have longitudinal welding.

10.13 Temporary Welds

10.13.1 Temporary welds shall be subject to the same welding procedure and quality requirements as final welds (see 3.3.7). Their possible effects on the material properties shall be considered in the design process.

10.13.2 In main stress-carrying members, temporary welds not incorporated in the final weld shall be identified on the shop drawings for these members for approval by the Engineer.

10.14 Weld Terminations

10.14.1 Weld terminations shall be subject to the provisions of 4.8. Peening of weld craters on exposed weld surfaces is permitted to relieve localized shrinkage stresses.

10.14.2 Craters existing in tack welds that are to be incorporated into groove welds or in root or inter-

mediate passes of groove welds, shall be removed by mechanical means prior to subsequent welding.

10.14.3 Weld terminations in pipe and tubing shall overlap the weld start by a minimum of 1 in. (25 mm).

10.14.4 Groove and fillet weld terminations shall be made by any of the following techniques, or any combination thereof:

(1) by increasing the travel speed to reduce the crater size, or

(2) by stopping travel speed to allow significant build-up of weld metal to allow complete removal of the weld crater by mechanical means

10.15 Quality of Welds

10.15.1 Visual Inspection. All welds shall be inspected visually. For any weld to be acceptable, discontinuities shall not exceed the limitations shown in Table 10.2.

10.15.2 Radiographic Examination. The extent of radiographic examinations shall be as specified in the bid contract documents. Welds shall be unacceptable if the radiographs show any cracks or any of the types of discontinuities specified in 10.15.2.1 through 10.15.2.4.

Table 10.2
Acceptance Criteria — Class II Structures (see 10.15.1)

Description	Limit
Undercut	
Length, each undercut	0.20 in. (5 mm), maximum.
Depth	15% of minimum base metal thickness, maximum.
Distance between undercuts	2.0 in. (50 mm), minimum.
Underfill (Applies to penetration and reinforcing beads of complete joint penetration groove welds.)	
Depth	15% maximum of the minimum base metal thickness. For complete joint penetration groove welds, an underfill condition of the reinforcing and penetration beads shall not be permitted to coincide at any given length of the weld.
Length, each	0.75 in. (19 mm), maximum.
Length, cumulative	Not more than 1.5 in. (38 mm) in any 6 in. (150 mm) of weld.
Scratch or burn marks	
Depth	15% of minimum base metal thickness, maximum.
Fillet weld throat	
Convexity	20% of theoretical throat, maximum.
Concavity	Permissible only if required throat depth is maintained.
Cracks	None shall be accepted.

10.15.2.1 Porosity with sharp tails shall not be allowed.

10.15.2.2 Maximum permissible porosity in any 3 in. (75 mm) length of weld is shown in Table 10.3 and defined in (1) through (4) below. Porosity may be circular, elliptical, conical, or irregular in shape. The porosity may be a void or a void-like indication or solid tungsten or nonmetallic inclusion. Copper or ferrous inclusions shall not be permitted in welds. Only porosity whose major dimensions exceed 1/64 in. (0.4 mm) shall be considered relevant in evaluating radiographic soundness criteria.

(1) Assorted porosity is acceptable, providing the combination of the various sizes does not exceed the total area of indications permitted for a 3 in. (75 mm) length of weld.

(2) For welds of larger size than considered in Table 10.3, the total area of porosity, as determined from the radiographic film, shall not exceed 0.067E square inches in any 3 in. (75 mm) length of weld where E is the weld size. If the weld is less than 3 in. long, the total allowable area of porosity will be reduced in direct proportion.

(3) The maximum dimension of porosity shall be 26.7% of E or 1/8 in. (3 mm), whichever is smaller, except that an isolated indication separated from an adjacent large indication by 1-1/4 in. (32 mm) or more may be E/3 or 1/4 in. (6 mm), whichever is less.

(4) Aligned porosity will be acceptable, provided that the sum of the major dimensions of the indications is not more than E/2 in a length of 6E or 3 in. (75 mm), whichever is less. A sequence of four or more pores shall be considered to be aligned when they touch a line parallel to the length of the weld drawn through the center of the outer pores.

10.15.2.3 The length of inadequate joint penetration shall not exceed 20% of the length of weld.

10.15.2.4 Incomplete fusion will not be accepted, except in the fillet weld root area under the following condition: incomplete fusion in the fillet weld root area may be classified as inadequate joint penetration when it is less than 20% of the weld size, E.

10.15.3 Ultrasonic Testing. When ultrasonic testing is required by the contract documents, the testing procedure and acceptance criteria shall be specified therein.

Table 10.3
Maximum Acceptable Porosity^{1,2} in Radiographs for Any
3 in. (75 mm) Length of Weld (Tubular) (see 10.15.2)

(E) Weld Size ³ (in.)	Total Area ⁴ Permitted (sq. in.)	Large Pores		Medium Pores		Fine Pores	
		Major Dimension (in.)	Max No.	Major Dimension (in.)	Max No.	Major Dimension (in.)	Max No.
1/8	0.008	0.033	9	0.025	16	0.018	31
1/4	0.017	0.067	4	0.032	21	0.020	54
3/8	0.024	0.100	3	0.037	23	0.022	65
1/2	0.033	0.125	2	0.041	25	0.026	62
5/8	0.042	0.125	3	0.043	28	0.029	63

(E) Weld Size ³ (mm)	Total Area ⁴ Permitted (sq. mm)	Large Pores		Medium Pores		Fine Pores	
		Major Dimension (mm)	Max No.	Major Dimension (mm)	Max No.	Major Dimension (mm)	Max No.
3.2	5	0.84	9	0.64	16	0.46	31
6.4	11	1.70	4	0.81	21	0.50	54
9.5	15.5	2.54	3	0.94	23	0.56	65
12.7	21	3.17	2	1.04	25	0.66	62
16	27	3.17	3	1.09	28	0.74	63

Notes:

1. Porosity may be circular, elliptical, conical, or irregular in shape. The major dimension shall be measured in determining the size of an indication. The porosity may be a void or a tungsten or non-metallic inclusion. Copper or ferrous inclusions shall not be permitted in the welds.
2. Only that porosity whose major dimension exceeds 1/64 in. (0.4 mm) shall be considered relevant in evaluating the radiographic soundness criteria.
3. Values for intermediate sizes shall be determined by interpolation.
4. The maximum number of pores allowed is determined by the total area permitted for the type of pore (large, medium, or fine) being counted.

10.15.4 Liquid-Penetrant Inspection. Welds that are subject to liquid penetrant inspection shall be unacceptable if the inspection confirms the presence of surface cracks which render the weld unacceptable on the basis of the requirements for visual inspection.

10.16 Repair of Defective Welds

Welds identified as defective by visual, radiographic, dye penetrant, or ultrasonic examination, or any combination thereof, shall be corrected as specified in 3.7.

11. Strengthening and Repairing Existing Structures

11.1 General

The provisions of this section amplify or supersede provisions in the other sections in their application to the strengthening or repairing, or both, of existing structures. Strengthening may be required because of changes in the nature or magnitude of loading; repairs may be required because of deterioration by corrosion or damage.

11.2 Materials

11.2.1 The types of base metal involved shall be determined before preparing the drawings and specifications covering the strengthening or repair of an existing structure.

11.2.2 Where different base alloys are to be joined, special consideration shall be given to the selection of the filler metal and welding procedure.

11.3 Design

11.3.1 As part of the design procedure, the following shall be determined:

11.3.1.1 The character and extent of deterioration or damage to the parts and connections that require strengthening or repair

11.3.1.2 Whether the work consists only of restoring corroded or otherwise damaged parts, or replacing members in their entirety

11.3.2 A complete study of the loads and stresses shall be made if the design for strengthening goes beyond the restoration of corroded or otherwise damaged members. Allowance shall be made for fatigue stresses to which members may be subjected.

11.3.3 Members subject to cyclic loading shall be designed in accordance with the design rules and stresses

of the associated structural design code.²⁴ When the previous loading history of the structure is available, consideration shall be made to equalize the anticipated remaining lives of elements of the existing structure and the anticipated lives of the added or replacement parts.

11.4 Workmanship

11.4.1 Surfaces of old material which are to be covered by repair or reinforcing material shall be cleaned of dirt and other foreign matter except adherent paint film. If so specified, these areas shall be given a protective coating of paint, corrosion inhibitor, or similar material. The portions of such surfaces on which weld metal is to be deposited shall be cleaned thoroughly of all foreign matter, including paint film, for a distance of 2 in. (50 mm) on each side of the fusion zone.

11.4.2 Edges of members to be welded that have been reduced in thickness by corrosion or wear to less than the size of the specified weld shall be cut back to thicker material to provide a thickness equal to the size of the specified weld, or replaced.

11.4.3 Structural elements under stress shall not be removed or reduced in section, except as specified by the plans or allowed by the Engineer. The stability and safety of the structure shall be maintained.

11.5 Special

11.5.1 The Engineer shall determine whether a member will be permitted to carry live-load stress while welding is being performed on it, taking into consideration the

24. The term *associated structural design code* refers to the rules and specifications under which the plans for the work were prepared.

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extent of the heating of the member (both temperature and volume of material) which results from the welding operation.

11.5.2 When material is being added to a member carrying a dead-load stress in excess of 30% of its design stress, it is desirable to relieve the member of the dead-load stress or to prestress the material being added. If neither procedure is practicable, the new material to be added may be proportioned for a unit stress equal to the allowable unit stress in the original member minus the dead-load unit stress in the original member.

11.5.3 Where rivets or bolts are overstressed by the total load, not more than the dead-load shall be assigned to

them. In such cases, sufficient welding shall be provided to support all live and impact loads. If rivets or bolts are overstressed by dead-load alone, sufficient reinforcement shall be added to support the total load.

11.5.4 In strengthening members by the addition of material, the sequence of welding shall be arranged so as to maintain a symmetrical section at all times. This is of particular importance if a live-load is permitted on the structure while the welding is being performed.

11.5.5 Attention shall be given to the safety of the structure, especially to avoid (1) overheating, (2) accidental heating of adjacent members, and (3) ignition of combustible materials.

Appendix A

List of Publishers and Referenced Documents

(This Appendix is not part of ANSI/AWS D1.2-90, *Structural Welding Code-Aluminum*, but is included for information purposes only.)

1. Aluminum Association, 900 19th Street, N.W., Washington, DC 20006.
 "Specifications for Aluminum Structures", Construction Manual series—Section 1.
2. American Association of State Highway and Transportation Officials, 444 N. Capitol Street, N.W., Washington, DC 20001.
 Standard Specifications for Structural Supports for Highway Signs, Luminaires and Traffic Signals
3. American National Standards Institute, 1430 Broadway, New York, New York 10018.
 B46.1—Surface Texture
 Z49.1—Safety in Welding and Cutting
4. American Society of Mechanical Engineers, 345 E. 47th Street, New York, New York 10017.
 Boiler and Pressure Vessel Code—Section V, Non-Destructive Examination
5. American Society for Nondestructive Testing, 4153 Arlingate Plaza, Caller No. 28518, Columbus, Ohio 43228.
 Recommended Practice No. SNT-TC-1A (Personnel Qualification and Certification in Nondestructive Testing)
6. American Society for Testing and Materials, 1916 Race Street, Philadelphia, Pennsylvania 19103.
 ASTM B26, Standard Specification for Aluminum-Alloy Sand Castings
 ASTM B108, Standard Specification for Aluminum Alloy Permanent Mold Castings
 ASTM B209, Standard Specification for Aluminum and Aluminum Alloy Sheet and Plate
 ASTM B210, Standard Specification for Aluminum Alloy Drawn Seamless Tubes
 ASTM B211, Standard Specification for Aluminum Alloy Bar, Rod and Wire
 ASTM B221, Standard Specification for Aluminum and Aluminum Alloy Extruded Bars, Rods, Wire, Shapes, and Tubes
 ASTM B241, Standard Specification for Aluminum and Aluminum Alloy Seamless Pipe and Seamless Extruded Tube
 ASTM B247, Standard Specification for Aluminum Alloy Die and Hand Forgings
 ASTM B308, Standard Specification for Aluminum Alloy 6061-T6 Standard Structural Shapes, Rolled or Extruded
 ASTM B313, Standard Specification for Aluminum and Aluminum Alloy Round Welded Tubes
 ASTM B361, Standard Specification for Factory-Made Wrought Aluminum and Aluminum Alloy Welding Fittings
 ASTM B429, Standard Specification for Aluminum-Alloy Extruded Structural Pipe and Tube
 ASTM B483, Standard Specification for Aluminum-Alloy Drawn Tubes for General Purpose Applications
 ASTM B557, Standard Methods of Tension Testing Wrought and Cast Aluminum and Aluminum-Alloy and Magnesium-Alloy Products

ASTM B618, Standard Specification for Aluminum and Aluminum Alloy Investment Castings

ASTM B686, Standard Specification for Aluminum Alloy Castings

ASTM E94, Standard Recommended Practice for Radiographic Testing

ASTM E142, Standard Method for Controlling Quality of Radiographic Testing

ASTM E165, Recommended Practice for Liquid Penetrant Inspection Method

7. American Welding Society, 550 N.W. LeJeune Road, P.O. Box 351040 Miami, Florida 33135

ANSI/AWS A2.4, Symbols for Welding and Nondestructive Testing

ANSI/AWS A3.0, Standard for Welding Terms and Definitions

ANSI/AWS B4.0, Standard Method for Mechanical Testing of Welds

ANSI/AWS A5.10, Specification for Bare Aluminum and Aluminum Alloy Welding Electrodes and Rods

ANSI/AWS QC1, Standard for Qualification and Certification of Welding Inspectors

ANSI/AWS D1.2, Appendix J—Safe Practices

8. Compressed Gas Association, 1235 Jefferson Davis Avenue, Alexandria, Virginia 22202.

CGA G-11.1, Commodity Specification for Argon

Appendix B

Recommended Groove Welded Joints

(This Appendix is not part of ANSI/AWS D1.2-90, *Structural Welding Code—Aluminum*, but is included for information purposes only.)

B1. Recommended Complete Joint Penetration Groove Welded Joints. (See Figure B1).

B2. Recommended Partial Joint Penetration Groove Welded Joints. (See Figure B2).

Legend for Appendix B

Symbols for joint types

B — butt joint
C — corner joint
T — T-joint
BC — butt or corner joint
TC — T- or corner joint
BTC — butt, T-, or corner joint

Symbols for base metal thickness and penetration

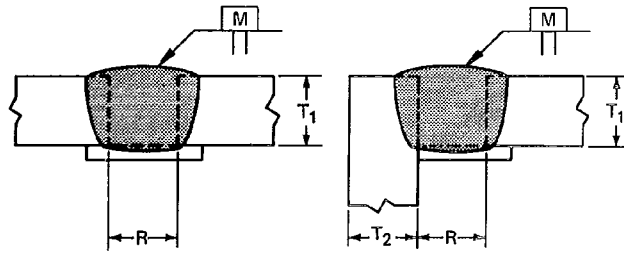
L — limited thickness—complete joint penetration
U — unlimited thickness—complete joint penetration
P — partial joint penetration

Symbols for weld types

1 — square-groove
2 — single-V-groove
3 — double-V-groove
4 — single-bevel-groove
5 — double-bevel-groove
6 — single-U-groove
7 — double-U-groove
8 — single-J-groove
9 — double-J-groove

The lower case letters, e.g., a, b, c, etc., are used to differentiate geometry and fitup characteristics.

Square-groove weld (1)
Butt joint (B)
Corner joint (C)



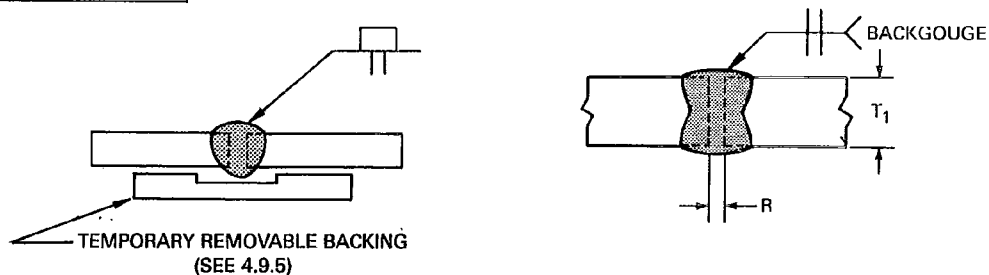
M = ALUMINUM (SEE 4.9)

Welding Process	Joint Designation	Base Metal Thickness (U = unlimited)		Groove Preparation			*Suggested Welding Positions
				Root Opening, (R)	Tolerances		
		T ₁	T ₂		As Detailed (see 2.9.3)	As Fit Up (see 3.3)	
GMAW	B-L1a	3/16 max	—	T ₁	+1/16, -0	+1/4, -1/16	F,V
	C-L1a	3/16 max	U	T ₁	+1/16, -0	+1/4, -1/16	F,V
GMAW	B-L1b	1/4 max	—	3/8	+1/16, -0	+1/4, -1/16	OH
	C-L1b	1/4 max	U	3/8	+1/16, -0	+1/4, -1/16	OH
GTAW	B-L1a	1/8 max	—	T ₁	+1/16, -0	+1/4, -1/16	All
	C-L1a	1/8 max	1/2	T ₁	+1/16, -0	+1/4, -1/16	All

Note: All dimensions in inches.

*F = flat, V = vertical, OH = overhead.

Square-groove weld (1)
Butt joint (B)



Welding Process	Joint Designation	Base Metal Thickness	Groove Preparation			*Suggested Welding Positions	Notes
			Root Opening. (R)	Tolerances			
		T ₁		As Detailed (see 2.9.3)	As Fit Up (see 3.3)		
GMAW	B-L1	3/8 max	0 to 1/16	+1/16, -0	±1/16	F, V	A
GTAW	B-L1	1/4 max	0 to 1/8	+1/16, -0	±1/16	All	A

Note: Backgouge root to sound metal before welding other side.

*F = flat, V = vertical, OH = overhead.

**Figure B1 — Recommended Complete Joint Penetration
Groove Welded Joints (Inches)**

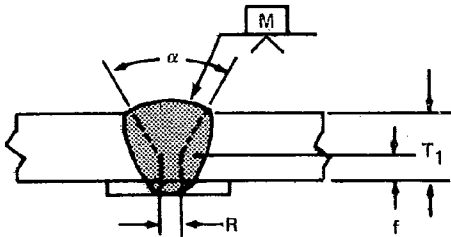
Square-groove weld (1)
T-joint (T)
Corner joint (C)

Welding Process	Joint Designation	Base Metal Thickness		Groove Preparation			*Suggested Welding Positions	Notes
				Root Opening (R)	Tolerances			
		T ₁	T ₂		As Detailed (see 2.9.3)	As Fit Up (see 3.3)		
GMAW	TC-L1C	3/8 max	≤ 1/4	0 to 1/16	+1/16, -0	± 1/16	F, V	A, B
			> 1/4 to 3/8	1/16 to 3/32				
GTAW	TC-L1C	1/4 max	≥ 1/2	0 to 1/8	+1/16, -0	± 1/16	All	A, B

Note A: Backgouge root to sound metal before welding other side.

Note B: If fillet welds are used in statically loaded structures to reinforce groove welds in corner and T-joints, they shall be equal to $1/4 T_1$, but need not exceed $3/8$ in. Groove welds in corner and T-joints in dynamically loaded structures shall be reinforced with fillet welds equal to $1/4 T_1$ but need not exceed $3/8$ in.

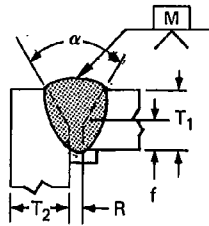
*F = flat, H = horizontal, V = vertical, OH = overhead.

Single-V-groove weld (2) Butt joint (B)																
																
M = ALUMINUM (SEE 4.9)																
<table><tr><td></td><td colspan="2">Tolerances</td></tr><tr><td></td><td>As Detailed (see 2.9.3)</td><td>As Fit Up (see 3.3)</td></tr><tr><td>R</td><td>+1/16, -0</td><td>+1/4, -1/16</td></tr><tr><td>f</td><td>+1/16, -0</td><td>±1/16</td></tr><tr><td>α</td><td>+10°, -0°</td><td>+10°, -5°</td></tr></table>			Tolerances			As Detailed (see 2.9.3)	As Fit Up (see 3.3)	R	+1/16, -0	+1/4, -1/16	f	+1/16, -0	±1/16	α	+10°, -0°	+10°, -5°
	Tolerances															
	As Detailed (see 2.9.3)	As Fit Up (see 3.3)														
R	+1/16, -0	+1/4, -1/16														
f	+1/16, -0	±1/16														
α	+10°, -0°	+10°, -5°														

Welding Process	Joint Designation	Base Metal Thickness (U = unlimited)	Groove Preparation			Suggested Welding Positions	Notes
		T ₁	Root Opening (R)	Root Face (f)	Groove Angle (α)		
GMAW	B-U2a	U	3/8	1/32 to 1/8	60°	All	C
GTAW	B-L2a	1/2 max	3/8	1/32 to 1/8	60°	All	—

Note C: If $T > 3/4$ in., U-groove or modified V-groove may be used.

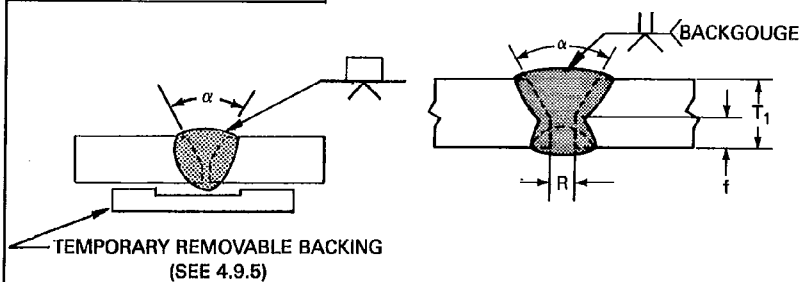
Figure B1 (continued) — Recommended Complete Joint Penetration Groove Welded Joints (Inches)

Single-V-groove weld (2)
Corner joint (C)

	Tolerances	
	As Detailed (see 2.9.3)	As Fit Up (see 3.3)
R	+1/16, -0	+1/4, -1/16
f	+1/16, -0	±1/16
α	+10°, -0°	+10°, -5°

M = ALUMINUM (SEE 4.9)

Welding Process	Joint Designation	Base Metal Thickness (U = unlimited)		Groove Preparation			*Suggested Welding Positions	Notes
		T ₁	T ₂	Root Opening (R)	Root Face (f)	Groove Angle (α)		
GMAW	C-U2a	U	U	1/4	1/16	70°	All	C
				3/8	1/16	60°	F, OH	
GTAW	C-L2a	1/2 max	1/2 max	1/4	1/16	70°	All	
				3/8	1/16	60°	All	

Single-V-groove weld (2)
Butt joint (B)

	Tolerances	
	As Detailed (see 2.9.3)	As Fit Up (see 3.3)
R	+1/16, -0	±1/16
f	+1/16, -0	±1/16
α	+10°, -0°	+10°, -5°

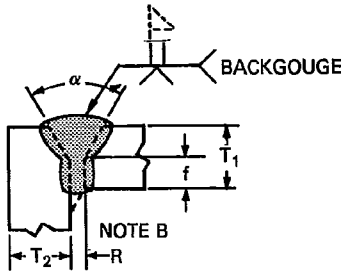
Welding Process	Joint Designation	Base Metal Thickness (U = unlimited)	Groove Preparation			Suggested Welding Positions	Notes
		T ₁	Root Opening (R)	Root Face (f)	Groove Angle (α)		
GMAW	B-U2b	≤1	0 to 1/8	1/16 to 1/8	60°	All	A, C
		>1	0 to 1/8	1/8 T ₁	60°		
GTAW	B-L2b	1/2 max	0 to 1/8	1/16 to 1/8	60°	All	A

Note A: Backgouge root to sound metal before welding other side.

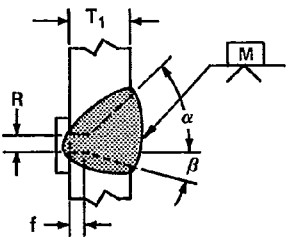
Note C: If T > 3/4 in., U-groove or modified V-groove may be used.

*F = flat, OH = overhead.

