

Specification for Metal Cutting Machine Tool Weldments

 American Welding Society

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machine tool fabrication, machine
tool weldments, metal cutting

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Specification For Metal Cutting Machine Tool Weldments

Third Edition

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Prepared by
AWS Machinery and Equipment Committee

Under the direction of
AWS Technical Activities Committee

Approved by
AWS Board of Directors

Abstract

Requirements are presented for welding during the manufacture of machine tools and components — also for the welding repair of welded machine tool structures and castings. Filler metals are recommended for the applicable base metals consisting of low alloy steels and AISI 304L and 316L stainless steels. Joint designs and unit stresses are provided for fillet and groove welds. The applicable welding processes are shielded metal arc welding (SMAW), submerged arc welding (SAW), flux cored arc welding (FCAW), oxyfuel gas welding (OFW), friction welding (FRW), resistance welding (RW), electron beam welding (EBW), electroslag welding (ESW), electrogas welding (EGW), plasma arc welding (PAW) and stud welding.



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Foreword

(This Foreword is not a part of ANSI/AWS D14.2-93 *Specification for Metal Cutting Machine Tool Weldments*, but is included for information purposes only.)

When the original version of this specification was conceived in 1969, welding and the use of weldments in machine tool design were new to most people in the industry. W. A. Maddox of Cincinnati Milacron, a pioneer in the design of weldments for machine tools, was chosen to form a committee from the industry and lead it in writing the new specification.

AWS D14.2-71 was prepared to guide designers and users in the most effective and economical use of weldments, which would deliver adequate and sustained performance of machine tools and maximum safety to personnel and equipment, and to establish clear, concise practices in fabricating that will be understood by designer, fabricator and user.

In 1975, D14.2-71 was followed by a revision identified as AWS D14.2-Rev 1-75. In 1985, further revisions were made, resulting in ANSI/AWS D14.2-86.

This current edition establishes common acceptance standards for weld performance and process application. It is intended for use in the metal cutting machine tool industry to continue the advancement of welding and increase product reliability in the area of chip making and electrical machining of machine tools. This specification is not intended for **forming** tools (brakes, punches, shear, etc.).

The use of thermosetting and thermoplastic materials for the fabrication of corrosion-resistant equipment will not be discussed in this specification. Such materials and joining procedures are beyond the scope of this specification.

The contributing companies, both manufacturers and users, realized that by joining in the preparation of this document, they would derive the benefits of a higher quality product and the most economical approach to production consistent with the capability of the manufacturer.

Comments or inquiries on this specification are welcome. They should be addressed to Secretary, AWS Committee on Machinery and Equipment, American Welding Society, 550 LeJeune Road, P.O. Box 351040, Miami, FL 33135.

Official interpretations of any of the technical requirements of this standard may be obtained by sending a request, in writing, to the Managing Director, Technical Services Division, American Welding Society. A formal reply will be issued after it has been reviewed by the appropriate personnel following established procedures.

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Specification for Metal Cutting Machine Tool Weldments

1. General Provisions

1.1 Object. The purpose of this specification is to establish practices for the design and fabrication of welded machine tool structures that will promote the following:

- (1) Economical machine tools of high-quality construction
- (2) Adequate initial and sustained performance of equipment
- (3) Safety to personnel and equipment
- (4) Clear, concise practices in fabricating that will be understood by the designer, fabricator, and user
- (5) The conservation of human and material resources in manufacturing and use of equipment
- (6) The general good of the public and of the national economy

Note: The values stated in U.S. customary units are to be regarded as the standard. The SI units are given as equivalent values to the U.S. customary units. The standard sizes and dimensions in the two systems are not identical, and for this reason conversion from a standard size or dimension in one system will not always coincide with the standard size or dimension in the other. Suitable conversions encompassing standard sizes of both can be made, however, if appropriate tolerances are applied in each case.

1.2 Introduction

1.2.1 This specification shall apply when welding is used in the manufacture of any of the following:

- (1) Chip-making machine tool or component thereof
- (2) Electrical machining machine or component thereof

It also shall apply to repair welding of welded machine tool structures.

1.2.2 This specification shall not apply to the manufacture of forming machine tools such as brakes, shears, punches, and similar equipment.