**Figure B1 (continued) — Recommended Complete Joint Penetration
Groove Welded Joints (Inches)**

Single-V-groove weld (2) Corner joint (C)		Tolerances		
		As Detailed (see 2.9.3)	As Fit Up (see 3.3)	
		R	+1/16, -0	±1/16
		f	+1/16, -0	±1/16
		α	+10°, -0°	+10°, -5°

Welding Process	Joint Designation	Base Metal Thickness (U = unlimited)		Groove Preparation			Suggested Welding Positions	Notes
		T ₁	T ₂	Root Opening (R)	Root Face (f)	Groove Angle (α)		
GMAW	C-U2	≤1	U	0 to 1/8	1/16 to 1/8	60°	All	A, B, C
		>1	U	0 to 1/8	1/8 T ₁	60°		
GTAW	C-L2	1/2 max	1/2 max	0 to 1/8	1/16 to 1/8	60°	All	A, B

Single-V-groove weld (2) Butt joint (B)		Tolerances		
		As Detailed (see 2.9.3)	As Fit Up (see 3.3)	
		R	+1/16, -0	+1/4, -1/16
		f	+1/16, -0	±1/16
		$\alpha + \beta$	+10°, -0°	+10°, -5°

M = ALUMINUM (SEE 4.9)

Welding Process	Joint Designation	Base Metal Thickness (U = Unlimited)	Groove Preparation			*Suggested Welding Positions	Notes
		T ₁	Root Opening (R)	Root Face (f)	Groove Angle (α & β)		
GMAW	B-U2c	U	3/8	0 to 1/16	$\alpha = 45^\circ$ $\beta = 15^\circ$	H	

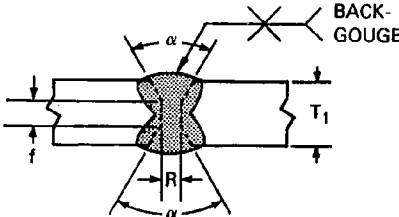
Note A: Backgouge root to sound metal before welding other side.

Note B: If fillet welds are used in statically loaded structures to reinforce groove welds in corner and T-joints, they shall be equal to $1/4 T_1$, but need not exceed 3/8 in. Groove welds in corner and T-joints in dynamically loaded structures shall be reinforced with fillet welds equal to $1/4 T_1$ but need not exceed 3/8 in.

Note C: If $T > 3/4$ in., U-groove or modified V-groove may be used.

*H = horizontal.

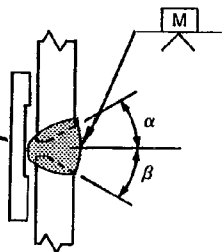
**Figure B1 (continued) — Recommended Complete Joint Penetration
Groove Welded Joints (Inches)**

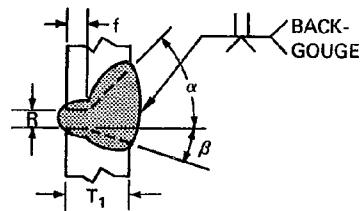
Double-V-groove weld (3) Butt joint (B)			
Tolerances			
As Detailed (see 2.9.3)	As Fit Up (see 3.3)		
R	+1/16, -0 ±1/16		
f	+1/16, -0 ±1/16		
alpha	+10°, -0° +10°, -5°		

Welding Process	Joint Designation	Base Metal Thickness (U = unlimited)	Groove Preparation			Suggested Welding Positions	Notes
		T ₁	Root Opening (R)	Root Face (f)	Groove Angle (α)		
GMAW	B-U3a	U, preferably 5/8 or thicker	0 to 1/16	1/16 to 1/8	60°	All	A, B, D, M

Single-V-groove weld (2)
Butt joint (B)

TEMPORARY
REMOVABLE
BACKING
(SEE 4.9.5)





	Tolerances	
	As Detailed (see 2.9.3)	As Fit Up (see 3.3)
R	+1/16, -0	±1/16
f	+1/16, -0	±1/16
$\alpha + \beta$	+10°, -0°	+10°, -5°

Welding Process	Joint Designation	Base Metal Thickness	Groove Preparation			*Suggested Welding Positions	Notes
		T ₁	Root Opening (R)	Root Face (f)	Groove Angle (α & β)		
GMAW	B-U2d	≤1	0 to 1/16	1/16 to 1/8	α + β = 60° β = 0° to 15°	H	A, C
		>1	0 to 3/32	1/8 T ₁	α + β = 60° β = 0° to 15°		

Note A: Backgouge root to sound metal before welding other side.

Note B: If fillet welds are used in statically loaded structures to reinforce groove welds in corner and T-joints, they shall be equal to 1/4 T₁, but need not exceed 3/8 in. Groove welds in corner and T-joints in dynamically loaded structures shall be reinforced with fillet welds equal to 1/4 T₁ but need not exceed 3/8 in.

Note C: If T > 3/4 in., U-groove or modified V-groove may be used.

Note D: Double-groove welds may have grooves of unequal depth, but the depth of the shallower groove shall be no less than one-fourth of the thickness of the thinner part joined.

Note M: If T > 1-1/2 in., Double-U-groove or modified double V-groove may be used.

*H = horizontal.

**Figure B1 (continued) — Recommended Complete Joint Penetration
Groove Welded Joints (Inches)**

Double-V-groove weld (3) Butt joint (B)		Tolerances		
Welding Process	Joint Designation	Base Metal Thickness (U = unlimited) T_1	As Detailed (see 2.9.3)	
			As Fit Up (see 3.3)	
			R	$\pm 1/16$
			f	$\pm 1/16$
			$\alpha + \beta$	$+10^\circ, -0^\circ$

Note: $\alpha + \beta = 60^\circ$

Welding Process	Joint Designation	Base Metal Thickness (U = unlimited)		Groove Preparation			*Suggested Welding Positions	Notes
		T_1		Root Opening (R)	Root Face (f)	Groove Angle (α & β)		
GMAW	B-U3b	U, preferably 5/8 or thicker		0 to 1/8	1/16 to 1/8	$\alpha + \beta = 60^\circ$ $\beta = 0^\circ$ to 15°	H	A, D, Z

Note A: Backgouge root of joint to sound metal before welding the other side.

Note D: Double-groove welds may have grooves of unequal depth, but the depth of the shallower groove shall be no less than one-fourth of the thickness of the thinner part joined.

Note Z: When lower plate is beveled, make first root pass on this side.

*H = horizontal.

Single-bevel-groove weld (4) T-joint (T) Corner joint (C)		Tolerances		
Welding Process	Joint Designation	Base Metal Thickness (U = Unlimited) T_1 T_2	As Detailed (see 2.9.3)	
			As Fit Up (see 3.3)	
			R	$+1/16, -0$
			f	$\pm 1/16$
			α	$+10^\circ, -0^\circ$

M = ALUMINUM (SEE 4.9)

Welding Process	Joint Designation	Base Metal Thickness (U = Unlimited)		Groove Preparation			Suggested Welding Positions	Notes
		T_1	T_2	Root Opening (R)	Root Face (f)	Groove Angle (α)		
GMAW	TC-U4a	U	U	3/8	0 to 1/16	60°	All	B, E, F
GTAW	TC-L4a	1/2 max	1/2 max	3/8	0 to 1/16	60°	All	B, E, F

Note B: If fillet welds are used in statically loaded structures to reinforce groove welds in corner and T-joints, they shall be equal to $1/4 T_1$, but need not exceed $3/8$ in. Groove welds in corner and T-joints in dynamically loaded structures shall be reinforced with fillet welds equal to $1/4 T_1$ but need not exceed $3/8$ in.

Note E: For corner joints, the outside groove preparation may be in either or both members, provided the basic groove configuration is not changed and adequate edge distance is maintained to support the welding operations without excessive edge melting.

Note F: In the horizontal position the bevel should be on the upper member.

Figure B1 (continued) — Recommended Complete Joint Penetration Groove Welded Joints (Inches)

Single-bevel-groove weld (4)
T-joint (T)
Corner joint (C)

The diagrams illustrate the geometry of single-bevel-groove welds. The left diagram is for a T-joint, showing a cross-section with base metal thicknesses T_1 and T_2 , a root opening R , and a groove angle α . The right diagram is for a corner joint, showing a cross-section with base metal thicknesses T_1 and T_2 , a root opening R , a root face f , and a groove angle α . Both diagrams include labels for BACK-GOUGE, NOTE E, and NOTE B.

	Tolerances	
	As Detailed (see 2.9.3)	As Fit Up (see 3.3)
R	+1/16, -0	±1/16
f	+1/16, -0	±1/16
α	+10°, -0°	+10°, -5°

Welding Process	Joint Designation	Base Metal Thickness (U = unlimited)		Groove Preparation			Suggested Welding Positions	Notes
				Root Opening (R)	Root Face (f)	Groove Angle (α)		
		T ₁	T ₂					
GMAW	TC-U4b	U	U	0 to 3/32	1/16 to 1/8	60°	All	A, B, E, F
GTAW	TC-L4b	1/2 max	1/2 max	0 to 3/32	1/16 to 1/8	60°	All	A, B, E, F

Note A: Backgouge root of joint to sound metal before welding the other side.

Note B: If fillet welds are used in statically loaded structures to reinforce groove welds in corner and T-joints, they shall be equal to $1/4 T_1$, but need not exceed 3/8 in. Groove welds in corner and T-joints in dynamically loaded structures shall be reinforced with fillet welds equal to $1/4 T_1$ but need not exceed 3/8 in.

Note E: For corner joints, the outside groove preparation may be in either or both members, provided the basic groove configuration is not changed and adequate edge distance is maintained to support the welding operations without excessive edge melting.

Note F: In the horizontal position the bevel should be on the upper member.

**Figure B1 (continued) — Recommended Complete Joint Penetration
Groove Welded Joints (Inches)**

Single-bevel-groove weld (4)
T-joint (T)
Corner joint (C)

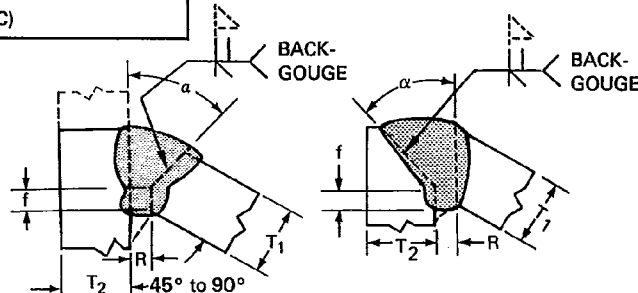
NOTE E

The diagram illustrates a single-bevel-groove weld joint. It shows two plates, one horizontal and one angled at α degrees. The horizontal plate has a thickness T_2 and the angled plate has a thickness T_1 . The groove has a root opening R and a root face f . A dimension M is indicated for the bevel face. The joint angle α is specified as 45° to 90° . A shaded area represents the weld metal.

M = ALUMINUM (SEE 4.9)

	Tolerances	
	As Detailed (see 2.9.3)	As Fit Up (see 3.3)
R	+1/16, -0	+1/4, -1/16
f	+1/16, -0	±1/16
α	+10°, -0°	+10°, -5°

Welding Process	Joint Designation	Base Metal Thickness (U = unlimited)		Groove Preparation			Suggested Welding Positions	Notes		
		T ₁	T ₂	Root Opening (R)	Root Face (f)	Groove Angle (α)				
GMAW	TC-U4c	U	U	3/8	1/16	60°	All	B,E		
GTAW	TC-L4c	1/2 max	1/2 max	3/8	1/16	60°	All	B,E		

Single-bevel-groove weld (4) T-Joint (T) Corner joint (C)					Tolerances		
					As Detailed (see 2.9.3)		As Fit Up (see 3.3)
		R			+1/16, -0		±1/16
					+1/16, -0		±1/16
					+10°, -0°		+10°, -5°

Welding Process	Joint Designation	Base Metal Thickness (U = unlimited)		Groove Preparation			Suggested Welding Positions	Notes
		T ₁	T ₂	Root Opening (R)	Root Face (f)	Groove Angle (α)		
GMAW	TC-U4d	U	U	0 to 3/32	1/16 to 1/8	60°	All	A, B, E, F
GTAW	TC-U4d	1/2 max	1/2 max	0 to 3/32	1/16 to 1/8	60°	All	A, B, E, F

Note A: Backgouge root of joint to sound metal before welding the other side.

Note B: If fillet welds are used in statically loaded structures to reinforce groove welds in corner and T-joints, they shall be equal to $1/4 T_1$, but need not exceed 3/8 in. Groove welds in corner and T-joints in dynamically loaded structures shall be reinforced with fillet welds equal to $1/4 T_1$ but need not exceed 3/8 in.

Note E: For corner joints, the outside groove preparation may be in either or both members, provided the basic groove configuration is not changed and adequate edge distance is maintained to support the welding operations without excessive edge melting.

Note F: In the horizontal position the bevel should be on the upper member.

Figure B1 (continued) — Recommended Complete Joint Penetration Groove Welded Joints (Inches)

Double-bevel-groove weld (5) Butt joint (B) T-joint (T) Corner joint (C)		<table><tr><td></td><td colspan="2">Tolerances</td></tr><tr><td></td><td>As Detailed (see 2.9.3)</td><td>As Fit Up (see 3.3)</td></tr><tr><td>R</td><td>+1/16, -0</td><td>±1/16</td></tr><tr><td>f</td><td>+1/16, -0</td><td>±1/16</td></tr><tr><td>α</td><td>+10°, -0°</td><td>+10°, -5°</td></tr></table>				Tolerances			As Detailed (see 2.9.3)	As Fit Up (see 3.3)	R	+1/16, -0	±1/16	f	+1/16, -0	±1/16	α	+10°, -0°	+10°, -5°
	Tolerances																		
	As Detailed (see 2.9.3)	As Fit Up (see 3.3)																	
R	+1/16, -0	±1/16																	
f	+1/16, -0	±1/16																	
α	+10°, -0°	+10°, -5°																	
Welding Process	Joint Designation	Base Metal Thickness (U = unlimited)		Groove Preparation			Suggested Welding Positions	Notes											
		T ₁	T ₂	Root Opening (R)	Root Face (f)	Groove Angle (α)													
GMAW	B-U5a	U, preferably 5/8 or thicker	—	0 to 1/16	1/16 to 1/8	60°	All	A, D											
	TC-U5a	U, preferably 5/8 or thicker	U	0 to 1/16	1/16 to 1/8	60°	All	A, B, D, E											

Note A: Backgouge root of joint to sound metal before welding the other side.

Note B: If fillet welds are used in statically loaded structures to reinforce groove welds in corner and T-joints, they shall be equal to $1/4 T_1$, but need not exceed $3/8$ in. Groove welds in corner and T-joints in dynamically loaded structures shall be reinforced with fillet welds equal to $1/4 T_1$ but need not exceed $3/8$ in.

Note D: Double-groove welds may have grooves of unequal depth, but the depth of the shallower groove shall be no less than one-fourth of the thickness of the thinner part joined.

Note E: For corner joints, the outside groove preparation may be in either or both members, provided the basic groove configuration is not changed and adequate edge distance is maintained to support the welding operations without excessive edge melting.

**Figure B1 (continued) — Recommended Complete Joint Penetration
Groove Welded Joints (Inches)**

Double-bevel-groove weld (5) T-joint (T) Corner joint (C)								Tolerances	
								As Detailed (see 2.9.3)	As Fit Up (see 3.3)
					R	+1/16, -0	+1/14, -1/16		
					f	+1/16, -0	±1/16		
					α	+10°, -0°	+10°, -5°		

Welding Process	Joint Designation	Base Metal Thickness (U = unlimited)		Groove Preparation			Suggested Welding Positions	Notes
		T ₁	T ₂	Root Opening (R)	Root Face (f)	Groove Angle (α)		
GMAW	TC-U5c	U, preferably 5/8 or thicker	U	0 to 3/8	1/16 to 1/8	60°	All	A,B,D,E
GTAW	TC-L5a	1/2 max	1/2 max	0 to 3/8	1/16 to 1/8	60°	All	A,B,D,E

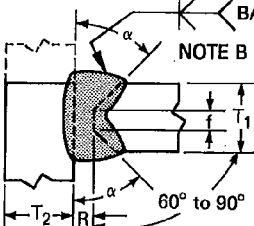
Note A: Backgouge root of joint to sound metal before welding the other side.

Note B: If fillet welds are used in statically loaded structures to reinforce groove welds in corner and T-joints, they shall be equal to $1/4 T_1$, but need not exceed $3/8$ in. Groove welds in corner and T-joints in dynamically loaded structures shall be reinforced with fillet welds equal to $1/4 T_1$ but need not exceed $3/8$ in.

Note D: Double-groove welds may have grooves of unequal depth, but the depth of the shallower groove shall be no less than one-fourth of the thickness of the thinner part joined.

Note E: For corner joints, the outside groove preparation may be in either or both members, provided the basic groove configuration is not changed and adequate edge distance is maintained to support the welding operations without excessive edge melting.

**Figure B1 (continued) — Recommended Complete Joint Penetration
Groove Welded Joints (Inches)**

Double-bevel-groove weld (5) T-joint (T) Corner joint (C)		Tolerances		
		As Detailed (see 2.9.3)	As Fit Up (see 3.3)	
		R	+1/16, -0	±1/16
		f	+1/16, -0	±1/16
		α	+10°, -0°	+10°, -5°

Welding Process	Joint Designation	Base Metal Thickness (U = unlimited)		Groove Preparation			Suggested Welding Positions	Notes
		T ₁	T ₂	Root Opening (R)	Root Face (f)	Groove Angle (α)		
GMAW	TC-U5b	U, preferably 5/8 or thicker	U	0 to 3/32	1/16 to 1/8	60°	All	A, B, D, E

Note A: Backgouge root of joint to sound metal before welding the other side.

Note B: If fillet welds are used in statically loaded structures to reinforce groove welds in corner and T-joints, they shall be equal to $1/4 T_1$, but need not exceed 3/8 in. Groove welds in corner and T-joints in dynamically loaded structures shall be reinforced with fillet welds equal to $1/4 T_1$ but need not exceed 3/8 in.

Note D: Double-groove welds may have grooves of unequal depth, but the depth of the shallower groove shall be no less than one-fourth of the thickness of the thinner part joined.

Note E: For corner joints, the outside groove preparation may be in either or both members, provided the basic groove configuration is not changed and adequate edge distance is maintained to support the welding operations without excessive edge melting.

**Figure B1 (continued) — Recommended Complete Joint Penetration
Groove Welded Joints (Inches)**

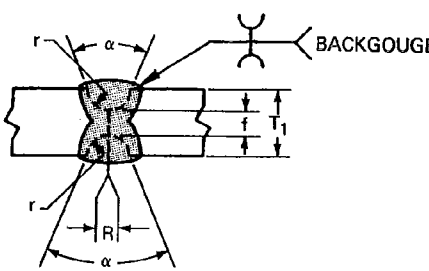
Single-U-groove weld (6) Butt joint (B) Corner joint (C)		Tolerances		
		As Detailed (see 2.9.3)	As Fit Up (see 3.3)	
	R	+1/16, -0	±1/16	
	f	+1/16, -0	±1/16	
	α	+10°, -0°	+10°, -5°	
	r	+1/8, -0	±1/16	

Welding Process	Joint Designation	Base Metal Thickness (U = unlimited)		Groove Preparation				Suggested Welding Positions	Notes
		T ₁	T ₂	Root Opening (R)	Root Face (f)	Groove Angle (α)	Groove Radius (r)		
GMAW	B-U6	U, preferably 5/8 or thicker	—	0 to 3/32	1/8 to 1/4	60°	1/4	All	A
	C-U6	U, preferably 5/8 or thicker	U	0 to 3/32	1/8 to 1/4	60°	1/4	All	A, B

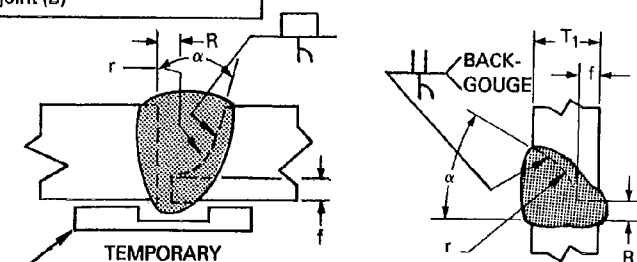
Note A: Backgouge root of joint to sound metal before welding the other side.

Note B: If fillet welds are used in statically loaded structures to reinforce groove welds in corner and T-joints, they shall be equal to $1/4 T_1$, but need not exceed $3/8$ in. Groove welds in corner and T-joints in dynamically loaded structures shall be reinforced with fillet welds equal to $1/4 T_1$ but need not exceed $3/8$ in.

**Figure B1 (continued) — Recommended Complete Joint Penetration
Groove Welded Joints (Inches)**

Double-U-groove weld (7) Butt joint (B)					
Tolerances					
	As Detailed (see 2.9.3)	As Fit Up (see 3.3)			
R	+1/16, -0	±1/16			
f	+1/16, -0	±1/16			
alpha	+10°, -0°	+10°, -5°			
r	+1/8, -0	±1/16			

Welding Process	Joint Designation	Base Metal Thickness (U = unlimited)	Groove Preparation				Suggested Welding Positions	Notes
		T ₁	Root Opening (R)	Root Face (f)	Groove Angle (α)	Groove Radius (r)		
GMAW	B-U7	U, preferably 5/8 or thicker	0 to 3/32	1/8 to 1/4	60°	1/4	All	A, D

Single-J-groove weld (8) Butt joint (B)					Tolerances	
			As Detailed (see 2.9.3)		As Fit Up (see 3.3)	
			R	+1/16, -0	±1/16	
			f	+1/16, -0	±1/16	
			α	+10°, -0°	+10°, -5°	
			r	+1/8, -0	±1/16	

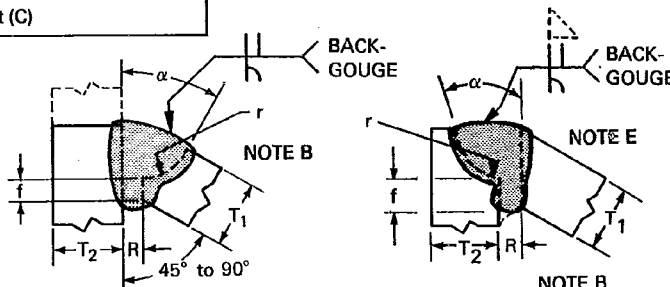
Welding Process	Joint Designation	Base Metal Thickness (U = unlimited)	Groove Preparation				Suggested Welding Positions	Notes
		T ₁	Root Opening (R)	Root Face (f)	Groove Angle (α)	Groove Radius (r)		
GMAW	B-U8	U, preferably 5/8 or thicker	0 to 3/32	1/8 to 1/4	60°	3/8	All	A, F

Note A: Backgouge root of joint to sound metal before welding other side.

Note D: Double-groove welds may have grooves of unequal depth, but the depth of the shallower groove shall be no less than one-fourth of the thickness of the thinner part joined.

Note F: In the horizontal position the bevel should be on the upper member.

**Figure B1 (continued) — Recommended Complete Joint Penetration
Groove Welded Joints (Inches)**

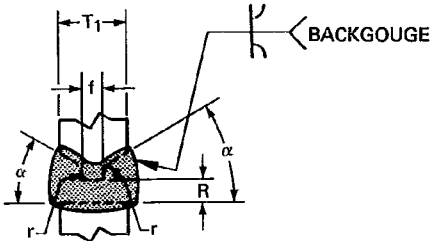
Single-J-groove weld (8) T-joint (T) Corner joint (C)		Tolerances		
		As Detailed (see 2.9.3)	As Fit Up (see 3.3)	
		R	+1/16, -0	±1/16
		f	+1/16, -0	±1/16
		α	+10°, -0°	+10°, -5°
		r	+1/8, -0	±1/16

Welding Process	Joint Designation	Base Metal Thickness (U = unlimited)		Groove Preparation				Suggested Welding Positions	Notes
		T ₁	T ₂	Root Opening (R)	Root Face (f)	Groove Angle (α)	Groove Radius (r)		
GMAW	TC-U8a	U, preferably 5/8 or thicker	U	0 to 3/32	1/8	60°	3/8	All	A, B, E

Note A: Backgouge root of joint to sound metal before welding the other side.

Note B: If fillet welds are used in statically loaded structures to reinforce groove welds in corner and T-joints, they shall be equal to $1/4 T_1$, but need not exceed 3/8 in. Groove welds in corner and T-joints in dynamically loaded structures shall be reinforced with fillet welds equal to $1/4 T_1$ but need not exceed 3/8 in.

Note E: For corner joints, the outside groove preparation may be in either or both members, provided the basic groove configuration is not changed and adequate edge distance is maintained to support the welding operations without excessive edge melting.

Double-J-groove weld (9) Butt joint (B)				
		Tolerances		
		As Detailed (see 2.9.3)	As Fit Up (see 3.3)	
R		+1/16, -0	±1/16	
f		+1/16, -0	±1/16	
α		+10°, -0°	+10°, -5°	
r		+1/8, -0	±1/16	

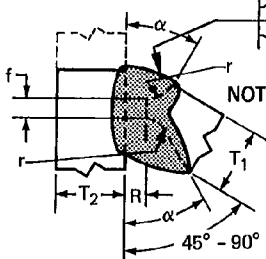
Welding Process	Joint Designation	Base Metal Thickness (U = unlimited)	Groove Preparation				Suggested Welding Positions	Notes
		T ₁	Root Opening (R)	Root Face (f)	Groove Angle (α)	Groove Radius (r)		
GMAW	B-U9	U, preferably 5/8 or thicker	0 to 3/32	1/8	60°	3/8	All	A,D,F

Note A: Backgouge root to sound metal before welding other side.

Note D: Double-groove welds may have grooves of unequal depth, but the depth of the shallower groove shall be no less than one-fourth of the thickness of the thinner part joined.

Note F: In the horizontal position the bevel should be on the upper member.

**Figure B1 (continued) — Recommended Complete Joint Penetration
Groove Welded Joints (Inches)**

Double-J-groove weld (9) T-joint (T) Corner joint (C)		Tolerances	
		As Detailed (see 2.9.3)	As Fit Up (see 3.3)
	R	+1/16, -0	± 1/16
	f	+1/16, -0	± 1/16
	α	+10°, -0°	+10°, -5°
	r	+1/8, -0	± 1/16

Welding Process	Joint Designation	Base Metal Thickness (U = unlimited)		Groove Preparation				Suggested Welding Positions	Notes
		T ₁	T ₂	Root Opening (R)	Root Face (f)	Groove Angle (α)	Groove Radius (r)		
GMAW	TC-U9a	U, preferably 5/8 or thicker	U	0 to 3/32	1/8	60°	3/8	All	A, B, D, E, F

Note A: Backgouge root to sound metal before welding other side.

Note B: If fillet welds are used in statically loaded structures to reinforce groove welds in corner and T-joints, they shall be equal to $1/4 T_1$, but need not exceed 3/8 in. Groove welds in corner and T-joints in dynamically loaded structures shall be reinforced with fillet welds equal to $1/4 T_1$ but need not exceed 3/8 in.

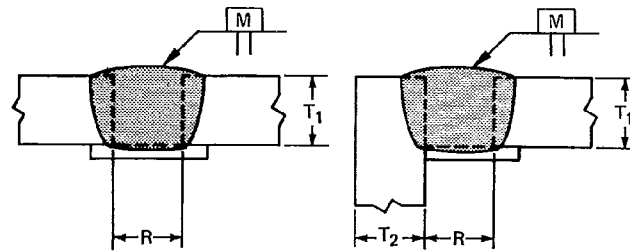
Note D: Double-groove welds may have grooves of unequal depth, but the depth of the shallower groove shall be no less than one-fourth of the thickness of the thinner part joined.

Note E: For corner joints, the outside groove preparation may be in either or both members, provided the basic groove configuration is not changed and adequate edge distance is maintained to support the welding operations without excessive edge melting.

Note F: In the horizontal position the bevel should be on the upper member.

Figure B1 (continued) — Recommended Complete Joint Penetration Groove Welded Joints (Inches)

Square-groove weld (1)
Butt-joint (B)
Corner joint (C)



M = ALUMINUM (SEE 4.9)

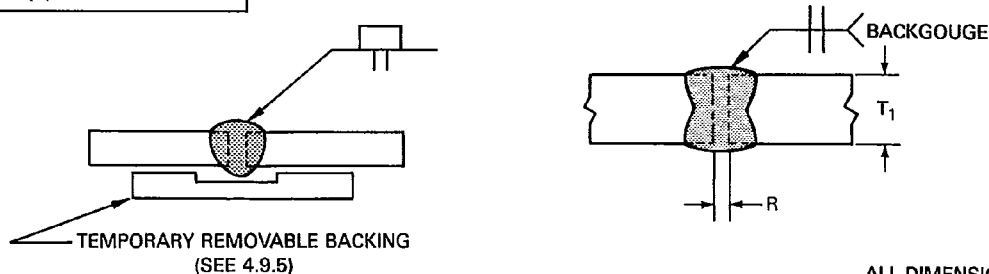
ALL DIMENSIONS IN mm

Welding Process	Joint Designation	Base Metal Thickness (U = unlimited)		Groove Preparation			*Suggested Welding Positions
				Root Opening (R)	Tolerances		
		T ₁	T ₂		As Detailed (see 2.9.3)	As Fit Up (see 3.3)	
GMAW	B-L1a	4.8 max	—	T ₁	+1.6, −0	+6, −1.6	F,V
	C-L1a	4.8 max	U	T ₁	+1.6, −0	+6, −1.6	F,V
GMAW	B-L1b	6.4 max	—	10	+1.6, −0	+6, −1.6	OH
	C-L1b	6.4 max	U	10	+1.6, −0	+6, −1.6	OH
GTAW	B-L1a	3.2 max	—	T ₁	+1.6, −0	+6, −1.6	All
	C-L1a	3.2 max	1/2	T ₁	+1.6, −0	+6, −1.6	All

Note: All dimensions in millimeters.

*F = flat, V = vertical, OH = overhead.

Square-groove weld (1)
Butt-joint (B)



TEMPORARY REMOVABLE BACKING
(SEE 4.9.5)

ALL DIMENSIONS IN mm

Welding Process	Joint Designation	Base Metal Thickness	Groove Preparation			*Suggested Welding Positions	Notes
			Root Opening (R)	Tolerances			
		T ₁		As Detailed (see 2.9.3)	As Fit Up (see 3.3)		
GMAW	B-L1	9.5 max	0 to 1.6	+1.6, −0	±1.6	F,V	A
GTAW	B-L1	6.4 max	0 to 3.2	+1.6, −0	±1.6	All	A

Note: Backgouge root to sound metal before welding other side.

*F = flat, V = vertical, OH = overhead.

Figure B1 (continued) — Recommended Complete Joint Penetration Groove Welded Joints (Millimeters)

Square-groove weld (1)
T-joint (T)
Corner joint (C)

ALL DIMENSIONS IN mm

Welding Process	Joint Designation	Base Metal Thickness		Groove Preparation			*Suggested Welding Positions	Notes
				Root Opening (R)	Tolerances			
		T ₁	T ₂		As Detailed (see 2.9.3)	As Fit Up (see 3.3)		
GMAW	TC-L1C	9.5 max	≤ 6.4	0 to 1.6	+ 1.6, -0	± 1.6	F, V	A, B
			> 6.4 to 9.5	1.6 to 2				
GTAW	TC-L1C	6.4 max	≥ 12.7	0 to 3	+ 1.6, -0	± 1.6	All	A, B

Note A: Backgouge root to sound metal before welding other side.

Note B: If fillet welds are used in statically loaded structures to reinforce groove welds in corner and T-joints, they shall be equal to $1/4 T_1$, but need not exceed 10 mm. Groove welds in corner and T-joints in dynamically loaded structures shall be reinforced with fillet welds equal to $1/4 T_1$ but need not exceed 10 mm.

*F = flat, V = vertical, H = horizontal, OH = overhead.

Single-V-groove weld (2)

Butt-joint (B)

	Tolerances	
	As Detailed (see 2.9.3)	As Fit Up (see 3.3)
R	+1.6, -0	+6, -1.6
f	+1.6, -0	± 1.6
α	+10°, -0°	+10°, -5°

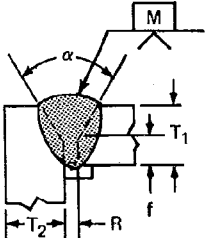
M = ALUMINUM (SEE 4.9)

ALL DIMENSIONS IN mm

Welding Process	Joint Designation	Base Metal Thickness (U = unlimited)	Groove Preparation			Suggested Welding Positions	Notes
		T ₁	Root Opening (R)	Root Face (f)	Groove Angle (α)		
GMAW	B-U2a	U	10	1 to 3	60°	All	C
GTAW	B-L2a	12.7 max	10	1 to 3	60°	All	—

Note C: If $T > 19$ mm, U-groove or modified V-groove may be used.

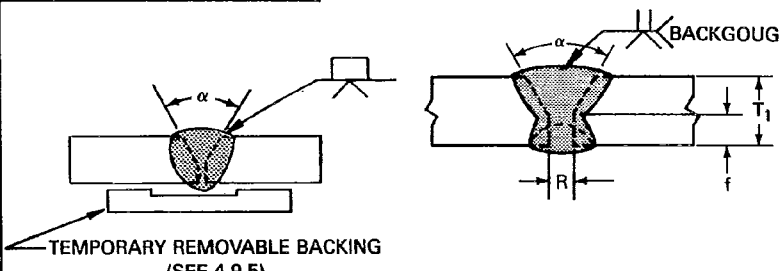
Figure B1 (continued) — Recommended Complete Joint Penetration Groove Welded Joints (Millimeters)

Single-V-groove weld (2) Corner joint (C)				Tolerances	
				As Detailed (see 2.9.3)	As Fit Up (see 3.3)
R		+1.6, -0	+6, -1.6		
f		+1.6, -0	±1.6		
α		+10°, -0°	+10°, -5°		

M = ALUMINUM (SEE 4.9)

ALL DIMENSIONS IN mm

Welding Process	Joint Designation	Base Metal Thickness (U = unlimited)		Groove Preparation			*Suggested Welding Positions	Notes
		T ₁	T ₂	Root Opening (R)	Root Face (f)	Groove Angle (α)		
GMAW	C-U2a	U	U	6	1.6	70°	All	C
				10	1.6	60°	F, OH	
GTAW	C-L2a	12.7 max	12.7 max	6	1.6	70°	All	
				10	1.6	60°	All	

Single-V-groove weld (2) Butt joint (B)		Tolerances			
		As Detailed (see 2.9.3)	As Fit Up (see 3.3)		
	R	+1.6, -0	±1.6		
	f	+1.6, -0	±1.6		
	$\alpha + \beta$	+10°, -0°	+10°, -5°		
TEMPORARY REMOVABLE BACKING (SEE 4.9.5)		ALL DIMENSIONS IN mm			

Welding Process	Joint Designation	Base Metal Thickness (U = unlimited)	Groove Preparation			Suggested Welding Positions	Notes
		T ₁	Root Opening (R)	Root Face (f)	Groove Angle (α)		
GMAW	B-U2b	≤25.4	0 to 3	1.6 to 3	60°	All	A, C
		>25.4	0 to 3	1/8T ₁	60°		
GTAW	B-L2b	12.7 max	0 to 3	1.6 to 3	60°	All	A

Note A: Backgouge root to sound metal before welding other side.

Note C: If T > 19 mm, U-groove or modified V-groove may be used.

*F = flat, OH = overhead.

Figure B1 (continued) — Recommended Complete Joint Penetration Groove Welded Joints (Millimeters)

Single-V-groove weld (2) Corner joint (C)		Tolerances	
		As Detailed (see 2.9.3)	As Fit Up (see 3.3)
R		+1.6, -0	±1.6
f		+1.6, -0	±1.6
α		+10°, -0°	+10°, -5°

NOTE B

ALL DIMENSIONS IN mm

Welding Process	Joint Designation	Base Metal Thickness (U = unlimited)		Groove Preparation			Suggested Welding Positions	Notes
		T1	T2	Root Opening (R)	Root Face (f)	Groove Angle (α)		
GMAW	C-U2	≤25.4	U	0 to 3	1.6 to 3	60°	All	A, B, C
		>25.4	U	0 to 3	1/8 T1	60°		
GTAW	C-L2	12.7 max	12.7 max	0 to 3	1.6 to 3	60°	All	A, B

Single-V-groove weld (2) Butt joint (B)		Tolerances	
		As Detailed (see 2.9.3)	As Fit Up (see 3.3)
R		+1.6, -0	+6, -1.6
f		+1.6, -0	±1.6
$\alpha + \beta$		+10°, -0°	+10°, -5°

M = ALUMINUM (SEE 4.9)

ALL DIMENSIONS IN mm

Welding Process	Joint Designation	Base Metal Thickness (U = Unlimited)		Groove Preparation			*Suggested Welding Positions	Notes
		T1	T2	Root Opening (R)	Root Face (f)	Groove Angle (α & β)		
GMAW	B-U2c	U	U	10	0 to 1.6	$\alpha = 45^\circ$ $\beta = 15^\circ$	H	

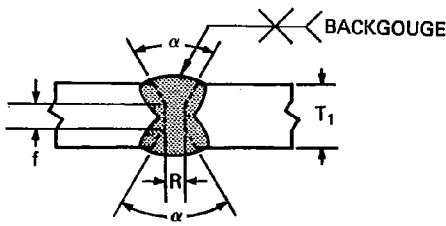
Note A: Backgouge root to sound metal before welding other side.

Note B: If fillet welds are used in statically loaded structures to reinforce groove welds in corner and T-joints, they shall be equal to $1/4 T_1$, but need not exceed 10 mm. Groove welds in corner and T-joints in dynamically loaded structures shall be reinforced with fillet welds equal to $1/4 T_1$ but need not exceed 10 mm.

Note C: If $T > 19$ mm, U-groove or modified V-groove may be used.

*H = horizontal.

**Figure B1 (continued) — Recommended Complete Joint Penetration
Groove Welded Joints (Millimeters)**

Double-V-groove weld (3) Butt joint (B)						
					Tolerances	
					As Detailed (see 2.9.3)	As Fit Up (see 3.3)
					R	+1.6, -0
		f	+1.6, -0	±1.6		
		α	+10°, -0°	+10°, -5°		

ALL DIMENSIONS IN mm

Welding Process	Joint Designation	Base Metal Thickness (U = unlimited)	Groove Preparation			Suggested Welding Positions	Notes
		T ₁	Root Opening (R)	Root Face (f)	Groove Angle (α)		
GMAW	B-U3a	U, preferably 15.9 or thicker	0 to 1.6	1.6 to 3	60°	All	A, B, D, M

Single-V-groove weld (2)
Butt joint (B)

TEMPORARY
REMOVABLE
BACKING
(SEE 4.9.5)

Tolerances

As Detailed
(see 2.9.3)

As Fit Up
(see 3.3)

R

+1.6, -0

±1.6

f

+1.6, -0

±1.6

$\alpha + \beta$

+10°, -0°

+10°, -5°

ALL DIMENSIONS IN mm

Welding
Process

Joint
Designation

Base
Metal Thickness

T_1

Groove Preparation

Root
Opening
(R)

Root
Face
(f)

Groove
Angle
(α & β)

*Suggested
Welding
Positions

Notes

GMAW

B-U2d

≤25.4

0 to 1.6

1.6 to 3

$\alpha + \beta = 60^\circ$
 $\beta = 0^\circ$ to 15°

H

A, C

>25.4

0 to 2

$1/8 T_1$

$\alpha + \beta = 60^\circ$
 $\beta = 0^\circ$ to 15°

Note A: Backgouge root to sound metal before welding other side.

Note B: If fillet welds are used in statically loaded structures to reinforce groove welds in corner and T-joints, they shall be equal to $1/4 T_1$, but need not exceed 10 mm. Groove welds in corner and T-joints in dynamically loaded structures shall be reinforced with fillet welds equal to $1/4 T_1$ but need not exceed 10 mm.

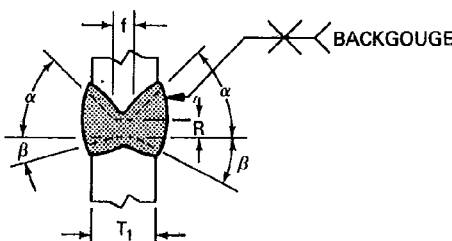
Note C: If $T > 19$ mm, U-groove or modified V-groove may be used.

Note D: Double-groove welds may have grooves of unequal depth, but the depth of the shallower groove shall be no less than one-fourth of the thickness of the thinner part joined.

Note M: If $T > 38.1$ mm, Double-U-groove or modified double V-groove may be used.

*H = horizontal.

**Figure B1 (continued) — Recommended Complete Joint Penetration
Groove Welded Joints (Millimeters)**

Double-V-groove weld (3) Butt joint (B)		Tolerances		
		As Detailed (see 2.9.3)	As Fit Up (see 3.3)	
		R	+1.6, -0	± 1.6
		f	+1.6, -0	± 1.6
		$\alpha + \beta$	+10°, -0°	+10°, -5°
Note: $\alpha + \beta = 60^\circ$		ALL DIMENSIONS IN mm		

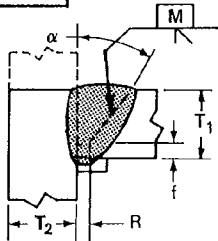
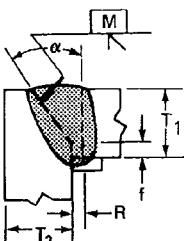
Welding Process	Joint Designation	Base Metal Thickness (U = unlimited)	Groove Preparation			*Suggested Welding Positions	Notes
		T ₁	Root Opening (R)	Root Face (f)	Groove Angle (α & β)		
GMAW	B-U3b	U, preferably 15.9 or thicker	0 to 3	1.6 to 3	$\alpha + \beta = 60^\circ$ $\beta = 0^\circ$ to 15°	H	A, D, Z

Note A: Backgouge root of joint to sound metal before welding the other side.

Note D: Double-groove welds may have grooves of unequal depth, but the depth of the shallower groove shall be no less than one-fourth of the thickness of the thinner part joined.

Note Z: When lower plate is beveled, make first root pass on this side.

*H = horizontal.

Single-bevel-groove weld (4) T-joint (T) Corner joint (C)								Tolerances	
								As Detailed (see 2.9.3)	As Fit Up (see 3.3)
		R	+1.6, -0	+6, -1.6					
		f	+1.6, -0	±1.6					
		α	+10°, -0°	+10°, -5°					
M = ALUMINUM (SEE 4.9)		ALL DIMENSIONS IN mm							

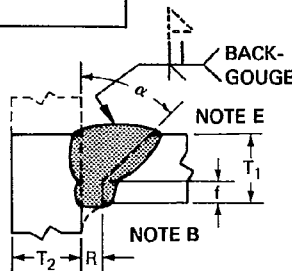
Welding Process	Joint Designation	Base Metal Thickness (U = Unlimited)		Groove Preparation			Suggested Welding Positions	Notes
		T ₁	T ₂	Root Opening (R)	Root Face (f)	Groove Angle (α)		
GMAW	TC-U4a	U	U	10	0 to 1.6	60°	All	B, E, F
GTAW	TC-L4a	12.7 max	12.7 max	10	0 to 1.6	60°	All	B, E, F

Note B: If fillet welds are used in statically loaded structures to reinforce groove welds in corner and T-joints, they shall be equal to $1/4 T_1$, but need not exceed 10 mm. Groove welds in corner and T-joints in dynamically loaded structures shall be reinforced with fillet welds equal to $1/4 T_1$ but need not exceed 10 mm.

Note E: For corner joints, the outside groove preparation may be in either or both members, provided the basic groove configuration is not changed and adequate edge distance is maintained to support the welding operations without excessive edge melting.

Note F: In the horizontal position the bevel should be on the upper member.

**Figure B1 (continued) — Recommended Complete Joint Penetration
Groove Welded Joints (Millimeters)**

Single-bevel-groove weld (4) T-joint (T) Corner joint (C)		Tolerances		
		As Detailed (see 2.9.3)	As Fit Up (see 3.3)	
	R	+1.6, -0	±1.6	
	f	+1.6, -0	±1.6	
	α	+10°, -0°	+10°, -5°	
ALL DIMENSIONS IN mm				

Welding Process	Joint Designation	Base Metal Thickness (U = unlimited)		Groove Preparation			Suggested Welding Positions	Notes
		T ₁	T ₂	Root Opening (R)	Root Face (f)	Groove Angle (α)		
GMAW	TC-U4b	U	U	0 to 2	1.6 to 3	60°	All	A, B, E, F
GTAW	TC-L4b	12.7 max	12.7 max	0 to 2	1.6 to 3	60°	All	A, B, E, F

Note A: Backgouge root of joint to sound metal before welding the other side.

Note B: If fillet welds are used in statically loaded structures to reinforce groove welds in corner and T-joints, they shall be equal to $1/4 T_1$, but need not exceed 10 mm. Groove welds in corner and T-joints in dynamically loaded structures shall be reinforced with fillet welds equal to $1/4 T_1$ but need not exceed 10 mm.

Note E: For corner joints, the outside groove preparation may be in either or both members, provided the basic groove configuration is not changed and adequate edge distance is maintained to support the welding operations without excessive edge melting.

Note F: In the horizontal position the bevel should be on the upper member.

**Figure B1 (continued) — Recommended Complete Joint Penetration
Groove Welded Joints (Millimeters)**

Single-bevel-groove weld (4)
T-joint (T)
Corner joint (C)

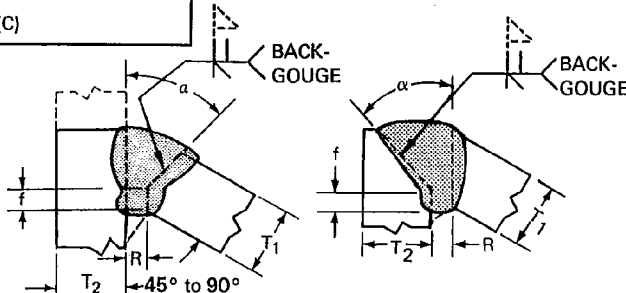
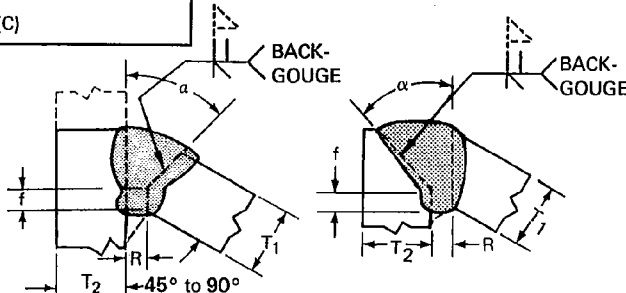
NOTE E

M = ALUMINUM (SEE 4.9)

Tolerances		
	As Detailed (see 2.9.3)	As Fit Up (see 3.3)
R	+1.6, -0	+6, -1.6
f	+1.6, -0	±1.6
α	+10°, -0°	+10°, -5°

ALL DIMENSIONS IN mm

Welding Process	Joint Designation	Base Metal Thickness (U = unlimited)		Groove Preparation			Suggested Welding Positions	Notes
		T ₁	T ₂	Root Opening (R)	Root Face (f)	Groove Angle (α)		
GMAW	TC-U4c	U	U	10	1.6	60°	All	B, E
GTAW	TC-L4c	12.7 max	12.7 max	10	1.6	60°	All	B, E

Single-bevel-groove weld (4) T-joint (T) Corner joint (C)				Tolerances	
				As Detailed (see 2.9.3)	As Fit Up (see 3.3)
		R	+1.6, -0	±1.6	
		f	+1.6, -0	±1.6	
		α	+10°, -0°	+10°, -5°	

ALL DIMENSIONS IN mm

Welding Process	Joint Designation	Base Metal Thickness (U = unlimited)		Groove Preparation			Suggested Welding Positions	Notes
		T ₁	T ₂	Root Opening (R)	Root Face (f)	Groove Angle (α)		
GMAW	TC-U4d	U	U	0 to 2	1.6 to 3	60°	All	A, B, E, F
GTAW	TC-L4d	12.7 max	12.7 max	0 to 2	1.6 to 3	60°	All	A, B, E, F

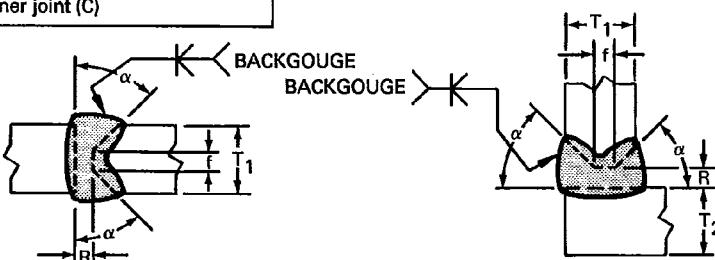
Note A: Backgouge root of joint to sound metal before welding the other side.

Note B: If fillet welds are used in statically loaded structures to reinforce groove welds in corner and T-joints, they shall be equal to $1/4 T_1$, but need not exceed 10 mm. Groove welds in corner and T-joints in dynamically loaded structures shall be reinforced with fillet welds equal to $1/4 T_1$ but need not exceed 10 mm.

Note E: For corner joints, the outside groove preparation may be in either or both members, provided the basic groove configuration is not changed and adequate edge distance is maintained to support the welding operations without excessive edge melting.

Note F: In the horizontal position the bevel should be on the upper member.

Figure B1 (continued) — Recommended Complete Joint Penetration Groove Welded Joints (Millimeters)

Double-bevel-groove weld (5) Butt joint (B) T-joint (T) Corner joint (C)		Tolerances		
		As Detailed (see 2.9.3)	As Fit Up (see 3.3)	
		R	+1.6, -0	±1.6
		f	+1.6, -0	±1.6
		α	+10°, -0°	+10°, -5°
ALL DIMENSIONS IN mm				

Welding Process	Joint Designation	Base Metal Thickness (U = unlimited)		Groove Preparation			Suggested Welding Positions	Notes
		T ₁	T ₂	Root Opening (R)	Root Face (f)	Groove Angle (α)		
GMAW	B-U5a	U, preferably 15.9 or thicker	—	0 to 1.6	1.6 to 3	60°	All	A, D
	TC-U5a	U, preferably 15.9 or thicker	U	0 to 1.6	1.6 to 3	60°	All	A, B, D, E

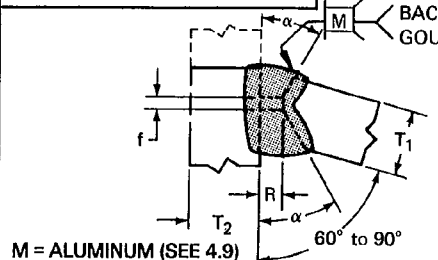
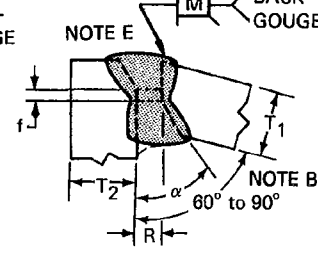
Note A: Backgouge root of joint to sound metal before welding the other side.