1.2.3 This specification includes sections on materials, design criteria, weld joint design, workmanship, stress-relief heat treatment, inspection and quality control, modification and repair, special requirements for stainless steel, and related information (in Appendices).

1.2.4 This specification establishes the minimum acceptable practice at the time of its publication. It is not intended to restrict new developments nor to inhibit in any way advances in the art of machine tool design engineering. Deviation from this specification as a result of advances in the art should be by mutual agreement between designer and user.

1.3 Nomenclature. The following terms are defined for the purpose of this document:

1.3.1 Metal Cutting Machine Tool. A metal cutting machine tool is a power-driven machine, not portable by hand, designed to remove metal from a workpiece.

1.3.2 Electrical Machining Machine. An electrical machining machine is power driven, not portable by hand, designed to remove metal from a workpiece primarily by the action of a controlled electric current. Included are electrochemical (ECM) machines, electrolytic grinding (ELG) machines, electrodischarge (EDM) machines, and electrolytic deburring equipment.

1.3.3 Designer. The person, company, or agency responsible for the design and performance of a machine tool or machine-tool component.

1.3.4 User. The person, company, or agency that utilizes the machine tool for the intended purpose.

1.3.5 Fabricator. The person, shop, or agency responsible for performing the actual welding. This person may be employed by the designer's company, or may be an independent shop doing work on a sub-contract basis.

1.3.6 Primary Weldment. A primary weldment is one in which failure will immediately affect the performance of the machine. Failure includes breakage, distortion, creep, corrosion, erosion, or other forms of deterioration that will compromise the performance of the machine.

1.3.7 Secondary Weldment. A secondary weldment is one in which failure (as defined in 1.3.6) will not immediately affect the performance of the machine.

1.3.8 All other welding terms used in this specification shall be interpreted in accordance with ANSI/AWS A3.0, *Standard Welding Terms and Definitions*, latest edition. (Also see Appendix A.)

1.4 Welding Symbols, Welding Processes, and Stress Relief

1.4.1 Welding symbols used on drawings shall conform to the latest edition of ANSI/AWS A2.4, *Standard Symbols for Welding, Brazing and Nondestructive Testing*.

1.4.2 When drawings do not contain a complete definition of the welding required, either by explanatory notes or by approved welding symbols, the fabricator shall so advise the designer.

1.4.3 When the design requires a particular process, procedure, or sequence of operations, the drawings shall so specify.

1.4.4 When stress relief is required, the designer shall so specify. Where stress relief appears to be needed, but is not specified, the fabricator shall so advise the designer.

1.5 Safety

1.5.1 Safety shall be a primary consideration in the design and fabrication of every machine tool weldment.

1.5.2 The designer is responsible for the safety of the finished weldment as it is used in the machine tool. The provisions of this specification, plus applicable standards for piping, pressure vessels, fittings,

and safety specifications covering a particular type of machine tool, shall be considered during the design of the machine tool weldment.

1.5.3 The fabricator is responsible for the safety of the welding and other factory operations involved in the fabrication of the weldment. Federal and local regulations for safety in the work place shall be followed. ANSI/AWS Z49.1 covers *Safety in Welding and Cutting*. Additional welding safety considerations are contained in Appendix B.

1.6 References. When specified, the following standards apply and become a part of this specification:

ASME Boiler and Pressure Vessel Code, Section VIII, Unfired Pressure Vessels, and Section IX, Welding Qualifications¹

ANSI B16.5 Steel Pipe Flanges and Flanged Fittings²

ANSI B16.9 Factory Made Wrought Steel Butt Welding Fittings

ANSI B16.11 Forged Steel Fittings, Socket Welding and Threaded

ANSI B16.28 Wrought Steel Butt Welding Short Radius Elbows and Returns

ANSI B31.0 Code for Pressure Piping

ANSI B31.1 Code for Pressure Piping

ANSI B31.1a Code for Pressure Piping

ANSI Z49.1 Safety in Welding and Cutting

ASTM A380 Abrasive blasting³

AWS A2.4 Standard Symbols for Welding, Brazing and Nondestructive Testing

AWS A3.0 Standard Welding Terms and Definitions

AWS A5.1 Specification for Carbon Steel Electrodes for Shielded Metal Arc Welding

AWS A5.4 Specification for Stainless Steel Electrodes for Shielded Metal Arc Welding