Note B: If fillet welds are used in statically loaded structures to reinforce groove welds in corner and T-joints, they shall be equal to $1/4 T_1$, but need not exceed 10 mm. Groove welds in corner and T-joints in dynamically loaded structures shall be reinforced with fillet welds equal to $1/4 T_1$ but need not exceed 10 mm.

Note D: Double-groove welds may have grooves of unequal depth, but the depth of the shallower groove shall be no less than one-fourth of the thickness of the thinner part joined.

Note E: For corner joints, the outside groove preparation may be in either or both members, provided the basic groove configuration is not changed and adequate edge distance is maintained to support the welding operations without excessive edge melting.

**Figure B1 (continued) — Recommended Complete Joint Penetration
Groove Welded Joints (Millimeters)**

Double-bevel-groove weld (5) T-joint (T) Corner joint (C)						<table><tr><th colspan="3">Tolerances</th></tr><tr><th></th><th>As Detailed (see 2.9.3)</th><th>As Fit Up (see 3.3)</th></tr><tr><td>R</td><td>+1.6, -0</td><td>+6, -1.6</td></tr><tr><td>f</td><td>+1.6, -0</td><td>±1.6</td></tr><tr><td>α</td><td>+10°, -0°</td><td>+10°, -5°</td></tr></table>		Tolerances				As Detailed (see 2.9.3)	As Fit Up (see 3.3)	R	+1.6, -0	+6, -1.6	f	+1.6, -0	±1.6	α	+10°, -0°	+10°, -5°
Tolerances																						
	As Detailed (see 2.9.3)	As Fit Up (see 3.3)																				
R	+1.6, -0	+6, -1.6																				
f	+1.6, -0	±1.6																				
α	+10°, -0°	+10°, -5°																				
M = ALUMINUM (SEE 4.9)		ALL DIMENSIONS IN mm																				

Welding Process	Joint Designation	Base Metal Thickness (U = unlimited)		Groove Preparation			Suggested Welding Positions	Notes
		T ₁	T ₂	Root Opening (R)	Root Face (f)	Groove Angle (α)		
GMAW	TC-U5c	U, preferably 15.9 or thicker	U	0 to 10	1.6 to 3	60°	All	A, B, D, E
GTAW	TC-L5a	12.7 max	12.7 max	0 to 10	1.6 to 3	60°	All	A, B, D, E

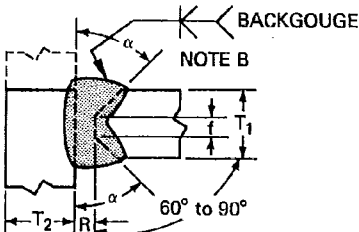
Note A: Backgouge root of joint to sound metal before welding the other side.

Note B: If fillet welds are used in statically loaded structures to reinforce groove welds in corner and T-joints, they shall be equal to $1/4 T_1$, but need not exceed 10 mm. Groove welds in corner and T-joints in dynamically loaded structures shall be reinforced with fillet welds equal to $1/4 T_1$ but need not exceed 10 mm.

Note D: Double-groove welds may have grooves of unequal depth, but the depth of the shallower groove shall be no less than one-fourth of the thickness of the thinner part joined.

Note E: For corner joints, the outside groove preparation may be in either or both members, provided the basic groove configuration is not changed and adequate edge distance is maintained to support the welding operations without excessive edge melting.

Figure B1 (continued) — Recommended Complete Joint Penetration Groove Welded Joints (Millimeters)

Double-bevel-groove weld (5) T-joint (T) Corner joint (C)					Tolerances			
		As Detailed (see 2.9.3)		As Fit Up (see 3.3)				
		R	+1.6, -0	±1.6				
		f	+1.6, -0	±1.6				
		α	+10°, -0°	+10°, -5°				
ALL DIMENSIONS IN mm								
Welding Process	Joint Designation	Base Metal Thickness (U = unlimited)		Groove Preparation			Suggested Welding Positions	Notes
		T ₁	T ₂	Root Opening (R)	Root Face (f)	Groove Angle (α)		
GMAW	TC-U5b	U, preferably 15.9 or thicker	U	0 to 2	1.6 to 3	60°	All	A, B, D, E

Note A: Backgouge root of joint to sound metal before welding the other side.

Note B: If fillet welds are used in statically loaded structures to reinforce groove welds in corner and T-joints, they shall be equal to $1/4 T_1$, but need not exceed 10 mm. Groove welds in corner and T-joints in dynamically loaded structures shall be reinforced with fillet welds equal to $1/4 T_1$ but need not exceed 10 mm.

Note D: Double-groove welds may have grooves of unequal depth, but the depth of the shallower groove shall be no less than one-fourth of the thickness of the thinner part joined.

Note E: For corner joints, the outside groove preparation may be in either or both members, provided the basic groove configuration is not changed and adequate edge distance is maintained to support the welding operations without excessive edge melting.

Figure B1 (continued) — Recommended Complete Joint Penetration Groove Welded Joints (Millimeters)

Single-U-groove weld (6)
Butt joint (B)
Corner joint (C)

The image contains three technical diagrams illustrating Single-U-groove welds. The first diagram on the left shows a butt joint (B) with a 'TEMPORARY REMOVABLE BACKING' indicated by an arrow and the text '(SEE 4.9.5)'. The second diagram in the middle shows a butt joint (B) with dimensions: root opening (R), root face (f), groove angle (α), and groove radius (r). It also shows 'BACK-GOUGE' on the back side and a dimension T₁ for the backing. The third diagram on the right shows a corner joint (C) with dimensions: root opening (R), root face (f), groove angle (α), and groove radius (r). It also shows 'BACK-GOUGE' on the back side and dimensions T₁ and T₂ for the backing. A 'NOTE B' points to the corner joint.

	Tolerances	
	As Detailed (see 2.9.3)	As Fit Up (see 3.3)
R	+1.6, -0	±1.6
f	+1.6, -0	±1.6
α	+10°, -0°	+10°, -5°
r	+3, -0	±1.6

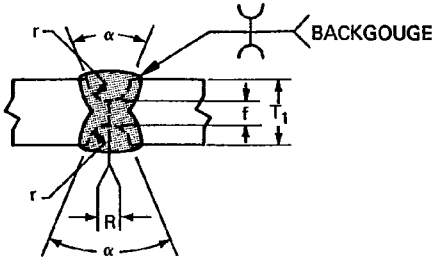
ALL DIMENSIONS IN mm

Welding Process	Joint Designation	Base Metal Thickness (U = unlimited)		Groove Preparation				Suggested Welding Positions	Notes
		T ₁	T ₂	Root Opening (R)	Root Face (f)	Groove Angle (α)	Groove Radius (r)		
GMAW	B-U6	U, preferably 15.9 or thicker	—	0 to 2	3 to 6	60°	6	All	A
	C-U6	U, preferably 15.9 or thicker	U	0 to 2	3 to 6	60°	6	All	A, B

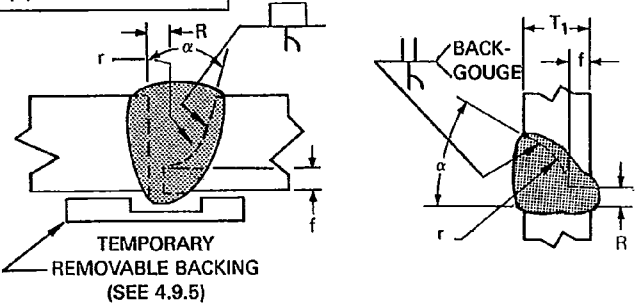
Note A: Backgouge root of joint to sound metal before welding the other side.

Note B: If fillet welds are used in statically loaded structures to reinforce groove welds in corner and T-joints, they shall be equal to $1/4 T_1$, but need not exceed 10 mm. Groove welds in corner and T-joints in dynamically loaded structures shall be reinforced with fillet welds equal to $1/4 T_1$ but need not exceed 10 mm.

**Figure B1 (continued) — Recommended Complete Joint Penetration
Groove Welded Joints (Millimeters)**

Double-U-groove weld (7) Butt joint (B)		Tolerances		
		As Detailed (see 2.9.3)	As Fit Up (see 3.3)	
		R	+1.6, -0	±1.6
		f	+1.6, -0	±1.6
		α	+10°, -0°	+10°, -5°
		r	+3, -0	±1.6
ALL DIMENSIONS IN mm				

Welding Process	Joint Designation	Base Metal Thickness (U = unlimited)	Groove Preparation				Suggested Welding Positions	Notes
		T ₁	Root Opening (R)	Root Face (f)	Groove Angle (α)	Groove Radius (r)		
GMAW	B-U7	U, preferably 15.9 or thicker	0 to 2	3 to 6	60°	6	All	A, D

Single-J-groove weld (8) Butt joint (B)		Tolerances		
		As Detailed (see 2.9.3)	As Fit Up (see 3.3)	
		R	+1.6, -0	±1.6
		f	+1.6, -0	±1.6
		α	+10°, -0°	+10°, -5°
		r	+3, -0	±1.6
ALL DIMENSIONS IN mm				

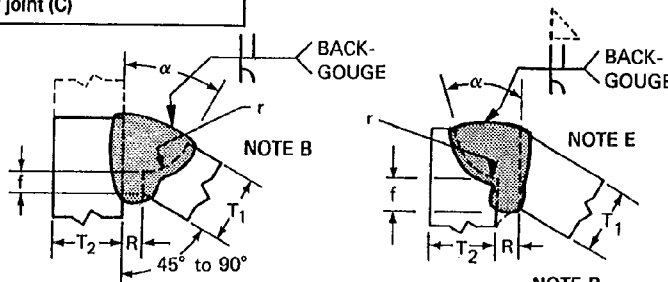
Welding Process	Joint Designation	Base Metal Thickness (U = unlimited)	Groove Preparation				Suggested Welding Positions	Notes
		T ₁	Root Opening (R)	Root Face (f)	Groove Angle (α)	Groove Radius (r)		
GMAW	B-U8	U, preferably 15.9 or thicker	0 to 2	3 to 6	60°	10	All	A, F

Note A: Backgouge root of joint to sound metal before welding other side.

Note D: Double-groove welds may have grooves of unequal depth, but the depth of the shallower groove shall be no less than one-fourth of the thickness of the thinner part joined.

Note F: In the horizontal position the bevel should be on the upper member.

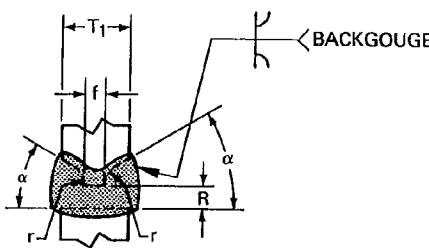
**Figure B1 (continued) — Recommended Complete Joint Penetration
Groove Welded Joints (Millimeters)**

Single-J-groove weld (8) T-joint (T) Corner joint (C)					<table><tr><td></td><td colspan="2">Tolerances</td></tr><tr><td></td><td>As Detailed (see 2.9.3)</td><td>As Fit Up (see 3.3)</td></tr><tr><td>R</td><td>+1.6, -0</td><td>±1.6</td></tr><tr><td>f</td><td>+1.6, -0</td><td>±1.6</td></tr><tr><td>α</td><td>+10°, -0°</td><td>+10°, -5°</td></tr><tr><td>r</td><td>+3, -0</td><td>±1.6</td></tr></table>				Tolerances			As Detailed (see 2.9.3)	As Fit Up (see 3.3)	R	+1.6, -0	±1.6	f	+1.6, -0	±1.6	α	+10°, -0°	+10°, -5°	r	+3, -0	±1.6
	Tolerances																								
	As Detailed (see 2.9.3)	As Fit Up (see 3.3)																							
R	+1.6, -0	±1.6																							
f	+1.6, -0	±1.6																							
α	+10°, -0°	+10°, -5°																							
r	+3, -0	±1.6																							
		ALL DIMENSIONS IN mm																							
Welding Process	Joint Designation	Base Metal Thickness (U = unlimited)		Groove Preparation				Suggested Welding Positions	Notes																
		T ₁	T ₂	Root Opening (R)	Root Face (f)	Groove Angle (α)	Groove Radius (r)																		
GMAW	TC-U8a	U, preferably 15.9 or thicker	—	0 to 2	3	60°	10	All	A, B, E																

Note A: Backgouge root of joint to sound metal before welding the other side.

Note B: If fillet welds are used in statically loaded structures to reinforce groove welds in corner and T-joints, they shall be equal to $1/4 T_1$, but need not exceed 10 mm. Groove welds in corner and T-joints in dynamically loaded structures shall be reinforced with fillet welds equal to $1/4 T_1$ but need not exceed 10 mm.

Note E: For corner joints, the outside groove preparation may be in either or both members, provided the basic groove configuration is not changed and adequate edge distance is maintained to support the welding operations without excessive edge melting.

Double-J-groove weld (9) Butt joint (B)				
		Tolerances		
		As Detailed (see 2.9.3)	As Fit Up (see 3.3)	
R		+1.6, -0	± 1.6	
f		+1.6, -0	± 1.6	
α		+10°, -0°	+10°, -5°	
r		+3, -0	± 1.6	

ALL DIMENSIONS IN mm

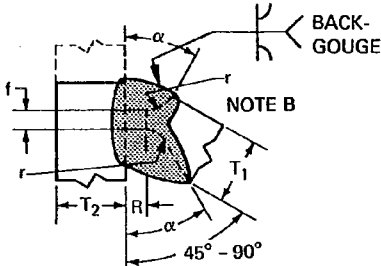
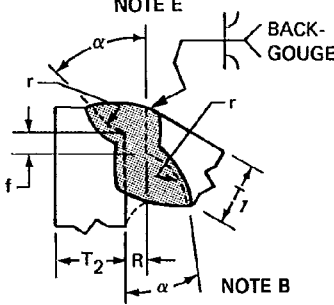
Welding Process	Joint Designation	Base Metal Thickness (U = unlimited)	Groove Preparation				Suggested Welding Positions	Notes
		T ₁	Root Opening (R)	Root Face (f)	Groove Angle (α)	Groove Radius (r)		
GMAW	B-U9	U, preferably 15.9 or thicker	0 to 2	3	60°	10	All	A, D, F

Note A: Backgouge root of joint to sound metal before welding the other side.

Note D: Double-groove welds may have grooves of unequal depth, but the depth of the shallower groove shall be no less than one-fourth of the thickness of the thinner part joined.

Note F: In the horizontal position the bevel should be on the upper member.

**Figure B1 (continued) — Recommended Complete Joint Penetration
Groove Welded Joints (Millimeters)**

Double-J-groove weld (9) T-joint (T) Corner joint (C)						Tolerances			
						As Detailed (see 2.9.3)	As Fit Up (see 3.3)		
	TC-U9a	U, preferably 15.9 or thicker	U	0 to 2	3	60°	10	All	A, B, D, E, F

Note A: Backgouge root of joint to sound metal before welding other side.

Note B: If fillet welds are used in statically loaded structures to reinforce groove welds in corner and T-joints, they shall be equal to $1/4 T_1$, but need not exceed 10 mm. Groove welds in corner and T-joints in dynamically loaded structures shall be reinforced with fillet welds equal to $1/4 T_1$ but need not exceed 10 mm.

Note D: Double-groove welds may have grooves of unequal depth, but the depth of the shallower groove shall be no less than one-fourth of the thickness of the thinner part joined.

Note E: For corner joints, the outside groove preparation may be in either or both members, provided the basic groove configuration is not changed and adequate edge distance is maintained to support the welding operations without excessive edge melting.

Note F: In the horizontal position the bevel should be on the upper member.

**Figure B1 (continued)—Recommended Complete Joint Penetration
Groove Welded Joints (Millimeters)**

Square-groove weld (1)
Butt joint (B)
Corner joint (C)

Welding Process	Joint Designation	Base Metal Thickness (U = unlimited)		Groove Preparation			*Suggested Welding Positions	Weld Size (E)	Notes	
				Root Opening (R)	Tolerances					
		T ₁	T ₂		As Detailed (see 2.10.3)	As Fit Up (see 3.3)				
GMAW	B-P1a	1/4 max	—	0 to 1/16	+1/16, -0	±1/16	All	$\frac{3T_1}{4}$	H, I	
	C-P1a	1/4 max	U		+1/16, -0	±1/16	All			
GTAW	B-P1a	1/8	—	0 to 1/16	+1/16, -0	±1/16	H, OH	$\frac{3T_1}{4}$	H, I	
	C-P1a	1/8	1/2 max		+1/16, -0	±1/16	All			

Note H: Joints welded from one side. These welds are not applicable to dynamically loaded structures.

Note I: If fillet welds are used to reinforce partial penetration groove welds in corner joints, they should be equal to $1/4T_1$, but need not exceed $3/8$ in. They are not considered in the design strength of the joint.

*H = horizontal, OH = overhead.

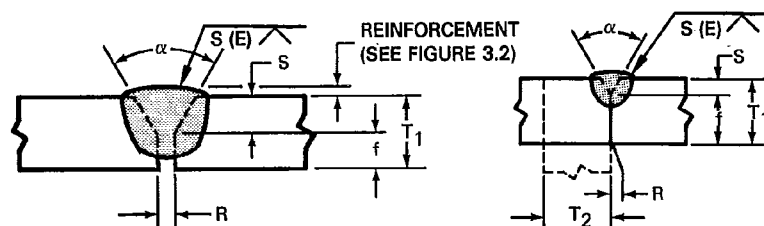
Figure B2 — Recommended Partial Joint Penetration Groove Welded Joints (Inches)

Square-groove weld (1)
Butt joint (B)

$$E_1 + E_2 \text{ MUST NOT EXCEED } \frac{3T_1}{4}$$

The diagram illustrates a square-groove weld butt joint. Two plates, each with a thickness of T_1 , are joined by a square-groove weld. The weld has a root opening of R . Reinforcement is shown on both sides of the weld, with dimensions E_1 and E_2 . A note points to the reinforcement: REINFORCEMENT (SEE FIGURE 3.2).

Welding Process	Joint Designation	Base Metal Thickness	Groove Preparation		Suggested Welding Positions	Weld Size (E)	Notes
			Root Opening (R)	Tolerances			
		T_1		As Detailed (see 2.10.3)	As Fit Up (see 3.3)		
GMAW	B-P1b	3/8 max	0 to 3/32	+1/16, -0	±1/16	All	$\frac{3T_1}{4}$ G

Single-V-groove weld (2) Butt joint (B) Corner joint (C)		Tolerances		
		As Detailed (see 2.10.3)	As Fit Up (see 3.3)	
		R	+1/16, -0	±1/16
		f	+1/16, -0	±1/16
		α	+10°, -0°	+10°, -5°

Welding Process	Joint Designation	Base Metal Thickness (U = unlimited)		Groove Preparation			Suggested Welding Positions	Weld Size (E)	Notes
		T ₁	T ₂	Root Opening (R)	Root Face (f)	Groove Angle (α)			
GMAW	BC-P2	1/4 min	U	0 to 1/16	1/16 min	60°	All	S	H, I, J
GTAW	BC-P2	1/8 min 1/2 max	1/2 max	0 to 1/16	1/16 min	60°	All	S	H, I, J

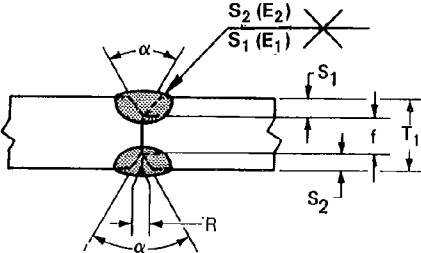
Note G: Root need not be backgouged before welding second side. This joint is not applicable to dynamically loaded structures..

Note H: Joints welded from one side. These welds are not applicable to dynamically loaded structures.

Note I: If fillet welds are used to reinforce partial penetration groove welds in corner joints, they should be equal to $1/4T_1$, but need not exceed 3/8 in. They are not considered in the design strength of the joint.

Note J: Minimum weld size (E) as shown in Table 2.1 and as specified on drawings.

Figure B2 (continued)—Recommended Partial Joint Penetration Groove Welded Joints (Inches)

Double-V-groove weld (3) Butt joint (B)						<table><tr><th rowspan="2"></th><th colspan="2">Tolerances</th></tr><tr><th>As Detailed (see 2.10.3)</th><th>As Fit Up (see 3.3)</th></tr><tr><td>R</td><td>+1/16, -0</td><td>±1/16</td></tr><tr><td>f</td><td>±0</td><td>±1/16</td></tr><tr><td>α</td><td>+10°, -0°</td><td>+10°, -5°</td></tr></table>				Tolerances		As Detailed (see 2.10.3)	As Fit Up (see 3.3)	R	+1/16, -0	±1/16	f	±0	±1/16	α	+10°, -0°	+10°, -5°
	Tolerances																					
	As Detailed (see 2.10.3)	As Fit Up (see 3.3)																				
R	+1/16, -0	±1/16																				
f	±0	±1/16																				
α	+10°, -0°	+10°, -5°																				

Welding Process	Joint Designation	Base Metal Thickness	Groove Preparation			Suggested Welding Positions	Weld Size (E)	Notes
		T1	Root Opening (R)	Root Face (f)	Groove Angle (α)			
GMAW	B-P3	3/8 min	0 to 1/16	1/16 min	60°	All	S1+S2	J, K
GTAW	B-P3	1/8 min 1/2 max	0 to 1/16	1/16 min	60°	All	S1+S2	J, K

Note J: Minimum weld size (E) as shown in Table 2.1 and as specified on drawings.

Note K: Double-groove welds may have grooves of unequal depth, provided they conform to the limitations of Note J. Also, the weld size (E) less any reduction, applies individually to each groove.

Single-bevel-groove weld (4)
Butt joint (B)
T-joint (T)
Corner joint (C)

NOTE I

Tolerances

As Detailed
(see 2.10.3)

As Fit Up
(see 3.3)

R

+1/16, -0

±1/16

f

± 0

±1/16

α

+10°, -0°

+10°, -5°

Welding
Process

Joint
Designation

Base
Metal Thickness
(U = unlimited)

T₁

T₂

Groove Preparation

Root
Opening
(R)

Root
Face
(f)

Groove
Angle
(α)

*Suggested
Welding
Positions

Weld
Size
(E)

Notes

GMAW

BTC-P4

1/4 min

U

0 to 1/16

1/16 min

60°

F, V

S

E, H, I, J, L

H, OH

S-1/8

GTAW

BTC-P4

1/8 min
1/2 max

1/2 max

0 to 1/16

1/16 min

60°

All

S-1/8

E, H, I, J, L

Note E: For corner joints, the outside groove preparation may be in either or both members, provided the basic groove configuration is not changed and adequate edge distance is maintained to support the welding operations without excessive edge melting.

Note H: Joints welded from one side. These welds are not applicable to dynamically loaded structures.

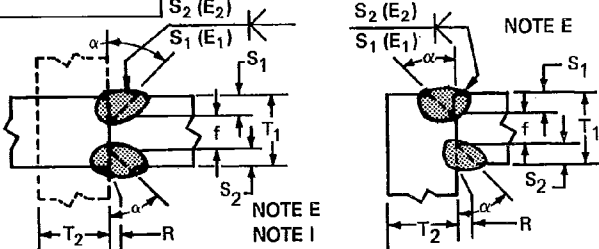
Note I: If fillet welds are used in buildings to reinforce groove welds in corner joints and T-joints, they should be equal to 1/4T₁, but need not exceed 3/8 in. They are not considered in the design strength of the joint.

Note J: Minimum weld size (E) as shown in Table 2.1 or as specified on drawings.

Note L: Unbeveled face is lower edge for horizontal weld.

*F = flat, V = vertical, H = horizontal, OH = overhead.

**Figure B2 (continued) — Recommended Partial Joint Penetration
Groove Welded Joints (Inches)**

Double-bevel-groove weld (5) Butt joint (B) T-joint (T) Corner joint (C)		Tolerances		
		As Detailed (see 2.10.3)	As Fit Up (see 3.3)	
		R	+1/16, -0	±1/16
		f	+1/16, -0	±1/16
		α	+10°, -0°	+10°, -5°

Welding Process	Joint Designation	Base Metal Thickness (U = unlimited)		Groove Preparation			*Suggested Welding Positions	Weld Size (E)	Notes
		T ₁	T ₂	Root Opening (R)	Root Face (f)	Groove Angle (α)			
GMAW	BT&P5	3/8 min	U	0 to 1/16	1/16 min	60°	F, V	S ₁ +S ₂	E, I, J, K
							H, OH	(S ₁ + S ₂) - 1/8	
GTAW	TC-P5	1/8 min 1/2 max	1/2 max	0 to 1/16	1/16 min	60°	All	(S ₁ + S ₂) - 1/8	E, I, J, K

Note E: For corner joints, the outside groove preparation may be in either or both members, provided the basic groove configuration is not changed and adequate edge distance is maintained to support the welding operation without excessive edge melting.

Note I: If fillet welds are used in statically loaded structures to reinforce groove welds in corner and T-joints, they should be equal to $1/4T_1$, but need not exceed $3/8$ in. They are not considered in the design strength of the joint.

Note J: Minimum weld size (E) as shown in Table 2.1 or as specified on drawings.

Note K: Double-groove welds may have grooves of unequal depth, provided they conform to the limitations of Note J. Also the weld size (E), less any reduction, applies individually to each groove.

*F = flat, V = vertical, H = horizontal, OH = overhead.

Figure B2 (continued) — Recommended Partial Joint Penetration Groove Welded Joints (Inches)

Single-U-groove weld (6) Butt joint (B) Corner joint (C)								Tolerances	
								As Detailed (see 2.10.3)	As Fit Up (see 3.3)
								R	$+1/16, -0$
								f	± 0
								α	$+10^\circ, -0^\circ$
								r	$+1/8, -0$

Welding Process	Joint Designation	Base Metal Thickness (U = unlimited)		Groove Preparation				Suggested Welding Positions	Weld Size (E)	Notes
		T ₁	T ₂	Root Opening (R)	Root Face (f)	Groove Angle (α)	Groove Radius (r)			
GMAW	BC-P6	1/4 min	U	0 to 1/16	1/16 min	60°	1/4	All	S	J, H

Double-U-groove weld (7) Butt joint (B)								Tolerances	
								As Detailed (see 2.10.3)	As Fit Up (see 3.3)
								R	$+1/16, -0$
								f	± 0
								α	$+10^\circ, -0^\circ$
								r	$+1/8, -0$

Welding Process	Joint Designation	Base Metal Thickness		Groove Preparation				Suggested Welding Positions	Weld Size (E)	Notes
		T ₁	T ₂	Root Opening (R)	Root Face (f)	Groove Angle (α)	Groove Radius (r)			
GMAW	B-P7	3/8 min		0 to 1/16	1/16 min	60°	1/4	All	S ₁ + S ₂	J, K

Note H: Joints welded from one side. These welds are not applicable to dynamically loaded structures.

Note J: Minimum weld size (E) as shown in Table 2.1 or as specified on drawings.

Note K: Double-groove welds may have grooves of unequal depth, provided they conform to the limitations of Note J. Also the weld size (E), less any reduction, applies individually to each groove.

**Figure B2 (continued) — Recommended Partial Joint Penetration
Groove Welded Joints (Inches)**

		Tolerances	
		As Detailed (see 2.10.3)	As Fit Up (see 3.3)
Single-J-groove weld (8) Butt joint (B) T-joint (T) Corner joint (C)	R	+1/16, -0	±1/16
	f	±0	±1/16
	α	+10°, -0°	+10°, -5°
	r	+1/8, -0	±1/16

Welding Process	Joint Designation	Base Metal Thickness (U = unlimited)		Groove Preparation				Suggested Welding Positions	Weld Size (E)	Notes
		T ₁	T ₂	Root Opening (R)	Root Face (f)	Groove Angle (α)	Groove Radius (r)			
GMAW	BTC-P8	1/4 min	U	0 to 1/16	1/16 min	60°	3/8	All	S	E, J, H

Note E: For corner joints, the outside groove preparation may be in either or both members, provided the basic groove configuration is not changed and adequate edge distance is maintained to support the welding operations without excessive edge melting.

Note H: Joints welded from one side. These welds are not applicable to dynamically loaded structures.

Note J: Minimum weld size (E) as shown in Table 2.1 or as specified on drawings.

		Tolerances	
		As Detailed (see 2.10.3)	As Fit Up (see 3.3)
Double-J-groove weld (9) Butt joint (B) T-joint (T) Corner joint (C)	R	+1/16, -0	±1/16
	f	±0	±1/16
	α	+10°, -0°	+10°, -5°
	r	+1/8, -0	±1/16

Welding Process	Joint Designation	Base Metal Thickness (U = unlimited)		Groove Preparation				Suggested Welding Positions	Weld Size (E)	Notes
		T ₁	T ₂	Root Opening (R)	Root Face (f)	Groove Angle (α)	Groove Radius (r)			
GMAW	BTC-P9	3/8 min	U	0 to 1/16	1/16 min	60°	3/8	All	S ₁ +S ₂	E, I, J, K

Note E: For corner joints, the outside groove preparation may be in either or both members, provided the basic groove configuration is not changed and adequate edge distance is maintained to support the welding operations without excessive edge melting.

Note I: If fillet welds are used in statically loaded structures to reinforce groove welds in corner or T-joints, they should be equal to 1/4T₁, but need not exceed 3/8 in. They are not considered in the design strength of the joint.

Note J: Minimum weld size (E) as shown in Table 2.1 or as specified on drawings.

Note K: Double-groove welds may have grooves of unequal depth, provided they conform to the limitations of Note J. Also the weld size (E), less any reduction, applies individually to each groove.

Figure B2 (continued) — Recommended Partial Joint Penetration Groove Welded Joints (Inches)

Square-groove weld (1)
Butt joint (B)
Corner joint (C)

ALL DIMENSIONS IN mm

Welding Positions	Joint Designation	Base Metal Thickness (U = unlimited)		Groove Preparation		Suggested Welding Positions	Weld Size (E)	Notes
				Root Opening (R)	Tolerances			
		T ₁	T ₂		As Detailed (see 2.10.3)	As Fit Up (see 3.3)		
GMAW	B-P1a	6.4 max	—	0 to 1.6	+1.6, -0	± 1.6	All	$\frac{3T_1}{4}$ H, I
	C-P1a	6.4 max	U		+1.6, -0	± 1.6	All	
GTAW	B-P1a	3.2	—	0 to 1.6	+1.6, -0	± 1.6	H, OH	$\frac{3T_1}{4}$ H, I
	C-P1a	3.2	12.7 max		+1.6, -0	± 1.6	All	

Note H: Joints welded from one side. These welds are not applicable to dynamically loaded structures.

Note I: If fillet welds are used to reinforce partial penetration groove welds in corner joints, they should be equal to $1/4T$ but need not exceed 10 mm. They are not considered in the design strength of the joint.

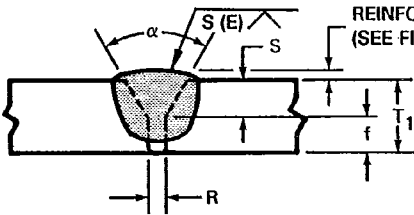
Figure B2 (continued) — Recommended Partial Joint Penetration Groove Welded Joints (Millimeters)

Square-groove weld (1)
Butt joint (B)

E₁ + E₂ MUST NOT EXCEED $\frac{3T_1}{4}$

ALL DIMENSIONS IN mm

Welding Positions	Joint Designation	Base Metal Thickness T ₁	Groove Preparation			Suggested Welding Positions	Weld Size (E)	Notes			
			Root Opening (R)	Tolerances							
				As Detailed (see 2.10.3)	As Fit Up (see 3.3)						
GMAW	B-P1b	9.5 max	0 to 2	+1.6, -0	±1.6	All	$\frac{3T_1}{4}$	G			

Single-V-groove weld (2) Butt joint (B) Corner joint (C)		Tolerances		
		As Detailed (see 2.10.3)	As Fit Up (see 3.3)	
	R	+1.6, -0	±1.6	
	f	+1.6, -0	±1.6	
	α	+10°, -0°	+10°, -5°	

ALL DIMENSIONS IN mm

Welding Process	Joint Designation	Base Metal Thickness (U = unlimited)		Groove Preparation			Suggested Welding Positions	Weld Size (E)	Notes
		T ₁	T ₂	Root Opening (R)	Root Face (f)	Groove Angle (α)			
GMAW	BC-P2	6.4 min	—	0 to 1.6	1.6 min	60°	All	S	H,I,J
GTAW	BC-P2	3.2 min 12.7 max	12.7 max	0 to 1.6	1.6 min	60°	All	S	H,I,J

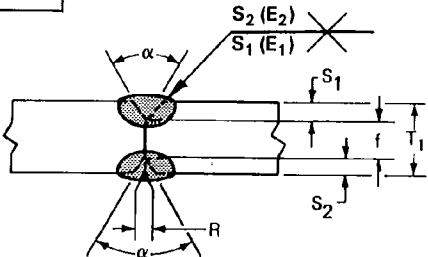
Note G: Root need not be backgouged before welding second side. This joint is not applicable to dynamically loaded structures.

Note H: Joints welded from one side. These welds are not applicable to dynamically loaded structures.

Note I: If fillet welds are used to reinforce partial penetration groove welds in corner joints, they should be equal to $1/4T_1$ but need not exceed 10 mm. They are not considered in the design strength of the joint.

Note J: Minimum weld size (E) as shown in Table 2.1 and as specified on drawings.

Figure B2 (continued) — Recommended Partial Joint Penetration Groove Welded Joints (Millimeters)

Double-V-groove weld (3) Butt joint (B)			Tolerances		
			As Detailed (see 2.10.3)	As Fit Up (see 3.3)	
R	+1.6, -0		±1.6		
f	±0		±1.6		
α	+10°, -0°	+10°, -5°			

ALL DIMENSIONS IN mm

Welding Process	Joint Designation	Base Metal Thickness	Groove Preparation			Suggested Welding Positions	Weld Size (E)	Notes
		T ₁	Root Opening (R)	Root Face (f)	Groove Angle (α)			
GMAW	B-P3	9.5 min	0 to 1.6	1.6 min	60°	All	S ₁ +S ₂	J,K
GTAW	B-P3	3.2 min 12.7 max	0 to 1.6	1.6 min	60°	All	S ₁ +S ₂	J,K

Note J: Minimum weld size (E) as shown in Table 2.1 and as specified on drawings.

Note K: Double-groove welds may have grooves of unequal depth, provided they conform to the limitations of Note J. Also, the weld size (E) less any reduction, applies individually to each groove.

Single-bevel-groove weld (4)
Butt joint (B)
T-joint (T)
Corner joint (C)

NOTE I

	Tolerances	
	As Detailed (see 2.10.3)	As Fit Up (see 3.3)
R	+1.6, -0	±1.6
f	±0	±1.6
α	+10°, -0°	+10°, -5°

Welding Process	Joint Designation	Base Metal Thickness (U = unlimited)		Groove Preparation			*Suggested Welding Positions	Weld Size (E)	Notes
		T ₁	T ₂	Root Opening (R)	Root Face (f)	Groove Angle (α)			
GMAW	BTC-P4	6.4 min	U	0 to 1.6	1.6 min	60°	F,V	S	E,H,I,J,L
							H,OH	S-3	
GTAW	BTC-P4	3.2 min 12.7 max	12.7 max	0 to 1.6	1.6 min	60°	All	S-3	E,H,I,J,L

Note E: For corner joints, the outside groove preparation may be in either or both members, provided the basic groove configuration is not changed and adequate edge distance is maintained to support the welding operations without excessive edge melting.

Note H: Joints welded from one side. These welds are not applicable to dynamically loaded structures.

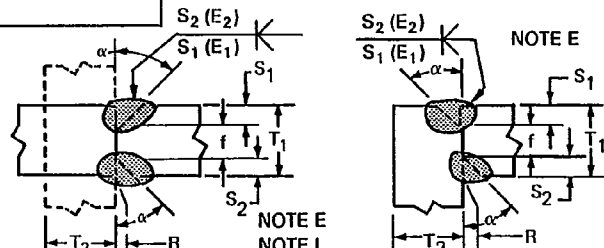
Note I: If fillet welds are used in buildings to reinforce groove welds in corner and T-joints, they should be equal to $1/4T_1$, but need not exceed 10 mm. They are not considered in the design strength of the joint.

Note J: Minimum weld size (E) as shown in Table 2.1 or as specified on drawings.

Note L: Unbeveled face is lower edge for horizontal weld.

*F = flat, V = vertical, H = horizontal, OH = overhead.

**Figure B2 (continued) — Recommended Partial Joint Penetration
Groove Welded Joints (Millimeters)**

Double-bevel-groove weld (5) Butt joint (B) T-joint (T) Corner joint (C)		Tolerances		
		As Detailed (see 2.10.3)	As Fit Up (see 3.3)	
		R	+1.6, -0	±1.6
		f	+1.6, -0	±1.6
		α	+10°, -0°	+10°, -5°
ALL DIMENSIONS IN mm				

Welding Process	Joint Designation	Base Metal Thickness (U = unlimited)		Groove Preparation			*Suggested Welding Positions	Weld Size (E)	Notes
		T ₁	T ₂	Root Opening (R)	Root Face (f)	Groove Angle (α)			
GMAW	BTC-P5	9.5 min	U	0 to 1.6	1.6 min	60°	F, V	S ₁ +S ₂	E, I, J, K
							H, OH	(S ₁ +S ₂)-3	
GTAW	TC-P5	3.2 min 12.7 max	12.7 max	0 to 1.6	1.6 min	60°	All	(S ₁ +S ₂)-3	E, I, J, K

Note E: For corner joints, the outside groove preparation may be in either or both members, provided the basic groove configuration is not changed and adequate edge distance is maintained to support the welding operation without excessive edge melting.

Note I: If fillet welds are used in statically loaded structures to reinforce groove welds in corner and T-joints, they should be equal to $1/4T_1$, but need not exceed 10 mm. They are not considered in the design strength of the joint.

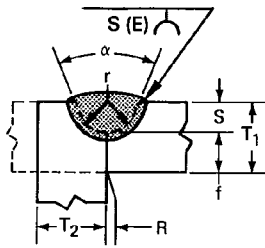
Note J: Minimum weld size (E) as shown in Table 2.1 or as specified on drawings.

Note K: Double-groove welds may have grooves of unequal depth, provided they conform to the limitations of Note J. Also, the weld size (E), less any reduction, applies individually to each groove.

*Flat = flat, H = horizontal, V = vertical, OH = overhead.

**Figure B2 (continued) — Recommended Partial Joint Penetration
Groove Welded Joints (Millimeters)**

Single-U-groove weld (6)
Butt joint (B)
Corner joint (C)

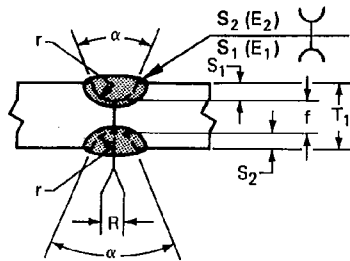


	Tolerances	
	As Detailed (see 2.10.3)	As Fit Up (see 3.3)
R	+1.6, -0	±1.6
f	±0	±1.6
α	+10°, -0°	+10°, -5°
r	+3, -0	±1.6

ALL DIMENSIONS IN mm

Welding Process	Joint Designation	Base Metal Thickness (U = unlimited)		Groove Preparation				Suggested Welding Positions	Weld Size (E)	Notes
		T ₁	T ₂	Root Opening (R)	Root Face (f)	Groove Angle (α)	Groove Radius (r)			
GMAW	BC-P6	6.4 min	U	0 to 1.6	1.6 min	60°	6	All	S	J, H

Double-U-groove weld (7)
Butt joint (B)



	Tolerances	
	As Detailed (see 2.10.3)	As Fit Up (see 3.3)
R	+1.6, -0	±1.6
f	±0	±1.6
α	+10°, -0°	+10°, -5°
r	+3, -0	±1.6

ALL DIMENSIONS IN mm

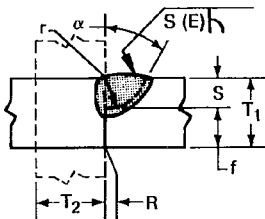
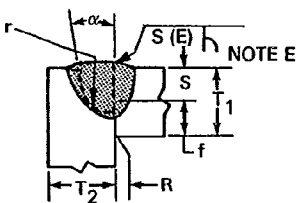
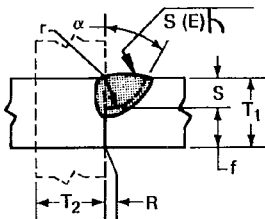
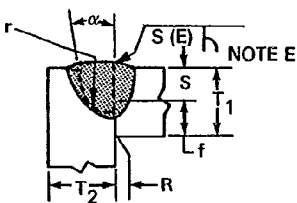
Welding Process	Joint Designation	Base Metal Thickness		Groove Preparation				Suggested Welding Positions	Weld Size (E)	Notes
		T ₁	T ₂	Root Opening (R)	Root Face (f)	Groove Angle (α)	Groove Radius (r)			
GMAW	B-P7	9.5 min	U	0 to 1.6	1.6 min	60°	6	All	S ₁ +S ₂	J, K

Note H: Joints welded from one side. These welds are not applicable to dynamically loaded structures.

Note J: Minimum weld size (E) as shown in Table 2.1 or as specified on drawings.

Note K: Double-groove welds may have grooves of unequal depth, provided they conform to the limitations of Note J. Also the weld size (E), less any reduction, applies individually to each groove.

**Figure B2 (continued) — Recommended Partial Joint Penetration
Groove Welded Joints (Millimeters)**

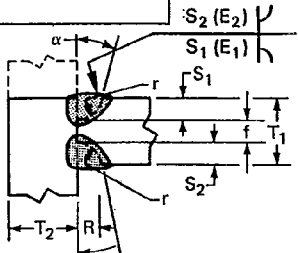
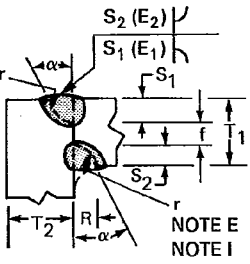
Single-J-groove weld (B) Butt joint (B) T-joint (T) Corner joint (C)						Tolerances		
						As Detailed (see 2.10.3)	As Fit Up (see 3.3)	
				R	+1.6, -0	±1.6		
				f	±0	±1.6		
				α	+10°, -0°	+10°, -5°		
				r	+3, -0	±1.6		
ALL DIMENSIONS IN mm								

Welding Process	Joint Designation	Base Metal Thickness (U = unlimited)		Groove Preparation				Suggested Welding Positions	Weld Size (E)	Notes
		T ₁	T ₂	Root Opening (R)	Root Face (f)	Groove Angle (α)	Groove Radius (r)			
GMAW	BTC-P8	6.4 min	U	0 to 1.6	1.6 min	60°	10	All	S	E, J, H

Note E: For corner joints, the outside groove preparation may be in either or both members, provided the basic groove configuration is not changed and adequate edge distance is maintained to support the welding operations without excessive edge melting.

Note H: Joints welded from one side. These welds are not applicable to dynamically loaded structures.

Note J: Minimum weld size (E) as shown in Table 2.1 or as specified on drawings.

Double-J-groove weld (9) Butt joint (B) T-joint (T) Corner joint (C)						<table><tr><th colspan="3">Tolerances</th></tr><tr><th></th><th>As Detailed (see 2.10.3)</th><th>As Fit Up (see 3.3)</th></tr><tr><td>R</td><td>+1.6, -0</td><td>±1.6</td></tr><tr><td>f</td><td>±0</td><td>±1.6</td></tr><tr><td>α</td><td>+10°, -0°</td><td>+10°, -5°</td></tr><tr><td>r</td><td>+3, -0</td><td>±1.6</td></tr></table>			Tolerances				As Detailed (see 2.10.3)	As Fit Up (see 3.3)	R	+1.6, -0	±1.6	f	±0	±1.6	α	+10°, -0°	+10°, -5°	r	+3, -0	±1.6
		Tolerances																								
	As Detailed (see 2.10.3)	As Fit Up (see 3.3)																								
R	+1.6, -0	±1.6																								
f	±0	±1.6																								
α	+10°, -0°	+10°, -5°																								
r	+3, -0	±1.6																								
ALL DIMENSIONS IN mm																										

Welding Process	Joint Designation	Base Metal Thickness (U = unlimited)		Groove Preparation				Suggested Welding Positions	Weld Size (E)	Notes
		T ₁	T ₂	Root Opening (R)	Root Face (f)	Groove Angle (α)	Groove Radius (r)			
GMAW	BTC-P9	9.5 min	U	0 to 1.6	1.6 min	60°	10	All	S ₁ +S ₂	E,I,J,K

Note E: For corner joints, the outside groove preparation may be in either or both members, provided the basic groove configuration is not changed and adequate edge distance is maintained to support the welding operations without excessive edge melting.

Note I: If fillet welds are used in statically loaded structures to reinforce groove welds in corner and T-joints, they should be equal to $1/4T_1$, but need not exceed 10 mm. They are not considered in the design strength of the joint.

Note J: Minimum weld size (E) as shown in Table 2.1 or as specified on drawings.

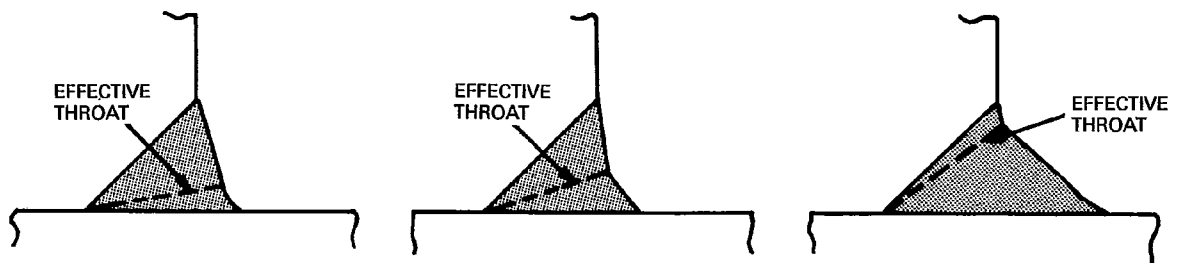
Note K: Double-groove welds may have grooves of unequal depth, provided they conform to the limitations of Note J. Also the weld size (E), less any reduction, applies individually to each groove.

Figure B2 (continued) — Recommended Partial Joint Penetration Groove Welded Joints (Millimeters)

Appendix C

Effective Throat

(This Appendix is not part of ANSI/AWS D1.2-90, *Structural Welding Code—Aluminum*, but is included for information purposes only)



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

Appendix D

Plug and Slot Welds

(This Appendix is not part of ANSI/AWS D1.2-90, *Structural Welding Code—Aluminum*, but is included for information purposes only.)

D1. Plug Welds

In making plug welds, the following technique may be used.

D1.1 For welds made in the flat and overhead positions, the arc is carried around the root of the joint and then carried along a spiral path to the center of the hole, fusing and depositing a layer of weld metal in the bottom of the hole. After the deposited layer has been cleaned, the arc is struck at the periphery of the hole and the procedure repeated, fusing and depositing successive layers to fill the hole to the required depth.

D1.2 For welds made in the vertical position, the arc is struck at the root of the joint, at the lower side of the hole, and carried upward along a zig-zag path, depositing a layer about 3/16 in. (5 mm) thick on the exposed surface of the inner member and fused to it and to the side of the hole. After cleaning the weld, additional layers are similarly deposited and cleaned to fill the hole to the required depth.

D2. Slot Welds

Slot welds shall be made with a technique similar to that specified for plug welds.

Appendix E

Sample Welding Forms

(This Appendix is not part of ANSI/AWS D1.2-90, *Structural Welding Code—Aluminum*, but is included for information purposes only.)

WELDING PROCEDURE SPECIFICATION (WPS)

Welding Procedure		
Specification No. _____	Date _____	Approved _____
Revisions _____	Date _____	Approved _____
_____	_____	_____
_____	_____	_____
_____	_____	_____
Supporting PQR Numbers _____		

Joints	Filler Metal	
Groove Design Sketch	F-No. _____ AWS No. _____ Class _____	
	Size of electrode _____	
	Type of electrode _____	
	Other _____	

	Shielding Gas	
	Shielding gas(es) _____	
	Percent composition _____	
	Flow rate _____	
	Other _____	

Backing	Position	
Type _____	Position of groove _____	
Permanent _____	Welding progression _____	
Removed _____	Other _____	
Other _____	_____	
_____	_____	
_____	_____	
_____	_____	
Base Metals _____	Preheat _____	
Group No. _____ Thickness _____ to _____	Preheat temperature _____	
Alloy and Temper _____	Interpass temperature _____	

Form E(a)

WELDING PROCEDURE SPECIFICATION (WPS)

	Pass no.	Welding process	Amps	Volts	Travel speed

Cleaning
 Initial cleaning oxide _____
 Initial cleaning oil and dirt _____
 Interpass cleaning _____

Post Weld Heat Treatment
 Original temper _____
 Final temper _____
 Temperature _____
 Time _____
 Quench _____

Process(es)
 Process _____ Type* _____
 Process _____ Type* _____
 Electrode (GTAW) _____

Technique
 Stringer or weave bead _____
 Orifice or gas cup size _____
 Oscillation _____
 Contact tube to work distance _____
 Single pass or multipass _____ per side
 Tungsten extension _____
 Method of back gouging _____
 Other _____

*Manual, automatic, polarity, pulse, etc.