AWS A5.5 Specification for Low Alloy Steel Covered Arc Welding Electrodes

AWS A5.9 Specification for Bare Stainless Steel Welding Electrodes and Rods

1. The American Society of Mechanical Engineers, United Engineering Center, 345 East 47th Street, New York, NY 10017.

2. American National Standards Institute, 11 W. 42nd Street, 13th Floor, New York, NY 10036

3. American Society for Testing and Materials, 1919 Race Street, Philadelphia, PA 19103.

AWS A5.17	Specification for Carbon Steel Electrodes and Fluxes for Submerged Arc Welding
AWS A5.18	Specification for Carbon Steel Filler Metals for Gas Shielded Arc Welding
AWS A5.20	Specification for Carbon Steel Electrodes for Flux Cored Arc Welding
AWS A5.23	Specification for Low Alloy Steel Electrodes and Fluxes for Submerged Arc Welding
AWS A5.28	Specification for Low Alloy Steel Filler Metals for Gas Shielded Arc Welding
AWS A5.29	Specification for Low Alloy Steel Electrodes for Flux Cored Arc Welding
AWS B2.1	Welding Procedure and Performance Qualification
AWS D1.1	Structural Welding Code—Steel

2. Materials

2.1 Introduction

2.1.1 This section describes base and filler metals that are normally used in machine tool weldments. The use of materials not covered by this specification shall be approved by the designer.

2.1.2 Electrical machining units covered by this specification shall include equipment for electrochemical machining, electrolytic grinding, and electrolytic deburring. This specification will consider electrodischarge equipment as a conventional machine tool because low-carbon steel is primarily used in its weldments.

2.1.3 Electrical machining equipment makes use of working fluids (electrolytes) that are corrosive to many metals. It is, therefore, necessary to substitute corrosion-resistant materials for the conventionally used structural materials.

2.2 Base Metals

2.2.1 Unalloyed steel covered by this specification shall be low carbon steel (generally AISI 1010 to 1024, or equivalent ASTM grade).

2.2.2 Stainless steel used for tank structures, piping, valves, or any part that is continuously submerged in or contains an electrolyte shall be AISI No. 316L, or an adequately corrosion-resistant grade.

2.2.3 AISI 304L, or an adequately corrosion-resistant grade, may be used for fixtures, tables, or other

components not subject to corrosion conditions as severe as those described in 2.2.2.

2.2.4 When mutually agreed by the designer and user, steel clad with an acceptable grade of stainless steel may be used as a substitute for the similar grade of solid stainless steel plate. The minimum thickness of the stainless steel shall be 20 percent of the composite plate thickness, but in no case less than 0.062 in. (1.6 mm).

2.3 Filler Metals

2.3.1 Filler metals used for low carbon steel shall be compatible with the process and base metal as specified in ANSI/AWS A5.1, A5.5, A5.17, A5.18, A5.20, A5.23, A5.28, or A5.29, latest editions.

2.3.2 Filler metal for welding 316L stainless steel shall be compatible with the process and shall meet, or exceed, the requirements for one of the following AWS electrode classifications: (1) E316L-XX, as specified in A5.4, or (2) ER316L, as specified in A5.9.

2.3.3 Filler metal for welding 304L stainless steel shall be compatible with the process and shall meet, or exceed, the requirements for one of the following AWS electrode classifications: (1) E308L-XX, as specified in A5.4, or (2) ER308L, as specified in A5.9.

2.3.4 Filler metal for stainless steel clad stock should be that recommended by the manufacturer of the clad stock.

3. Design Criteria

3.1 Introduction

3.1.1 This section will describe the general principles by which machine tool components should be designed in order to carry their loads within certain limits of stress and deflection.

3.1.2 In the design of machine tool components, for which rigidity is usually the governing factor, the stresses are generally low [under 3000 psi (20 kPa)] because of the heavy construction used to minimize deflections. In some designs, however, the stresses are much higher and should be computed to ensure that the allowable unit stress of the material and the required deflection limits are not exceeded.

3.2 Designing for Rigidity

3.2.1 Thick plates are often used to keep deflections low, and in such cases, full-strength welds are unnecessary. Due to the rapid cooling of the weld metal

or the high restraint imposed by thick plates, or both, cracks may start in welds which are too small (see Tables 1 and 2). Preheating of the heavy plates in the weld area will retard rapid cooling of the weld metal.