Sketch of welding sequence

Form E(a) (continued)

PROCEDURE QUALIFICATION RECORD (PQR)

Procedure Qualification Record no. _____		Date _____																																				
WPS no. _____	Process(es) 1. _____	2. _____																																				
	1. _____	2. _____																																				
Design sketch		Welding sequence sketch																																				
Base metals Group no. _____ To _____ Alloy and Temper _____ To _____ Thickness _____ To _____ Filler metals F-number _____ AWS class _____ Diameter _____ Shielding gas(es) _____ Percent composition _____ Flow rate _____ Tungsten electrode (GTAW) _____ Size _____ Type _____ Backup type _____ Alloy _____ Back gouging _____		<table border="1" style="width: 100%; border-collapse: collapse; text-align: center;"> <thead> <tr> <th>Pass no.</th> <th>Process no.</th> <th>Amps</th> <th>Volts</th> <th>Travel speed</th> </tr> </thead> <tbody> <tr><td> </td><td> </td><td> </td><td> </td><td> </td></tr> <tr><td> </td><td> </td><td> </td><td> </td><td> </td></tr> <tr><td> </td><td> </td><td> </td><td> </td><td> </td></tr> <tr><td> </td><td> </td><td> </td><td> </td><td> </td></tr> <tr><td> </td><td> </td><td> </td><td> </td><td> </td></tr> <tr><td> </td><td> </td><td> </td><td> </td><td> </td></tr> </tbody> </table> Type of welding power source _____ Single or multiple electrode _____ Stringer or weave bead _____ Welding current _____ Polarity _____ AC or DC Position of groove _____		Pass no.	Process no.	Amps	Volts	Travel speed																														
Pass no.	Process no.	Amps	Volts	Travel speed																																		
Cleaning procedure Initial Oxide removal method _____ Degreasing agent _____ Cleaning procedure Interpass Smut removal _____ Dye penetrant removal _____		Preheat Preheat temperature _____ Interpass temperature _____ Post weld heat treatment Original temper _____ Final temper _____ Temperature _____ Time _____ Quench _____																																				

Form E(b)

PROCEDURE QUALIFICATION RECORD (PQR)

GROOVE WELD TEST

Specimen no.	Width	Thickness	Area	Ultimate tensile load, lb	Ultimate unit stress, psi	Character of failure and location

GUIDED BEND TEST

Type of bend	Bend jig Fig. no.	Result	Type of bend	Bend jig Fig. no.	Results

Visual examination _____ Pass _____ Fail

Type and character of failure _____

FILLET WELD TEST

Fracture test _____ Pass or fail

Root fusion _____ Yes or no

Macro test: Weld size and contour _____ Sat. or Unsat.

Penetration _____ Sat. or Unsat.

Welder's name _____

Clock no. _____ Stamp no. _____

Tests conducted by: _____ Laboratory

Test number _____ Per: _____

We certify that the statements in this record are correct and that the test welds were prepared, welded, and tested in accordance with the requirements of section 5, ANSI/AWS D1.2, Structural Welding Code—Aluminum.

Signed _____ Manufacturer

Date _____ By _____

Title _____

Form E(b) (continued)

MANUFACTURER'S RECORD QUALIFICATION TESTS OF WELDER OR WELDING OPERATOR OR TACK WELDER

Name _____ Clock No. _____ Stamp No. _____ Retest _____
 Welding Process _____ Type _____
 In accordance with welding procedure specification WPS No. _____ and PQR No. _____
 Material Group _____ To Group _____ Alloy _____ To _____
 Thickness of Test Material _____
 Filler Metal F No. _____ AWS Class _____ Diameter _____
 Other _____
 Position _____ Backing Material _____
 (1G, 2G, 6G)
 Electrical Characteristics: Current _____ Polarity _____
 Shielding Gas _____ Flow _____

For Information Only

Power Source _____
 (Make, model, type)
 Wire Feeder _____
 Welding Torch _____

VISUAL INSPECTION (9.8.1)

Appearance _____ Undercut _____ Piping Porosity _____

GUIDED BEND TEST RESULTS

Type of bend	Specimen thick., in.	Bend jig Fig. no.	Bend diam., in.	Result	Type of bend	Specimen thick., in.	Bend jig Fig. no.	Bend diam., in.	Result

Radiographic results: Alternative qualification of groove welds by radiography in accordance with Subs. 5.7.3 _____

Test conducted by _____ Laboratory: Test No. _____
 per _____

FILLET WELD TEST RESULTS

Fracture test _____
 (Describe the location, nature, and size of any crack or tearing of specimen.)
 Length and percent of defects _____ Inches _____ %
 Appearance: Fillet Size _____ in. X _____ in. Convexity or Concavity _____ in.
 Test conducted by _____ Laboratory: Test No. _____
 per _____

We certify that the statements in this record are correct and that the test welds were prepared, welded, and tested in accordance with the requirements of ANSI/AWS D1.2, Structural Welding Code—Aluminum.

Signed _____ (Organization) By _____
 Date _____ Title _____

WELDING PROCEDURE SPECIFICATION (WPS) FOR STUD WELDING APPLICATIONS

Specification No. _____	Date _____	Approved _____
Revisions _____	Date _____	Approved _____
_____	_____	_____
_____	_____	_____
Supporting PQR Numbers _____	_____	_____
_____	_____	_____

Joints Stud Base Sketch 	Base Metals M-No. _____ Specification _____ Thickness _____ to _____ Alloy and Temper _____ Pipe or Tube Diameter _____ Alloy and Temper _____ Stud Materials F-No. _____ Specification _____ Stud Diameter _____ Other _____ Shielding Gas Shielding Gas(es) _____ Percent Composition _____ Flow Rate _____ Other _____ Ferrules Ferrule Material _____ Ferrule Specification _____ Ferrule Description _____ Model No. _____ Timer Range Setting _____ Capacitance or Power Tap Setting _____ Other _____
--	--

Welding Process Arc Stud Welding _____ Capacitor Discharge _____ Contact Method _____ Gap Method _____ Drawn Arc Method _____ Cleaning Initial Oxide Cleaning _____ Initial Oil & Dirt Cleaning _____ Machine Settings Power Supply Make _____ Stud Gun Model _____ Current/Polarity _____ Amperage Range Setting _____ Stud-to-work Distance _____ Lift Setting _____ Cable Size _____ Length _____	
---	--

Form E(d)

PROCEDURE QUALIFICATION RECORD (PQR) FOR STUD WELDING APPLICATIONS

Procedure Qualification Record No. _____ Date _____	
WPS No. _____	Process _____

Machine Settings Power Supply Make _____ Model No. _____ Stud Gun Model _____ Timer Range Setting _____ Current/Polarity _____ Capacitance or Power Tap Setting _____ Amperage Range Setting _____ Stud-to-work Distance _____ Lift Setting _____ Cable Size _____ Length _____ Other _____ Base Metals M-No. _____ Specification _____ Thickness _____ to _____ Alloy and Temper _____ Pipe or Tube Diameter _____ Alloy and Temper _____ Ferrules Ferrule Material _____ Ferrule Specification _____ Ferrule Description _____ Cleaning Initial Oxide Cleaning _____ Initial Oil & Dirt Cleaning _____	Stud Base Sketch Stud Materials F-No. _____ Specification _____ Stud Diameter _____ Other _____ Shielding Gas Shielding Gas(es) _____ Percent Composition _____ Flow Rate _____ Other _____ Other Welding Position _____ Wetting Agent _____ Ferrule Description _____
--	---

Test Results	Visual Acceptance	Bend Test	Tension Test Option No. 1	Tension Test Option No. 2
Stud No. 1	_____	_____	_____	_____
Stud No. 2	_____	_____	_____	_____
Stud No. 3	_____	_____	_____	_____
Stud No. 4	_____	_____	_____	_____
Stud No. 5	_____	_____	_____	_____
Stud No. 6	_____	_____	_____	_____
Stud No. 7	_____	_____	_____	_____
Stud No. 8	_____	_____	_____	_____
Stud No. 9	_____	_____	_____	_____
Stud No. 10	_____	_____	_____	_____

We certify that the statements in this record are correct and that the test welds were prepared, welded, and tested in accordance with the requirements of section 7, ANSI/AWS D1.2, Structural Welding Code-Aluminum.

Signed _____ Date _____	(Manufacturer)	By _____ Title _____
----------------------------	----------------	-------------------------

Form E(e)

Appendix F

Sample Nondestructive Testing Forms

(This Appendix is not part of ANSI/AWS D1.2-90, *Structural Welding Code—Aluminum*, but is included for information purposes only.)

7

[illegible]

Form F(b)

Appendix G

Solutions for Macroetching Aluminum Weldments

(This Appendix is not part of ANSI/AWS D1.2-90, *Structural Welding Code—Aluminum*, but is included for information purposes only.)

G1. Acidic Etchant:

- 15 ml — hydrochloric acid (conc.)
- 10 ml — hydrofluoric acid (48%)
- 85 ml — water

The solution shall be used at room temperature. The weldment should be rinsed in clean water. Proper safety procedures shall be followed when handling and mixing acids. Always add the acids to water, never add the water to the acids. Always wear safety goggles when mixing chemicals. The etching solution should never be allowed to come into contact with the skin or clothing.

G2. Basic Etchant

A 20% solution of sodium hydroxide is applied at 120°F (50°C) to the area to be etched. The weldment should be rinsed in clean water. If desmutting is necessary to reveal the weld boundaries, a concentrated nitric acid dip at room temperature should be used. The weldment should be rinsed thoroughly in clean water prior to handling with bare hands.

G3. Safety Procedure

G3.1 General. All chemicals used as etchants are potentially dangerous. All persons using any of the etchants listed in G1 and G2 should be thoroughly familiar with all of the chemicals involved and the proper procedure for handling and mixing these chemicals. Safety goggles must be worn at all times when using chemical etchants. Avoid contact with the skin.

G3.2 Handling and Mixing Acids

G3.2.1 Caution shall be used in mixing all chemicals, especially strong acids. In all cases, various chemicals should be added slowly INTO the water or solvent while stirring.

G3.2.2 Hydrofluoric Acid, HF. In cases where hydrofluoric acid is used, the solution should be mixed and used in polyethylene vessels. **CAUTION:** Hydrofluoric acid or its solutions should not be allowed to contact the skin since it can cause painful, serious ulcers if not washed off immediately.

G4. Basic Recommendations for Handling of Etching Chemicals

G4.1 Always use protective garb (gloves, apron, protective glasses or face shield, etc.) when pouring, mixing, or etching.

G4.2 Use proper devices (glass or plastic) for weighing, mixing, containing, or storage of solutions.

G4.3 Wipe up or flush any spills.

G4.4 Dispose of any solutions not properly identified. Do NOT use unidentified solutions; when in doubt throw it out!

G4.5 Store and handle chemicals according to manufacturer's recommendations and observe any printed cautions on chemical containers.

G4.6 If uncertain about the proper use of a chemical, contact your Safety Department.

Appendix H

Guidelines for Preparation of Technical Inquiries for the Structural Welding Committee

(This Appendix is not a part of ANSI/AWS D1.2-90, *Structural Welding Code—Aluminum*, but is included for information purposes only.)

H1. Introduction

The AWS Board of Directors has adopted a policy whereby all official interpretations of AWS Standards will be handled in a formal manner. Under that policy, all interpretations are made by the Committee that is responsible for the Standard. Official communication concerning an interpretation is through the AWS Staff member who works with that committee. The policy requires that all requests for an interpretation be submitted in writing. Such requests will be handled as expeditiously as possible, but due to the complexity of the work and the procedures that are required to be followed, some interpretations may require considerable time.

H2. Procedure

All inquiries should be directed to:

Secretary, Structural Welding Committee
American Welding Society
550 N.W. LeJeune Road
P.O. Box 351040
Miami, Florida 33135

All inquiries should contain the name, address, and affiliation of the inquirer, and they should provide enough information for the Committee to fully understand the point of concern in the inquiry. Where that point is not clearly defined, the inquiry will be returned for clarification. For efficient handling, all inquiries should be typewritten and should also be in the format used here.

H2.1 Scope. Each inquiry should address one single provision of the Code, unless the point of the inquiry involves two or more interrelated provisions. That provision should be identified in the Scope of the inquiry, along with the edition of the Code that contains the provisions which the Inquirer is addressing.

H2.2 Purpose of the Inquiry. The purpose of the inquiry should be stated in this portion of the inquiry. The purpose can be either to obtain an interpretation of a Code requirement or to request the revision of a particular provision in the Code.

H2.3 Content of the Inquiry. The inquiry should be concise, yet complete, to enable the Committee to quickly and fully understand the point of the inquiry. Sketches should be used when appropriate and all paragraphs, figures, and tables (or the appendix), which bear on the inquiry should be cited. If the point of the inquiry is to obtain a revision of the Code, the inquiry should provide technical justification for that revision.

H2.4 Proposed Reply. The inquirer should, as a proposed reply, state an interpretation of the provision that is the point of the inquiry, or the wording for a proposed revision, if that is what the inquirer seeks.

H3. Interpretation of Code Provisions

Interpretations of Code provisions are made by the Structural Welding Committee. The Secretary of the Committee refers all inquiries to the chairman of the particular subcommittee that has jurisdiction over the

portion of the Code addressed by the inquiry. The subcommittee reviews the inquiry and the proposed reply to determine what the response to the inquiry should be. Following the subcommittee's development of the response, the inquiry and the response are presented to the entire Structural Welding Committee for review and approval. Upon approval by the Committee, the interpretation becomes an official interpretation of the Society, and the Secretary will transmit the response to the inquirer and to the *Welding Journal* for publication.

H4. Publication of Interpretations

All official interpretations are published in the *Welding Journal*.

H5. Telephone Inquiries

Telephone inquiries to AWS Headquarters concerning the Structural Welding Code should be limited to questions of a general nature or to matters directly related to the use of the Code. The Board of Directors'

Policy requires that all Staff members respond to a telephone request for an Official Interpretation of any AWS Standard with the information that such an interpretation can be obtained only through a written request. The Headquarters Staff can not provide consulting services. The Staff can, however, refer a caller to any of those consultants whose names are on file at AWS Headquarters.

H6. The Structural Welding Committee

The Structural Welding Committee's activities, in regard to interpretations, are limited strictly to the Interpretation of Code provisions or to consideration of revisions to existing provisions on the basis of new data or technology. Neither the Committee nor the Staff is in a position to offer interpretive or consulting services on: (1) specific engineering problems, or (2) Code requirements applied to fabrications outside the scope of the Code or points not specifically covered by the Code. In such cases, the inquirer should seek assistance from a competent engineer experienced in the particular field of interest.

Appendix I

Guide for Specification Writers

(This Appendix is not a part of ANSI/AWS D1.2-90, *Structural Welding Code—Aluminum*, but is included for information purposes only.)

A statement in a contract document that all welding be done in accordance with ANSI/AWS D1.2, *Structural Welding Code—Aluminum*, covers only the mandatory welding requirements. Other provisions in the Code are optional. They apply only when they are specified. Following are some of the more commonly used optional provisions and examples of how they may be specified.

Optional Provision	Typical Specification
Fabrication/Erection Inspection	Fabrication/Erection inspection shall be performed by the owner. (When not the responsibility of the contractor 6.1.1)
	<i>or</i>
	Fabrication/Erection inspection shall be performed by testing agency retained by the owner.
	Note: When fabrication/erection inspection is performed by the owner or the owner's testing agency, complete details on the extent of such testing shall be given.
Verification Inspection (6.1.1)	Verification inspection shall be performed by the contractor.
	<i>or</i>
	Verification inspection shall be performed by the owner.
	<i>or</i>
	Verification inspection shall be performed by a testing agency retained by the owner.
	<i>or</i>
	Verification inspection is waived.

Nondestructive Testing
[other than visual (6.7)]

General: For each type of joint and type of stress (tension, compression, and shear) indicate type of NDT to be used, extent of inspection, any special techniques to be used, and acceptance criteria. Specific examples (to be interpreted as examples and not recommendations) follow. The Engineer shall determine the specific requirements for each condition.

Statically Loaded Structure Fabrication: Moment Connection Tension Groove Welds in Butt Joints—25% UT inspection of each of the first four joints, dropping to 10% of each of the remaining joints.

Fillet welds—LP—Inspection of 10% of the length of each weld.

Dynamically Loaded Structure Fabrication: Tension Butt Joints—100% RT.

Appendix J

Safe Practices

(This Appendix is not a part of ANSI/AWS D1.2-90, *Structural Welding Code—Aluminum*, but is included for information purposes only.)

This appendix covers many of the basic elements of safety general to arc welding processes. It includes many, but not all, of the safety aspects related to structural welding. The hazards that may be encountered and the practices that should minimize personal injury and property damage are reviewed here.

J1. Electrical Hazards

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

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

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

Cables and connectors should be kept in good condition. Worn, damaged, or bare cables should not be used. In case of electric shock, the power should be turned off immediately. If the rescuer must resort to pulling the victim from the live contact, nonconducting materials should be used. A physician should be called and CPR continued until breathing has been restored, or until a physician has arrived. See References 1, 2, and 3.

J2. Fumes and Gases

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

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

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

For more detailed information on fumes and gases produced by the various welding processes, see References 4, 5, and 6.

J3. Noise

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

Personal protective devices such as ear muffs or ear plugs may be employed. Generally, these devices are only

accepted when engineering controls are not fully effective. For more information, see References 7, 8, and 9.

J4. Burn Protection

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

Workers should wear protective clothing made of fire resistant material. Pant cuffs or clothing with open pockets or other places on clothing that can catch and retain molten metal or sparks should not be worn. High top shoes or leather leggings and fire resistant gloves should be worn. Pant legs should be worn over the outside of high top boots. Helmets or hand shields that provide protection for the face, neck, and ears should be worn, as well as a covering to protect the head. Clothing should be kept free of grease and oil. Combustible materials should not be carried in pockets. If any combustible substance is spilled on clothing, it should be replaced with clean fire resistant clothing before working with open arcs or flame.

Appropriate eye protection should be used at all times. Goggles or equivalent also should be worn to give added eye protection.

Insulated gloves should be worn at all times when in contact with hot items or handling electrical equipment.

For more detailed information on personal protection, References 1, 10, 11, and 12 should be consulted.

J5. Fire Prevention

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

Explosions have occurred where welding or cutting has been performed in spaces containing flammable gases, vapors, liquids, or dust. All combustible material should be removed from the work area. Where possible, move the work to a location well away from combustible materials. If neither action is possible, combustibles should be protected with a cover of fire resistant material. All combustible materials should be removed or safely protected within a radius of 35 feet (11 m) around the work area.

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

tainers should be cleaned and purged before applying heat.

For more detailed information on fire hazards from welding and cutting operations, see References 1, 13, 14, and 15.

J6. Radiation

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

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

Some processes such as resistance welding and cold pressure welding ordinarily produce negligible quantities of radiant energy. However, most arc welding and cutting processes (except submerged arc when used properly), laser welding and torch welding, cutting, brazing, or soldering can produce quantities of nonionizing radiation such that precautionary measures are necessary.

Protection from possible harmful radiation effects include the following:

(1) Welding arcs should not be viewed except through welding filter plates (see Reference 16). Transparent welding curtains are not intended as welding filter plates, but rather are intended to protect passersby from incidental exposure.

(2) Exposed skin should be protected with adequate gloves and clothing as specified. See Reference 1.

(3) The casual passerby to welding operations should be protected by the use of screens, curtains, or adequate distance from aisles, walkways, etc.

(4) Safety glasses with ultraviolet protective side shields have been shown to provide some beneficial protection from ultraviolet radiation produced by welding arcs.

J7. Radiographic Procedures

The problems of protecting personnel against X-rays and gamma rays are not covered in this standard. Radiographic procedures should be carried out under protected conditions so that the radiographer will not receive a maximum whole body radiation dosage exceeding that permitted by city, state, or national codes. Mandatory rules and regulations are published by governmental licensing agencies. Careful radiation surveys should be made in accordance with appropriate regulations and codes and should be conducted in the inspection area as well as adjacent areas under all possible operating conditions.

For more complete information the user should refer to References 17, 18, and 19.

References Cited

1. *Safety in Welding and Cutting*, ANSI/ASCZ49.1. Miami, Florida: American Welding Society.
 2. *Safe Practices*, Reprint from Welding Handbook, Volume 1, Eighth Edition, Miami, Florida: American Welding Society.
 3. *National Electrical Code* NFPA No. 70, National Fire Protection Association, Batterymarch Park, Quincy, Massachusetts 02269.
 4. *Code of Federal Regulations* (CFR), Title 29, Chapter XVII, Part 1910: Washington, DC 20402, U.S. Government Printing Office.
 5. *Threshold Limit Values for Chemical Substances and Physical Agents in the Workroom Environment*, Cincinnati, Ohio: American Conference of Governmental Industrial Hygienists (ACGIH).
 6. *Fumes and Gases in the Welding Environment*, AWS report. Miami, Florida: American Welding Society.
 7. *Code of Federal Regulations* (CFR), Title 29, Chapter XVII, Part 1910: U.S. Government Printing Office, Washington, DC 20402.
 8. *Threshold Limit Values for Chemical Substances and Physical Agents in the Workroom Environment*, Cincinnati, Ohio: American Conference of Governmental Industrial Hygienists (ACGIH).
 9. *Method for Sound Level Measurement of Manual Arc Welding and Cutting Processes*, ANSI/AWS F6.1. Miami, Florida: American Welding Society.
 10. *Code of Federal Regulations*, Title 29 Labor, Chapter XVII, Part 1019, OSHA General Industry Standards. Washington, DC: U.S. Government Printing Office.
 11. *Practice for Occupational and Educational Eye and Face Protection*, ANSI Z87.1. New York: American National Standards Institute, latest edition.
 12. *Safety—Toe Footwear*, ANSI Z41.1. New York: American National Standards Institute, latest edition.
 13. *Cutting and Welding Processes*, NFPA Standard 51B. Quincy, Massachusetts: Fire Protection Association, latest edition.
 14. *Code of Federal Regulations*, Title 29, Labor, Chapter XVII, Part 1910, OSHA General Industry Standards. Washington, DC: U.S. Government Printing Office.
 15. *Recommended Safe Practices for the Preparation for Welding and Cutting Containers that Have Held Hazardous Substances*, ANSI/AWS F4.1. Miami, Florida: American Welding Society, latest edition.
 16. *Practice for Occupational and Educational Eye and Face Protection*, ANSI Z87.1. New York: American National Standards Institute.
 17. National Bureau of Standards Handbooks:

NBS-HDBK-60	X-ray Protection
NBS-HDBK-93	Safety Standard for Non-Medical X-ray and Sealed Gamma Ray Sources
NBS-HDBK-114	General Safety Standard for Installation using Non-Medical X-ray and Sealed Gamma Ray Sources up to 10 MeV Equipment Design and Use
- National Bureau of Standards publications are available from National Bureau of Standards, Gaithersburg, Maryland 20899.
18. ASTM E586 Definitions of Terms Relating to Gamma and X-Radiography, 1988 Annual Book of ASTM Standards, Section 3, Volume 03.03.
- Available from ASTM, 1916 Race Street, Philadelphia Pennsylvania 19103-1187.
19. Federal Standard No. 21 — *Code of Federal Regulations*, 1020.40 Safety Requirements for Cabinet X-Ray.
- Available from U.S. Government Printing Office, Washington, DC.

**Commentary on
Structural Welding Code
—Aluminum**

Foreword

(This Foreword is not a part of the Commentary of ANSI/AWS D1.2-90, *Structural Welding Code—Aluminum*, but is included for information purposes only.)

This Commentary on ANSI/AWS D1.2-90, *Structural Welding Code—Aluminum*, has been prepared to generate better understanding in the application of the Aluminum Code to welding in aluminum construction. Since the Aluminum Code is written in the form of a specification, it cannot present background material or discuss the Committee's intent; it is the function of this commentary to fill that need. Suggestions for application as well as clarification of the Aluminum Code requirements are offered with specific emphasis on sections that may be less familiar to the user.

The Committee recommends that the owner or owner's representative be guided by this commentary in application of the Aluminum Code to the structure to be welded. The commentary is not intended to supplement Aluminum Code requirements, but only to provide a useful document for interpretation and application of the Aluminum Code; the commentary provisions are not binding.

The fundamental premise of the Aluminum Code is to provide general stipulations applicable to any situation and to leave sufficient latitude for the exercise of engineering judgement. The Aluminum Code represents the collective experience of the Committee. Although some provisions may seem overly conservative, they have been based on sound engineering practice. The Committee believes that a commentary is the most suitable means to provide clarification as well as proper interpretation of many of the Aluminum Code requirements. Obviously, the size of the commentary had to impose some limitations with respect to the extent of coverage.

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

Generally, the Code does not treat such design considerations as loading and the computation of stresses for the purpose of proportioning the load-carrying members of the structure and their connections. Such considerations are assumed to be covered elsewhere, such as the Aluminum Association's Specification for Aluminum Structures, or similar documents.

The Committee has endeavored to produce a useful document suitable in language, form, and coverage for welding in aluminum construction. The Aluminum Code provides a means for establishing welding standards for use in design and construction by the owner or the owner's designated representative. The Aluminum Code incorporates provisions for regulation of welding that are considered necessary for public safety.

Commentary on Structural Welding Code—Aluminum

C1. General Provisions

Note: All references to numbered subsections, tables, and figures, unless otherwise indicated, refer to subsections, tables, or figures in ANSI/AWS D1.2-90—Structural Welding Code—Aluminum. References to subsections, tables, or figures in this commentary are prefixed with a C. For example, 8.8.1 is in AWS D1.2, while C8.8.1 is in this Commentary.

C1.1 Scope

The Structural Welding Code—Aluminum, hereinafter referred to as the Code, provides welding requirements for the construction of aluminum structures. It is intended to be complementary with any general code or specification for design and construction of aluminum structures.

Although the provisions of the Code are generally applicable to any aluminum structure, owners, architects, and engineers using the Code for structures should recognize that not all of its provisions may be applicable or suitable to their particular structures.¹ However, any modifications of the Code deemed necessary by these authorities should be clearly referenced in the contractual agreement between the owner and the contractor.²

1. Recommended provisions are given in section 2, Design; section 3, Workmanship; and section 4, Technique. Section 4 includes welding procedures, with specific reference to preheat, filler metals, and other pertinent requirements. Additional requirements for recommended joints in tubular construction are given in section 10.

2. As used in this commentary, the Contractor designates the party responsible for performing the welding under the Code. The term is used collectively to mean contractor, fabricator, erector, manufacturer, etc.

C1.3 Materials

C1.3.1 The ANSI H35.2-1982 (see Appendix A) specifications provide for dimensional tolerances. Base metal used for structural applications is usually furnished based on these requirements. The Engineer should recognize this, and any special dimensional requirements should be specified in the information furnished to the bidders.

C1.3.2 Filler Metals. Several materials have been added to Table 1.2 in this revision. The user should be aware of the material properties of these alloys which may require special welding practices and techniques to achieve published properties.

C1.4 Welding Processes

Certain gas metal arc and gas tungsten arc welding procedures in conjunction with certain related types of joints have a long record of proven satisfactory performance. These welding procedures and joints are designated as recommended; they may not be used without tests or qualification (see section 5).

C2. Design of Welded Connections

C2.1.3 The Engineer preparing contract design drawings cannot specify the depth of groove (S) without knowing the welding process and the position of welding. The Code is explicit in stipulating that only the weld size (E) is to be specified on design drawings for partial joint penetration groove welds (2.1.3.1). This allows the contractor to produce the weld size by assigning a depth of preparation to grooves shown on shop drawings as related to the chosen welding process and position of welding.

The root penetration will generally depend on the angle subtended at the root of the groove in combination with the root opening, the welding position, and the welding process.

C2.5 Partial Joint Penetration Groove Welds

A partial joint penetration groove weld has an unwelded portion at the root of the weld. This condition may also exist with a groove weld in a single-welded joint without backing and with a groove weld in a double-welded joint without back gouging. Therefore, the Code places the same application limits on these welds as for partial joint penetration groove welds.

The unwelded portions are no more harmful than those in fillet welded joints. These unwelded portions constitute a significant stress concentration when fatigue loading is applied transversely to the joint.

However, when the load is applied longitudinally, there is no appreciable reduction in fatigue strength. Irrespective of the rules governing the service application of these particular groove welds, the eccentricity of shrinkage forces in relation to the center of gravity of the joint members will result in angular distortion on cooling

after welding. This angular distortion can also result in secondary bending due to axial load acting through the shrinkage-induced eccentricity. Therefore, means shall be applied to restrain or preclude such rotation, both during fabrication and in service.

C2.7 Details of Fillet Welds

The Code specifies the minimum fillet weld size and requires that this size be made in a single pass. This provision is intended to insure sufficient heat input during welding to reduce the possibility of cracking in the weld metal on cooling, especially in a restrained joint. The minimum size applies if it is greater than the size required to carry design loads.

C2.9 Recommended Joint Details — Complete Joint Penetration Groove Welds

Recommended joint details have been moved to Appendix B1 in the Code. Since these details are recommended and not mandatory, it is more appropriate that they be referenced in an appendix.

C2.10 Recommended Joint Details — Partial Joint Penetration Groove Welds

Recommended joint details have been moved to Appendix B2 in the Code. Since these details are recommended and not mandatory, it is more appropriate that they be referenced in an appendix.

C3. Workmanship

C3.1 General

C3.1.3 Experience has shown that a welder cannot produce optimum results when working in an environment where the temperature is lower than 32° F (0° C). Reference is made in 3.1.3, 4.13.3, and 4.16.3 relative to the use of a heated structure or shelter to protect the welder and the area being welded, from inclement weather conditions. The environmental conditions inside the structure or shelter do not alter the preheat or interpass temperature requirements for base metals stated elsewhere in the Code.

C3.2 Preparation of the Base Material

C3.2.1.1 Grinding of aluminum for edge preparation is generally not recommended; however, the Code recognizes that it is necessary in some instances. In these instances, care must be taken not to contaminate the base metal by embedding abrasive particles in the aluminum surface.

C3.2.1.2 When plasma arc cuts are made on heat treatable alloys, 1/8 in. (3 mm) of base metal shall be removed by machining, except as allowed in 10.7.

C3.2.4 Visual Inspection and Repair of Plate Cut Edges. The repair procedures for discontinuities in plate cut edges may not be adequate where tension is applied in the through-thickness direction of the base metal. For other directions of loading, this article permits some lamination-type discontinuities in the base metal. Experience and tests have shown that laminations parallel to the direction of tensile stresses do not generally adversely affect the load-carrying capacity of a structural member.

C3.2.5 In buildings and tubular structures, the Code permits a smaller re-entrant corner radius than is permitted for bridges. The smaller radius is necessary for some standard bolted or riveted connections. The unacceptable condition defined in the last sentence of 3.2.5 is illustrated in Figure C3.1.

C3.2.7 Heat-shrink techniques used to correct moderate variations from specified dimensions shall be employed only within the limitations outlined in 3.7.5.

C3.3 Assembly

C3.3.1 Typical sketches of the application of the alignment requirements for abutting parts to be joined by welds in butt joints are shown in Figure C3.2 and C3.3.

C3.3.4 Except for the root opening in lap joints and the separation between a backing and base metal, a root opening of 1/16 in. (1.6 mm) maximum is permitted for fillet welding base metal not exceeding 3 in. (75 mm) in thickness. For base metal over 3 in., the maximum permissible root opening is 5/16 in. (8 mm). These root openings are necessitated by the allowable mill tolerances and inability to bring thick parts into closer alignment. The Code presupposes straightening of members prior to assembly or an application of an external load mechanism to force and keep the members in alignment during assembly.

These root openings may require backing, either as a backing weld or other types of backing capable of supporting molten weld metal. It should be realized that upon release of any external jacking loads, additional stresses may act upon the welds. Any root opening 1/16 in. (1.6 mm) or greater requires an increase in size of the fillet weld leg size by the size of the root opening.

C3.3.7 Tack welds shall comply with the same workmanship, preheat, etc., and quality criteria required for finished welds, except as allowed in 10.8.

C3.5 Dimensional Tolerances

C3.5.3 The cambering of structural members is used to eliminate the appearance of sagging or to match elevation of adjacent building components when the member is fully loaded.

C3.5.6 The combined warpage and tilt (Δ) of the flange of welded beams and girders is measured, as shown in Figure C3.4.

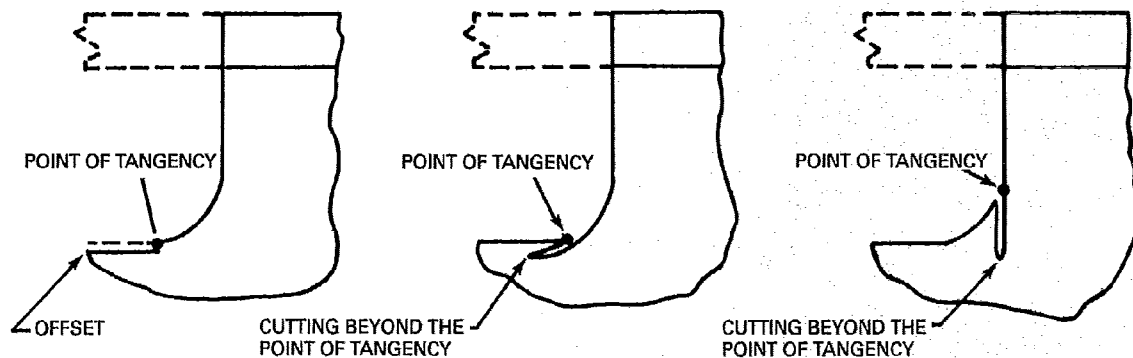
C3.6 Weld Profiles

C3.6.1 Acceptable and unacceptable weld profiles are shown in Figure 3.2; unacceptable profiles are shown with modification in Table 10.1 for Class I structures, and Table 10.2 for Class II Structures.

C3.7 Repairs

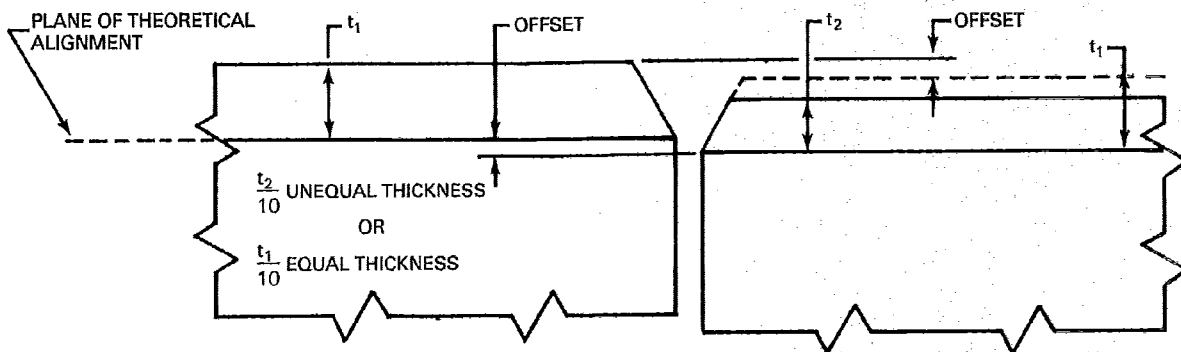
C3.7.2 The Code permits the contractor to either repair or remove and replace an unacceptable weld. It is not the intent of the Code to give the Inspector authority to specify the mode of correction.

C3.7.4 Application of localized heat is permitted for straightening members; however, this shall be done carefully so as not to exceed temperature limitations that would adversely affect the properties of the aluminum base metal.



Note: Any cutting beyond the point of tangency is unacceptable.

Figure C3.1 — Examples of Unacceptable Cutting Beyond the Point of Tangency (see C3.2.5)



Note: An offset not exceeding 10% of the thickness of the thinner part joined, but in no case more than 1/8 in. (3 mm), may be permitted as a departure from the theoretical alignment. (see C3.3.1)

Figure C3.2 — Permissible Offset in Abutting Members. (see C3.3.1)

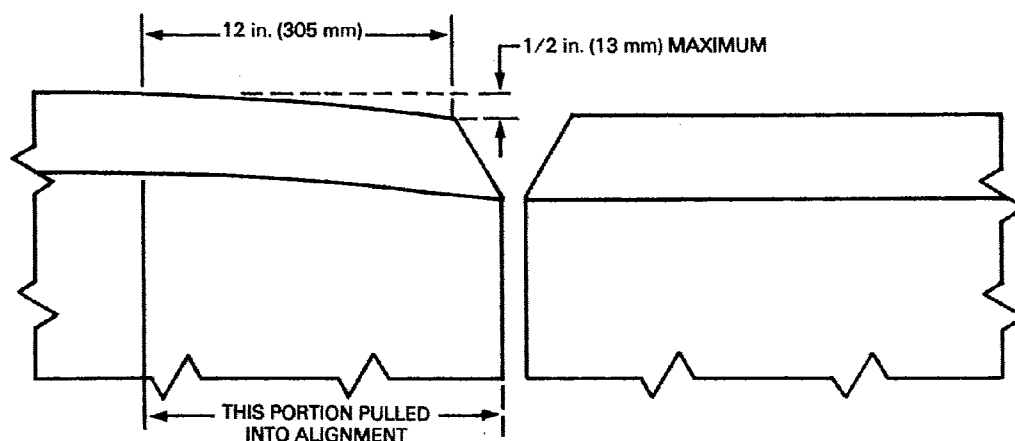


Figure C3.3 — Correction of Misaligned Members (see C3.3.1)

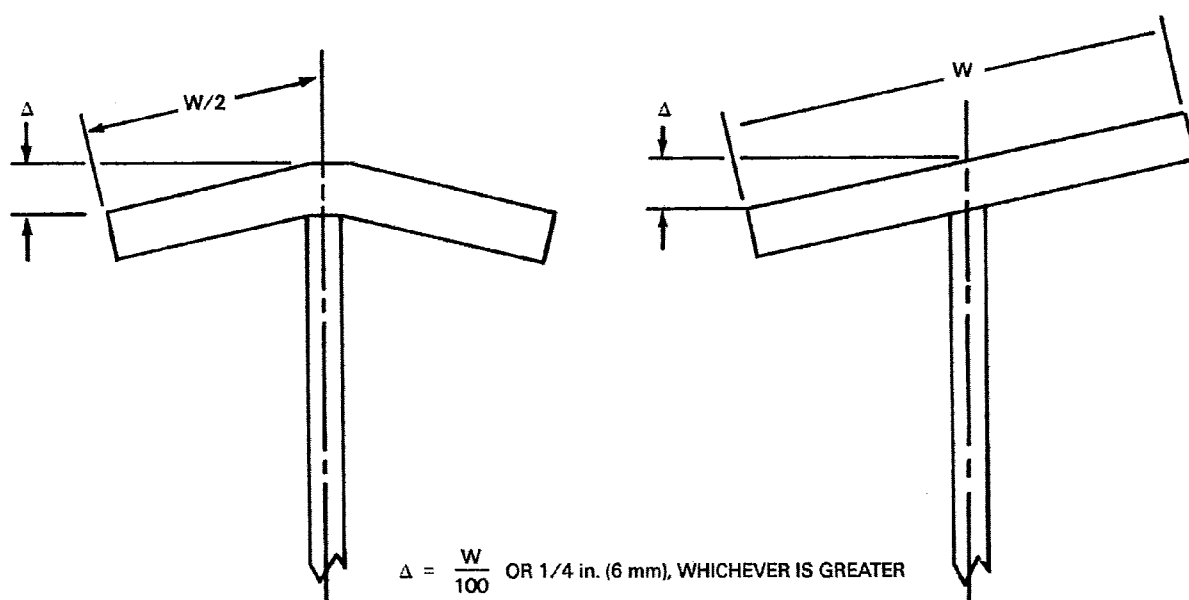


Figure C3.4 — Measurement of Flange Warpage and Tilt (see C3.5.1.6)

C4. Technique

C4.1 Material Requirements

Recommended combinations of base metals and filler metals are shown in Table 1.2.

C4.2 Welding Processes

Welding processes covered by the Code are limited to (1) the gas metal arc welding (GMAW) process, (2) the gas tungsten arc welding (GTAW) process, and (3) the plasma arc welding (PAW) process using variable polarity defined in 4.17.

C4.6 Arc Strikes

Arc strikes result in heating and very rapid cooling. When located outside the intended weld area, they may result in localized cracking and may serve as potential sites for initiating fracture.

C4.11 Thermal Stress-Relief Treatment

When stress-relief of a welded assembly is required, the limitations listed in this subsection and in Table 3.2 shall apply. These limitations do not apply to artificial aging of heat-treatable alloys.

C5. Qualification of Procedures and Personnel

Part A General Requirements

C5.2 Qualification of Welding Procedures

C5.2.2 Many aluminum alloys used in structural applications are heat treatable. During welding, certain areas of the heat-affected zone are subjected to temperatures that cause a partial annealing of the base metal. The extent of this partial annealing is dependent upon the welding conditions affecting the heat input. Thus, these variations in heat input can drastically alter the load carrying capacity of the welded structures. Therefore, all procedures approved for use under this Code shall be qualified by test.

C5.2.3 The Engineer is encouraged to accept properly documented evidence of previously qualified procedures. If the Engineer specifically intends to require requalification of procedures, it should be clearly stated in the contract documents, so that the contractor can make a proper estimate of costs.

C5.3 Qualification of Welders, Welding Operators and Tack Welders

C5.3.1 Welders, welding operators, and tack welders should have a minimum of three months of successful experience welding on aluminum alloys. In lieu of such experience, they should be instructed in the welding of aluminum and its alloys.

Since tack welds sometimes become a part of the final weld, the importance of tack welders receiving instruction in welding aluminum is stressed.

C5.4 Qualification Responsibility

All contractors are responsible for their final product. Therefore, it is their responsibility to comply with the

qualification requirements of the Code relative to welding procedures, welders, welding operators and tack welders. Properly documented welding procedures and personnel qualification tests conducted by the contractor in accordance with this Code are generally acceptable to the Engineer for the contract.

Part B Types of Tests, Test Methods, and Acceptance Criteria

The types of tests, test methods, and acceptance criteria for each specific requirement are found in this part of the Code. It alerts the user to the types of tests required for procedure and performance qualification and to see the types and limits of discontinuities that each type of test is designed to detect.

C5.7 Types and Purposes of Tests

This section describes tests, the procedures for conducting them, and the basis for acceptance. Tables 5.3, 5.4, and 5.5 describe the number, type, and range of thicknesses for complete joint penetration groove, partial joint penetration groove, and fillet welds, respectively.

Part C Procedure Qualification

This part sets forth the requirements for qualifying a welding procedure. The Code recognizes that the approved aluminum alloys are weldable and that certain conditions are applicable to many of them.

C5.13 General

In the Procedure Qualification Record (PQR) [see Appendix E], the type of welding process should be identified. That information should include whether the process was done manually or automatically. Other key information, such as polarity, whether pulsed, etc., should be specified in the PQR.

C5.14 Limits of Qualified Positions for Procedures

Table 5.2 summarizes the requirements for the positions that are qualified by each qualification test. The test positions qualified are based on the experience and skill required to make a welded joint.

C5.16 Limitation of Variables — Procedure Qualification

Some degree of departure from the variables stated in the welding procedure specification is recognized as permissible without requiring verification. Departures from a welding procedure that do affect predictable results are referred to as essential variables and are considered to be items that will affect the mechanical or chemical properties, or both, of the weldment. The limits set forth in this section are based on the combined experience of the members of the subcommittee on welded aluminum structures.

C5.17 Tests — Procedure Qualifications

When a previously qualified complete joint penetration groove weld procedure is used on a partial joint penetration groove weld procedure, it is only necessary to perform the macroetch test required in Table 5.4, since the complete joint penetration groove weld procedure has met the mechanical property requirements when qualified. The PQR should reference the original PQR that contains the mechanical test data with a note to the effect that a previously qualified complete joint penetration groove weld PQR was used.

C5.17.3 Test Specimens: Number, Type and Preparation

Tables 5.3, 5.4, and 5.5 summarize the requirements for the number and type of test specimens and the range of thickness qualified. A test weld plate thickness of 1 in. (25.4 mm) or over qualifies a procedure for unlimited maximum thickness. The 1 in. thickness has been shown generally to reflect the influence of weld metal chemical composition, heat input, and preheat and interpass temperature on the weld metal and heat-affected zone properties.

Tables 5.3, 5.4, and 5.5 summarize the procedure qualifications for (A) complete joint penetration groove welds, (B) partial joint penetration groove welds, and (C) fillet welds.

The procedure qualification for pipe and tubing is divided into Class I and Class II structures based on the criteria outlined in section 10 of the Code. Class I structures deal with the welding of castings, and provisions are made in these tables to qualify these procedures. Conditions for large diameter job-size pipe or tubing are found in the section of the tables dealing with Class II tubular structures.

All partial joint penetration groove welds and all test weld plates with fillet welds (except option No. 2) require a macroetch test to determine the weld size of the weld being tested.

Part D Performance Qualification

C5.19 General

The welder, welding operator, or tack welder qualification test is specifically designed to determine their ability to produce sound welds in any given test weld. After successfully completing the performance qualification tests, the welder, welding operator, or tack welder should be considered to have minimum acceptable qualifications.

Knowledge of the base metal is beneficial to welders, welding operators, or tack welders in producing a sound weldment; therefore, it is recommended that before welding aluminum wrought alloys or aluminum castings, welders, welding operators, or tack welders be given instructions as to the properties of these base metals, except where they have had prior experience in welding aluminum products.

C5.22 Limitations of Variables — Welder Performance Qualification

C5.23 Limitations of Variables — Welding Operator Performance Qualification

C5.24 Limitations of Variables — Tack Welder Performance Qualification

The ability of a welder to produce a sound weld is considered by the Code to be dependent on certain essential variables. These are listed in 5.22 for welders, under 5.23 for welding operators, and 5.24 for tack welders.

Table 5.7 lists the number and type of specimens and range of thickness qualified for welder and welding operator qualification. Performance qualification for pipe and tubing is divided into Class I and Class II structures to recognize the use of castings in Class I structures. Tack welders qualify by performing one of the designated fillet weld tests.

C5.26 Retests

If a specimen from the test weld fails a specific test, an immediate testing of two additional specimens from the same test weld or an additional test weld is allowed under the Code. If it is apparent that additional training is necessary, a complete retest at such time as this training has been accomplished is allowed by the Code.

C6. Inspection

Part A **General Requirements**

ANSI/AWS D1.2 parallels the ANSI/AWS D1.1 on the basic premise of contractual obligations when providing products and services. Those who submit competitive bids or otherwise enter into a contract to provide materials and workmanship for structural weldments in accordance with the provisions of the Code assume an obligation to furnish the products as specified in the contract documents and are fully responsible for product quality.

C6.1 General

In this section, the term fabrication/erection inspection is separated from verification inspection. These broader terms are used to avoid confusion with the terms quality control and quality assurance as used by some industries (e.g., nuclear). It was advantageous to use more general terms that place greater emphasis on timely inspection. The contractor is solely responsible for the ordering of materials, and assembly and welding of the structural weldments.

C6.1.1 This paragraph describes the responsibility of the contractor for fabrication/erection inspection and testing, which is basically the quality control responsibility described in other contract documents. The owner has the right, but generally not the responsibility, to provide independent inspection to verify that the product meets specified requirements. This inspection may be done independently by the owner or the owner's representative or, when provided in the contract, verification inspection may be waived or it may be stipulated that the contractor shall perform both the inspection and the verification.³

3. When this is done, fabrication/erection inspection (quality control) and verification inspection (quality assurance) remain separate functions. Verification inspection should be performed independently by personnel whose primary responsibility is not production inspection.

C6.2 Inspection of Materials

This Code provision is all-encompassing. It requires inspection of materials and review of materials certification and mill test reports. It is important that this work be done in a timely manner so that unacceptable materials are not used or incorporated in the work.

C6.3 Inspection of Welding Procedure Qualification and Equipment

The requirements of 6.3.1 and 6.3.2, should be completed before welding is begun on weldments required by the contract documents. Qualification for each weldment should always be done before welding is started, but qualification for all weldments does not have to be completed before welding with qualified procedures can be started.

C6.4 Inspection of Welder, Welding Operator, and Tack Welder Qualifications

C6.4.1 It is important that the Inspector determine that all welders are qualified before they begin welding on the project. If discovered after welding has begun, lack of welder qualification documentation may cause serious delays in the acceptance of weldments.

C6.4.2 The Inspector shall regularly appraise the quality of welds produced by welders, welding operators, and tack welders. Individuals producing unacceptable welds should be required to produce satisfactory test welds of the type causing difficulties. Complete requalification may not always be necessary. Only qualified welders producing acceptable welds shall be employed in the work.

C6.4.3 Welders who cannot provide evidence that they have used the welding process for which they were qualified within the preceding six months are required to take appropriate tests to become requalified. Since active welders can maintain certification as long as they con-

tinue to do good work, it is essential that the Inspector regularly evaluate the quality of the welds produced by each welder, welding operator, and tack welder.

C6.5 Inspection of Work and Records

The Inspector shall determine from inspection of the work prior to assembly, during assembly, during welding, and after welding (see 6.1.1) that all requirements of the Code are met. Inspectors shall identify the work they have inspected and accepted or rejected. The method of identification should not be destructive to the weldment. Die stamping of welds is not recommended, since die stamp marks may form sites for crack initiation. It is essential that the Inspector keep accurate records documenting the inspectors basis for accepting or rejecting weldments.