3.2.2 Intermittent fillet welds may be used, provided they agree with 4.4.16.

3.2.3 Partial joint penetration groove welds shall have minimum sizes as shown in Table 2.

3.2.4 Partial joint penetration welds shall have the effective throat determined as shown in Figures 1 and 2. Partial joint penetration submerged arc welds may be assigned a effective throat (E) equal to the full value of "S" for joints shown in Figures 1 and 2.

3.3 Designing for Strength

3.3.1 When the weld is designed for strength, the various types of loading and stresses the weld will be subject to shall be considered.

3.3.2 Base metal sizes and weld sizes shall be computed using the allowable unit stresses.

3.3.3 The designer may apply a greater safety factor to these allowable unit stresses, if so desired.

3.4 Types of Loading

3.4.1 Stresses may result from bending, tension, compression, shear, torsion, or any combination of these factors.

3.4.2 Variable or fatigue loads are loads that cause the welds to be subjected to alternating or cycling (varying) stresses.

3.4.3 Static or steady loads will not cause varying stresses in the welds.

3.5 Allowable (Maximum) Unit Stresses

3.5.1 Allowable unit tensile stress for base metal with static loading shall be 60 percent of the minimum tensile strength of the base metal, as specified in the applicable material specification.

3.5.2 Allowable unit shear stress for base metal with static loading shall be 40 percent of the minimum tensile strength of the base metal, as specified in the applicable material specification.

3.5.3 Allowable unit stresses for static loading on the effective areas (see 3.8) of weld metal shall be as listed in Table 3.

3.5.4 Members subject to repeated variations, or reversals, of stress shall be designed so that the max-

Table 1
Minimum Size of Fillet Welds

Material Thickness of Thicker Part Joined		Minimum Size* of Fillet Weld	
in.	mm	in.	mm
To 1/2 incl.	12.7	3/16	4.8
Over 1/2 to 3/4	12.7-19.0	1/4	6.4
Over 3/4 to 1-1/2	19.0-38.1	5/16	7.9
Over 1-1/2 to 2-1/4	38.1-57.2	3/8	9.5
Over 2-1/4 to 6	57.2-212.4	1/2	12.7
Over 6	212.4	5/8	15.9

*Except that the weld size need not exceed the thickness of the thinner part joined.

Table 2
Minimum Size of Partial Joint Penetration Welds

Material Thickness of Thicker Part Joined		Minimum Size* (E) of Partial Penetration Weld (See Figure 1)	
in.	mm	in.	mm
To 1/2 incl.	12.7	3/16	4.8
Over 1/2 to 3/4	12.7-19.0	1/4	6.4
Over 3/4 to 1-1/2	19.0-38.1	5/16	7.9
Over 1-1/2 to 2-1/4	38.1-57.2	3/8	9.5
Over 2-1/4 to 6	57.2-212.4	1/2	12.7
Over 6	212.4	5/8	15.9

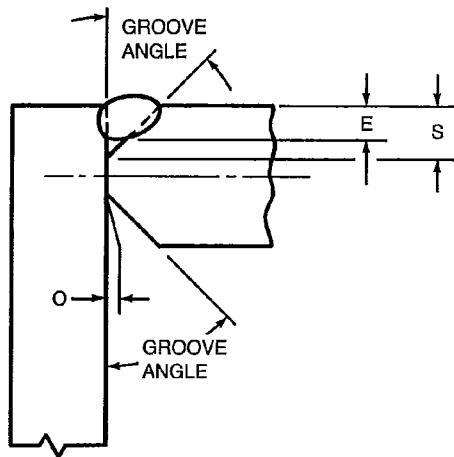
*Except that the weld size need not exceed the thickness of the thinner part joined.

imum stress does not exceed the basic allowable stresses of Table 3, nor the allowable unit stress for fatigue loading given in Figure 3.

3.6 Fatigue Loading. Welds subjected to fatigue loading shall be designed so as not to exceed the fatigue strength of the thinner member.