C6.6 Obligations of the Contractor

C6.6.1 The Contractor is responsible for the product acceptability. The Contractor shall conduct inspection to the extent necessary to ensure conformance with the Code, except as provided in 6.6.5.

C6.6.2 If the Verification Inspector finds deficiencies in materials and workmanship, regardless of whether the Verification Inspector is a representative of the owner or an employee of the contractor, the contractor shall be responsible for all necessary repairs or replacements.

C6.6.4 and C6.6.5 When nondestructive testing is specified in the information furnished to bidders, the contractor shall take necessary steps to ensure that the nondestructive testing acceptance criteria prescribed by the Code are met. When nondestructive testing other than visual inspection is not specified, the owner shall be responsible for all associated costs of testing and surface preparation plus the repair of defects not reasonably expected to be discovered during visual inspection.

Since there is a limit to the defects that might reasonably be expected to be found in visual inspection of welds, welds that contain defects that are considered beyond reasonable weld quality standards and which appear to result from gross nonconformance to this Code shall be repaired or replaced at the contractor's expense in accordance with 3.7.2.

C6.7 Nondestructive Testing

In addition to visual inspection, which is always necessary to achieve compliance with Code requirements, three nondestructive testing (NDT) methods are provided for in the Code. They are (1) radiographic testing (RT), (2) ultrasonic testing (UT), and (3) liquid penetrant testing (PT). Radiographic and ultrasonic testing are used to detect both surface and internal discontinuities.

Dye penetrant testing is used to detect discontinuities open to the surface. Other NDT methods may be used upon agreement between owner and contractor.

C6.7.1 It is essential that the contractor know in advance the categories of welds that will be subject to nondestructive tests, the testing procedure to be used, and the level of acceptance. Unless otherwise provided in the contract, the quality criteria for the acceptance of welds are stated in 8.8, 9.8, 10.10 and 10.15.

It is not necessary to write in the contract documents exactly which weld or what portions of specific welds will be examined by a specific test method. A general description of weld test requirements may be specified, e.g., "All welds in complete joint penetration butt joints in tension flanges of girders shall be radiographed."

If the location of tension flange butt joints is not obvious, their location should be designated on the plans.

When spot checking is specified, e.g., 10% of all fillet welds, it should not be taken to imply that the contractor be notified prior to welding which specific welds or portion of welds shall be tested. It is a basic premise of the specifications that if spot tests are made, there should be a sufficient number of test locations to give a reliable indication of weld quality.

There are different acceptance criteria for buildings, bridges, and tubular structures. The basic difference in acceptance criteria for each of these structures is based upon the difference between static and dynamic loading.

When fatigue crack growth is anticipated, acceptable initial weld flaw sizes must of necessity be small. All criteria are established in an attempt to preclude weld failure during the anticipated service life of the weldment.

C6.7.6 Personnel Qualification. Only individuals who qualify to SNT-TC-1A NDT Level II may perform non-destructive tests without supervision. Level III individuals may also perform NDT tests, provided they meet the requirements of NDT Level II.

NDT Level III engineers and technicians are generally supervisors and may not be actively engaged in the actual work of testing. Since there is no performance qualification test for individuals qualified to NDT Level III, all individuals providing testing services under the Code shall be qualified to Level II, which has specific performance qualification requirements.

Part B *Radiographic Testing of* *Groove Welds in Butt Joints*

C6.8 General

C6.8.1 The procedures and standards set forth in this section are primarily designed for the radiographic

inspection of complete joint penetration groove welds. Typical geometries for structural welds and design requirements for these structures were taken into account in the preparation of the specification.

C6.8.2 Since this section does not provide for the radiographic testing of welds in pipe or tubular structures, variations are permitted based upon agreement between the contractor and the owner. The provisions of section 10 shall apply to radiographic testing of welds in pipe and tubular structures.

C6.9 Extent of Testing

C6.9.1 It is important that joints to be radiographed be clearly described in the information furnished to bidders as explained in Part A of this Commentary.

C6.9.4 The Code requires that if rejectable discontinuities are found in one spot and again in either of the additional required spot radiographs, the remainder of the weld shall be radiographed to determine the extent of any remaining defects.

C6.10 Radiographic Procedures

C6.10.1 A single source of radiation is specified to avoid confusion or blurring of the radiographic image. Radiographic sensitivity is judged solely on the quality of the penetrameter image(s), as specified in both ASTM and ASME standard provisions.

C6.10.2 Ionizing radiation and chemicals used in radiographic inspection can present serious health hazards. All safety regulations must be complied with.

C6.10.3 When the owner wishes weld surfaces to be ground flush or otherwise smoothed in preparation for radiographic testing, it should be so stated in the contract documents. The owner and the contractor should attempt to agree in advance on which weld surface irregularities will not need to be ground unless surface irregularities interfere with interpretation of the radiograph. It is extremely difficult and often impossible to separate internal discontinuities from surface discontinuities when reviewing radiographs in the absence of information describing the weld surface. When agreement can be reached on weld surface preparation prior to radiography, rejections and delays will generally be reduced.

C6.10.3.1 Weld tabs (extension bars and run-off plates) are generally removed prior to radiographic inspection so that the radiograph will represent the weld as finished and placed in service. Contraction cracks are commonly found in the weld at the interface between weld tabs and the edge of the plate or shape joined by the weld. These cracks are hard to identify in the radiograph under the best conditions. It is considered necessary to

remove the weld tabs before attempting to radiograph the boundaries of the welded joint.

C6.10.3.3 When weld reinforcement or backing, or both, are not removed, shims placed under the penetrameters are required so that the penetrameter image may be evaluated on the average total thickness of aluminum (weld metal, backing, reinforcement) exposed to radiation.

C6.10.4 Provisions of this section are to assure the use of fine grain film and to avoid coarseness in the image that may result from the use of fluorescent screens.

C6.10.5 The source of radiation is centered with respect to the portion of the weld being examined to avoid as much geometric distortion as possible.

C6.10.5.1 This paragraph is provided to limit geometric unsharpness⁴ that causes distortion and blurring of the radiographic image.

C6.10.5.2 and **C6.10.5.3** These sections are intended to limit geometric distortion of the object as shown in the radiograph. An exception is made for panoramic exposures.

C6.10.6 The maximum permissible voltage for radiographic inspection depends on the material thickness, when X-ray units are used. These units may be used on all radiographic inspection, provided they have adequate penetrating ability.

Aluminum has a lower radiographic density than steel, and the resulting poor radiation contrast and sensitivity with isotope sources limit their use. Iridium 192 is approved as a radiographic source only when aluminum exceeds 2.5 in. (65 mm) thickness. Cobalt 60 is not an approved source.

Care should be taken to ensure that the effective size of the radiograph source is small enough to preclude excessive geometric unsharpness.

C6.10.7, C6.10.7.1, and C6.10.7.2 Since radiographic sensitivity and the acceptability of radiographs are based upon the image of the required penetrameters, care is taken in describing the manufacture and use of the required penetrameters. Penetrameters are placed as shown in Figure 6.1.

Penetrameters may be placed only on the source side, unless otherwise approved by the Engineer. Failure to

4. Geometric unsharpness is defined as a blurring of the edges of a radiographic image due to the radiation source having finite dimensions, dependent on relative source-to-film and object-to-film distances. Geometric unsharpness may be expressed mathematically as: $U_g = F(L_i - L_o)/L_o$, where U_g is the geometric unsharpness, F is the size of the X-ray tube focal spot or the diameter of the gamma source, L_i is the source-to-film distance, L_o is the source-to-object distance, and $L_i - L_o$ is the object-to-film distance.

place the penetrameters on the source side during the radiographic exposure, without prior approval of the Engineer, shall be cause for rejection of the radiographs.

C6.10.8 Welds shall be radiographed and the film indexed by methods that will ensure continuous inspection of the weld within the limits specified.

C6.10.8.1 Backscattered radiation can cause general fogging and produce artifacts in the radiograph. The method described in this section will identify back-scattered radiation so that corrective steps can be taken.

C6.10.9 Radiographic inspection is designed to inspect all of the weld zone. Defects in the weld metal or the adjacent heat-affected zones can produce weld failure. Film widths shall be sufficient to inspect all portions of the weld joint and have sufficient room for weld identification.

C6.10.10 Quality of Radiographs. Quality radiographs with the appropriate penetrometer sensitivity are the only indicators of proper radiographic inspection.

C6.10.11 Density Limitations. It is the intent of the specification to use radiographic films within the full limits of the useful film density. An effort is made in this Code to avoid the necessity of making multiple exposures or using films of more than one exposure speed when examining welded joints expected to be routinely encountered.

C6.10.12 This section describes all information required to identify the radiograph and also provides methods for matching the radiograph to the weld joint, so that weld repairs, when necessary, may be made without repetitive or unnecessary metal removal. Radiograph identification marks and location identification marks shall be used to locate defects and to verify that unacceptable discontinuities have been repaired as demonstrated by the subsequent radiograph of the repair.

C6.11 Acceptability of Welds

The provisions of 8.8.2, 9.8.2, and 10.15.2 prescribe the radiographic quality of welds for non-tubular statically and dynamically loaded structures, and tubular structures, respectively.

C6.12 Examination, Report, and Disposition of Radiographs

C6.12.2 Since more accurate film viewing is possible when the eyes of the viewer are not subjected to light from portions of the radiograph not under examination, a suitable, variable intensity illuminator with spot review or masked spot review capability is required. The ability

to adjust the light intensity reduces eye discomfort and enhances visibility of weld discontinuities. Subdued light in the viewing area allows the reviewer's eyes to adjust to see small discontinuities in the radiographic image. Film review in complete darkness is not advisable since the contrast between darkness and the intense light from portions of the radiograph with low density causes discomfort and loss of accuracy.

Film densities within the range of 2.5 to 3.5, as described in 6.10.11, are preferred. The illuminator shall have sufficient capacity to properly illuminate radiographs with densities up to 4.0. In general, within the limits of density approved by the Code, the greater the film density, the greater the radiographic sensitivity.

C6.12.3 and C6.12.4 After the radiographic inspection technician and the fabrication/erection Inspector have reviewed and approved both the radiographs and the report interpreting them, the radiographic examination report shall be submitted to the Verification Inspector for a separate review on behalf of the owner. All radiographs, including those showing unacceptable quality prior to repair, shall, unless otherwise provided in the contract documents, become the property of the owner. The contractor shall not discard radiographs or reports under the provisions of the Code until the owner has been given, and has acknowledged, prior notice in writing.

The term "a full set of radiographs" as used in 6.12.4 means one radiograph of acceptable weld quality from each radiographic exposure required for complete radiographic inspection, plus one radiograph of any unacceptable weld quality prior to repair from each radiographic exposure. If the contractor elects to load more than one film in each cassette to produce an extra radiograph for the Contractor's own use or to avoid possible delays due to film artifacts, the extra radiographs are, unless otherwise specified, the property of the contractor.

Part C

Ultrasonic Testing of Groove Welds

C6.13 General

Ultrasonic testing (UT) of aluminum weldments is recognized as an acceptable nondestructive testing method. Ultrasonic testing is regularly being used on aluminum welds to provide information about the location, size, and orientation of discontinuities.

This method is not treated in detail in the Aluminum Code because of the lack of consensus, at this time, about formulating a simple procedure giving satisfactory results.

C6.13.1 When ultrasonic testing is included in the contract documents, not only the extent of testing, but also the testing procedures and the acceptance criteria shall be specified.

There are existing standards and codes that provide applicable information for ultrasonic testing. These include: ASTM E164, *Standard Recommended Practice for Ultrasonic Contact Examination of Weldments*; and Section V of *ASME Boiler and Pressure Vessel Code, Non-Destructive Examination*.

C6.13.2 The provisions for maintaining and retaining records on welds subjected to ultrasonic testing parallel

those for radiographic testing. Likewise, unless otherwise specified in the contract documents, the records become the property of the owner.

6.18 Record of Inspection

The provisions for maintaining and retaining records on welds subjected to dye-penetrant inspection parallel those for radiographic testing. Likewise, unless otherwise specified in the contract documents, the records become the property of the owner.

C7. Stud Welding

C7.1 General

The section on stud welding consists of three parts: Part A contains general requirements applicable to all stud welding; Part B applies to the arc stud welding process; and Part C applies to the capacitor discharge stud welding process. Parts B and C contain complete specifications for stud welding and each Part is intended to stand alone with Part A, depending upon the process chosen.

C7.3 Material Requirements

Aluminum filler wire alloys have been developed for use with various base alloy materials so as to prevent the generation of toxic fumes when welding in poorly ventilated enclosures and to minimize weld cracking. Generation of toxic fumes is controlled by limiting beryllium content in the filler alloys to a maximum of 0.0008%. A grain refiner such as titanium is added to the filler alloys to minimize weld cracking by producing a finer grain structure in the as-cast weld. These features are also desirable when making stud welds. Since the filler wire alloys are produced at wire and rod manufacturing facilities, they are also more readily available in the forms most desirable for stud manufacturing. For these reasons, the alloys shown in Table 7.1 are specified as aluminum stud base metal for arc stud welding. The capacitor discharge process takes place almost instantaneously so the need to control beryllium content is not so critical. Therefore, additional aluminum alloys, listed in Table 7.4, can be specified as a stud base metal. The Engineer should be familiar with the chemistry of other aluminum alloys before specifying other materials.

C7.4 Workmanship

The surface of the base metal must be smooth enough after a grinding or brushing operation so as not to adversely affect the welding results.

C7.5 Technique

The arc stud welding process requires precise setting of the welding conditions used to make the weld. As a starting point to developing these conditions it is often advisable to rely on the recommendations of the stud or equipment manufacturer to supply base settings for the application being developed. More seasoned users may rely more on past practice to provide this same information.

C7.6 Qualification Requirements

A welding procedure specification shall be prepared for each application. It shall be supported by a welding procedure that has been qualified by test. The Code allows the qualification of a range of thicknesses under one procedure qualification by welding the maximum and minimum thicknesses of base material. The contractor has the option of choosing a bend test only in lieu of making tension tests.

C7.6.6.3 Tension test values are given in the Code for F-22 materials only. Other material tension test values may be obtained from the stud manufacturer or by testing. If one of the tension test options is specified in the welding procedure qualification test, then the minimum tensile values for the stud alloy being welded shall be supplied by the Engineer.

C7.7 Operator and Preproduction Qualification

Stud welding equipment is usually considered automatic and therefore requires minimal expertise on the part of the operator. Basic skills such as loading the stud, applying the ferrule or a wetting agent and maintaining correct alignment of the stud welding gun can readily be determined at the time of welding. Such operator qualification doubles as the preproduction

application testing of the stud welding process prior to starting the day's or shift's operation.

C7.8 Acceptance Criteria — Production Welds

Flash, as evidenced during inspection according to 7.8, is not a fillet weld such as those formed by conventional arc welding processes. The expelled metal, which is excess to the weld required for strength, is not detrimental but, on the contrary, is essential to provide evidence of a sound stud weld. The containment of this excess molten metal around an arc welded stud by the ferrule (arc shield) assists in securing sound fusion of the entire cross section of the stud base. The stud weld flash may have nonfusion in its vertical leg and overlap on its horizontal leg, and it may contain occasional small shrink fissures or other discontinuities that usually form at the top of the flash with essentially radial, or longitudinal orientation, or both, to the axis of the stud. Such discontinuities are acceptable.

C7.9 Mislocated Studs

Mislocated studs are those studs which are applied to the wrong location on the structure. It is the contractor's or stud applicator's responsibility to remove these mislocated studs from the structure and repair the area where the stud was applied to its original surface condition. The Engineer may approve leaving the mislocated stud attached to the structure.

C7.10 Repair of Misapplied Studs

Misapplication of studs usually is caused by foreign materials on the surface of the base material or a malfunction of the stud welding equipment. The latter may

cause severe arcing on the surface of the base metal which may have to be repaired before another stud welding attempt is made. Once a stud has been used in an attempted arc stud weld, it is deemed as being unfit for use in production and shall be discarded.

C7.12 Material Requirements

(See C7.3)

C7.13 Workmanship

(See C7.4)

C7.14 Technique

(See C7.5)

C7.15 Qualification Requirements

(See C7.6)

C7.15.6.3 (See C7.6.6.3)

C7.16 Operator and Preproduction Qualification

(See C7.7)

C7.18 Mislocated Studs

(See C7.9)

C7.19 Repair of Misapplied Studs

(See C7.10)

C8. Nontubular Statically Loaded Structures

Part A *General Requirements*

C8.1 Application

The provisions of section 8, like those of most building codes, assume static loading under service conditions. However, in situations where a significant number of repetitions of a substantial stress range is likely to occur in service so as to constitute fatigue loading, the provisions of nontubular dynamically loaded structures are recommended.

C8.2 Base Metal

Aluminum alloys specifically approved for nontubular statically loaded structures are listed in 8.2.

C8.2.3 When an alloy not listed is considered for use, a special welding investigation is required to confirm the weldability of a specific composition and heat-treated or work-hardened condition.

Part B *Allowable Stresses*

C8.4 Allowable Stresses

Allowable stresses in heat-treated and work-hardened structural alloys may vary with the alloy and the extent of the heat-affected zone.

For allowable stresses for the various available alloys, the user of the Code is referred to the documents listed

in Appendix A, and in particular to the *Specifications for Aluminum Structures* issued by the Aluminum Association.

Part C *Workmanship*

C8.5 Dimensional Tolerances

8.5.1 The flatness tolerances for webs with intermediate stiffeners on both sides are somewhat more liberal than those for interior dynamically loaded girders (see 9.5.2). The tolerance given for intermediate stiffeners, placed only on one side of the web, is the same for either dynamic or static loading and is the same as that for interior dynamically loaded girders.

C8.6 Temporary Welds

Because of the effects of heat on the aluminum structural alloys, it is essential that temporary welds, not incorporated in the final welds, be identified and approved by the Engineer.

C8.8 Quality of Welds

8.8.1 Visual Inspection. These requirements make visual inspection of all welds mandatory and contain the acceptance criteria.

C9. Nontubular Dynamically Loaded Structures

Part A *General Requirements*

C9.1 Application

Sections 1 through 6 are supplemented by the specific requirements of this section to provide a structure capable of serving for a finite period under dynamic and repeated or cyclical loads. Design constraints, except those specifically related to welding and given in this section, should be those of the applicable general specification.

C9.2 Base Metal

All the aluminum alloys that are generally used in welded nontubular dynamically loaded structures are included in the list.

C9.2.3 When an alloy not listed is considered for use, a special welding investigation is required to confirm the weldability of a specific composition and heat-treated or work-hardened condition.

Part B *Allowable Stresses*

C9.4 Allowable Stresses

Allowable stresses in heat-treated and work-hardened structural alloys vary with the alloy and the extent of the heat-affected zone.

For allowable stresses for the various available alloys, the user of the Code is referred to the documents listed in

Appendix A, and in particular to the *Specifications for Aluminum Bridge and Other Highway Structures* issued by the Aluminum Association.

Part C *Workmanship*

C9.5 Dimensional Tolerances

Permissible tolerances for variations from flatness of dynamically loaded girder webs are given in the Code separately for interior and fascia girders. The stricter tolerance for fascia girders is based only on appearance, as there is no structural requirement for the difference. Even the fascia girder distortion permitted will be somewhat noticeable. The fascia tolerances are considered satisfactory for most requirements. If more stringent tolerances are needed for appearance, they should be included in the contract documents, but some distortion is unavoidable.

C9.5.3 Web distortions of twice the amount permitted for interior or fascia girder panels are permitted if the installation of field bolted splice plates will reduce the distortion to the level otherwise permitted. To avoid the possibility of costly field correction, the contractor should determine by a shop assembly that the bolted splice plate will reduce the distortion to acceptable limits.

C9.8 Quality of Welds

The quality requirements set forth in 9.8 are more stringent than those required by 8.8. All weldments are subject to mandatory visual inspection by the contractor.

C10. Tubular Structures

Part A **General Requirements**

C10.1 Application

The requirements of section 10 are intended to be generally applicable to a wide variety of tubular structures. However, welded tubular construction involves new terminology and a sufficient number of unique requirements for design detailing, workmanship, and inspection to fill a separate section of the Code.

The Committee recognized that while using a general format in ANSI/AWS D1.2, *Structural Welding Code—Aluminum*, similar to that of ANSI/AWS D1.1, *Structural Welding Code—Steel*, the types of structures made from aluminum likely would not be of the magnitude of offshore drilling platforms. Further, the Committee also recognized that the workmanship requirements differed greatly among tubular structures.

For these reasons, this Code establishes two classes of tubular structures with different workmanship requirements. Unless otherwise specified, Class I structures are those identified in *Standard Specifications for Structural Supports for Highway Signs, Luminaires, and Traffic Signals*, published by AASHTO (Appendix A). All structures that have more stringent requirements are Class II. There are also certain support structures, in the AASHTO Specifications, that should be treated as Class II structures because of their configuration and loadings.

Additionally, the joint configurations shown in Figures 10.1, 10.2, and 10.3 are intended to apply only to Class II structures. This is because the typical Class I structure most often utilizes fillet welds with member sizes that vary from approximately 3/4 in. (19 mm) NPS to 12 in. (305 mm) NPS.

C10.2 Base Metal

The aluminum alloys listed in 10.2 of the Code include those considered suitable for nontubular statically and

dynamically loaded structures, as well as tubular structures.

While any base metal listed in 1.2.1 may be used for Class I or Class II structures, material availability would likely dictate the specification of the 3000, 5000, and 6000 wrought alloys and 356 and 443 cast alloys.

C10.2.3 When an alloy not listed is considered for use, a special welding investigation is required to confirm the weldability of a specific composition and heat treated or work-hardened condition.

Part B **Allowable Stresses**

C10.4 Allowable Stresses

The Committee recognizes that several specifications exist that specify allowable stresses for aluminum structures. In most cases, these specifications reference the allowable stresses as given in *Specifications for Aluminum Structures—Construction Manual Series*, Section I (see Appendix A). Regardless of the specification used, the Engineer should be aware that the allowable stresses should reflect the difference in strength of welded aluminum versus unwelded aluminum; allowable stresses in heat-treated and work-hardened structural alloys will vary with the alloy and the extent of the heat-affected zone.

Part C **Details of T-, Y-, and K-Connections**

C10.5 Tubular Branch Connections

The definitions of the various types of connections are as shown. The intended application of these joint details is for Class II structures.

Part D
Workmanship—Class I Structures

C10.6 Dimensional Tolerances

Due to the nature of the types of structures covered by the *Standard Specifications for Structural Supports for Highway Signs, Luminaires, and Traffic Signals*, dimensional tolerances for Class I structures should be specified by the Engineer. This is because the tolerances vary greatly between users. Therefore, the provisions of 3.5 would not be applicable.

C10.7 Finishing Cut Edges

Plasma arc cuts, as described in this paragraph, have been successfully used by fabricators for many years. The most common application is for cutting handhole openings for luminaire supports. Other successful applications include cutting for connections of intersecting tubes for cantilever sign support structures. For this reason, the Committee agreed that plasma arc cutting would be permissible for Class I structures.

C11. Strengthening and Repairing Existing Structures

C11.2 Materials

One essential requirement in strengthening and repairing existing structures is the identification of the base metal.

Obviously, when welding is anticipated, weldability of the aluminum alloys in the existing structure is of primary importance. Together with the mechanical properties of the base metal, it will provide information essential for establishment of safe and sound welding procedures. Only then will realistic data be available for reliable cost estimates. Should poor weldability make such cost economically prohibitive, other means of joining should be considered by the Engineer.

Mechanical properties are normally determined by tension testing from a representative sample taken from the existing structure.

If the chemical composition has to be established by test, then it will be advisable to take samples from the greater thicknesses as these are more indicative of the extremes in composition.

C11.3 Design

Repair and strengthening of existing structures differ from new construction, inasmuch as the operations will need to be executed with the structure or the structural element under some condition of working stress.

There is presently little guidance with respect to welding of structural members under stress. Hence, each given situation shall be evaluated on its own merits, and

sound engineering judgement must be exercised as to the optimum manner in which repair or strengthening should be accomplished.

Economy is the obvious underlying consideration when deciding whether a member should be repaired or entirely replaced. However, the cost estimate supporting the decision to be made shall be related not only to material and labor, but also should include the returns from an uninterrupted use of the member or, conversely, the loss due to its time out of service.

Generally, in the case of dynamically loaded structures, sufficient data regarding past service are not available to estimate the remaining fatigue life. If such is the case, an inspection program designed to locate possible fatigue cracks in stable growth prior to their becoming critical is a reasonable alternative.

The only practical methods of extending the expected fatigue life of a member in a given service is to reduce the stress or stress range, or to provide joint geometry less susceptible to fatigue failure.

C11.5 Special

C11.5.1 This Commentary subsection stipulates that the extent of cross-sectional heating must be considered by the Engineer when determining whether dynamic stresses may be carried by the member during welding.

The significance of this provision lies in the fact that the properties of heat-treated and work hardened aluminum alloys are influenced by heat, and their weldability varies considerably.

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