3.7 Combining Unit Stresses

3.7.1 In the case of axial stress combined with bending, the allowable unit stress of each kind shall be governed by the requirements of Table 3, and



E = EFFECTIVE THROAT OF WELD
 E = S FOR GROOVE ANGLES $\geq 60^\circ$
 E = S - 1/8 in. FOR GROOVE ANGLES $< 60^\circ$
 S = GROOVE DEPTH SPECIFIED

NOTE: MINIMUM ALLOWABLE GROOVE ANGLE = 45°

Figure 1 — Partial Joint Penetration Groove Welds

the maximum combined unit stresses shall be limited accordingly.

3.7.2 When algebraically combining stresses on a weld, the forces shall be resolved to determine the maximum stress point of the weld. The weld size shall be determined by the resultant stress on this point.

3.8 Effective Weld Areas. See 4.3.1 for groove welds, 4.4.11 for fillet welds, and 4.4.14 for plug and slot welds.

3.9 Design of Full-Strength Fillet Welds

3.9.1 When the weld is designed for strength, if the full strength of the thinner plate must be developed in the welds, the fillet weld sizes from Table 4 may be used, provided that (1) the welds are loaded statically, (2) the welds are stressed within the allowable limits, and (3) the thinner plate is welded continuously on both sides.

3.9.2 If intermittent welding is used for full strength, the weld sizes and lengths shall be proportioned so that the total throat area is equal to or greater than the continuous total throat area of the weld sizes in Table 4.

3.10 Stress Relief. Major weldments wherein distortion during machining of the weldment or operation of the machine tool will be unacceptable to the designer, and those weldments subjected to fatigue loading, should have residual stresses relieved according to the provision of 6, Stress Relief and Heat Treating.

3.11 Secondary Weldments. Parts such as guards, cabinet enclosures, troughs, tanks, brackets, etc., shall be welded to meet the functional requirements of their applications.

4. Weld Joint Design

4.1 Introduction

4.1.1 This section describes the various weld joints that are used in the fabrication of metal cutting machine tools.

4.1.2 Weld joints shall be designed according to the service to which they will be subjected.

4.2 Weld Joint Nomenclature. Weld joint nomenclature shall be as shown in Figures 4 and 5 and in accordance with the latest edition of ANSI/AWS A3.0, *Standard Welding Terms and Definitions*.

4.3 Details of Groove Welds

4.3.1 For design calculations, the effective area shall be the effective weld length multiplied by the effective throat thickness, except as follows:

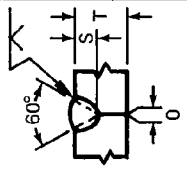
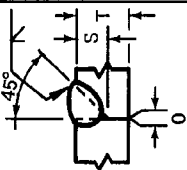
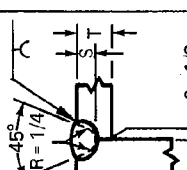
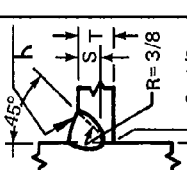
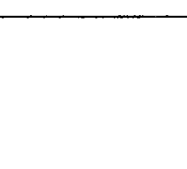
(1) The effective length of a skewed groove weld shall be the length dimension as projected to a plane perpendicular to the direction of stress (i.e., it shall not exceed the width of the parts joined).

(2) The effective throat thickness (E) of a complete joint penetration weld shall be no greater than the thickness of the member joined.

4.3.2 The effective throat thickness (E) of a complete joint penetration weld shall be the thickness of the thinner piece of base metal joined. (Weld reinforcement is not considered part of effective throat thickness.)

4.3.3 The effective throat thickness (E) of a partial joint penetration bevel-groove weld with less than 60° degree included angle preparation shall be established by subtracting 1/8 in. (3.2 mm) from the groove depth (S) (see Figure 1).

4.3.4 The effective throat thickness (E) of a partial joint penetration groove weld with 60° degrees or greater

WELDS JOINTS	V-GROOVE WELD		BEVEL-GROOVE WELD		U-GROOVE WELD		J-GROOVE WELD	
	SINGLE V-GROOVE WELD (2)	DOUBLE V-GROOVE WELD (3)	SINGLE-BEVEL- GROOVE WELD (4)	DOUBLE-BEVEL- GROOVE WELD (5)	SINGLE-U-GROOVE WELD (6)	DOUBLE-U-GROOVE WELD (7)	SINGLE-J-GROOVE WELD (8)	DOUBLE-J-GROOVE WELD (9)
BUTT (B) T (T) OR C CORNER (C) JOINT	 EFFECTIVE THROAT (E) = S* BC-P2	 EFFECTIVE THROAT (E) = S* B-P3	 EFFECTIVE THROAT (E) = S - 1/8 BTC-P4	 EFFECTIVE THROAT (E) = S - 1/8 BTC-P5	 EFFECTIVE THROAT (E) = S* BC-P6	 EFFECTIVE THROAT (E) = S* B-P7	 EFFECTIVE THROAT (E) = S* BTC-P8	 EFFECTIVE THROAT (E) = S* BTC-P9

*EFFECTIVE THROAT (SEE TABLE 2 AND FIG. 4 FOR GROOVE ANGLES AS NOTED IN SKETCHES).

NOTE: GROOVE DEPTH (S) AND EFFECTIVE THROAT (E) SHOULD BE SHOWN ON THE WELD SYMBOL AS FOLLOWS:

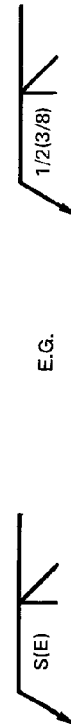


Figure 2 — Partial Joint Penetration Shielded Metal Arc Welded Joints

Table 3
Unit Stresses in Welds

Kind of Stress	Allowable Unit Stress	Matching ¹ ASTM Base Metal
Tension and compression parallel to the axis of any groove or fillet weld.	Same as allowable shear stress for base metal ²	-----
Tension normal to effective throat of complete-penetration groove weld.	Same as allowable tensile stress for base metal ²	-----
Compression normal to effective throat of complete-or partial-penetration groove welds.	Same as allowable compressive stress for base metal ²	-----
Shear on effective throat of complete penetration groove weld.	Same as allowable for shear stress for base metal.	-----
Shear stress ³ on effective throat of fillet weld and partial-penetration groove weld regardless of direction of application of load; tension normal to the axis on the effective throat of a partial-penetration groove weld; and shear stress on effective area of a plug or slot weld. The given unit stresses shall also apply to such welds made with the specified electrode on steel having a yield strength greater than that of the matching base metal. The permissible unit stress, regardless of electrode classification used, shall not exceed that given in the table for the weaker matching base metal being joined.	18,000 psi (124 MPa) - using AWS A5.1, A5.17, or A5.20 filler metals whose classified minimum tensile strength is 60 ksi (414 MPa) 21,000 psi (145 MPa) - using AWS A5.1, A5.5, A5.17, A5.18, A5.20, A5.23, or A5.29 filler metals whose classified minimum tensile strength is 70 ksi (483 MPa)	A500, Grade A; and A570, Grade D A36; A53, Grade B; A500, Grade B; A501; A529; A570, Grade E

1. Steels having a tensile strength essentially equal to that required of an electrode classification can be regarded as "matching" steels.

2. Steels without ASTM specifications may be used for machine tool construction, provided the mechanical properties of the steel are acceptable to the designer.

3. For definition of effective throat of fillet and partial-penetration groove welds see 4.3, 4.4.11 and 4.4.12.

included angle preparation shall be equal to the depth of joint preparation (S). (See Figure 1)

4.3.5 Root openings should be limited to the dimensions noted in the recommended proportions of weld joint geometry of 4.5.

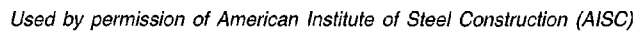
4.4 Details of Fillet Welds

4.4.1 Where fillet welds are used and the space between abutting surfaces exceeds 1/16 in. (1.6 mm), the fillet weld size shall be increased by the amount of the opening.

4.4.2 No allowance for penetration into the plate surfaces at the root of a fillet weld shall be made when computing the effective throat, except when sectioned test pieces show that the welding procedure gives penetration >3/32 in. (2.4 mm) beyond the root of the joint. Then the effective throat may be considered to extend from the root of the weld to the face of the weld as defined in Figure 4(B).

4.4.3 The details of fillet welds are listed in the following paragraphs and detailed in Figure 6.

4.4.4 In joints connected only by fillet welds, the minimum size of the fillet weld to be used shall be



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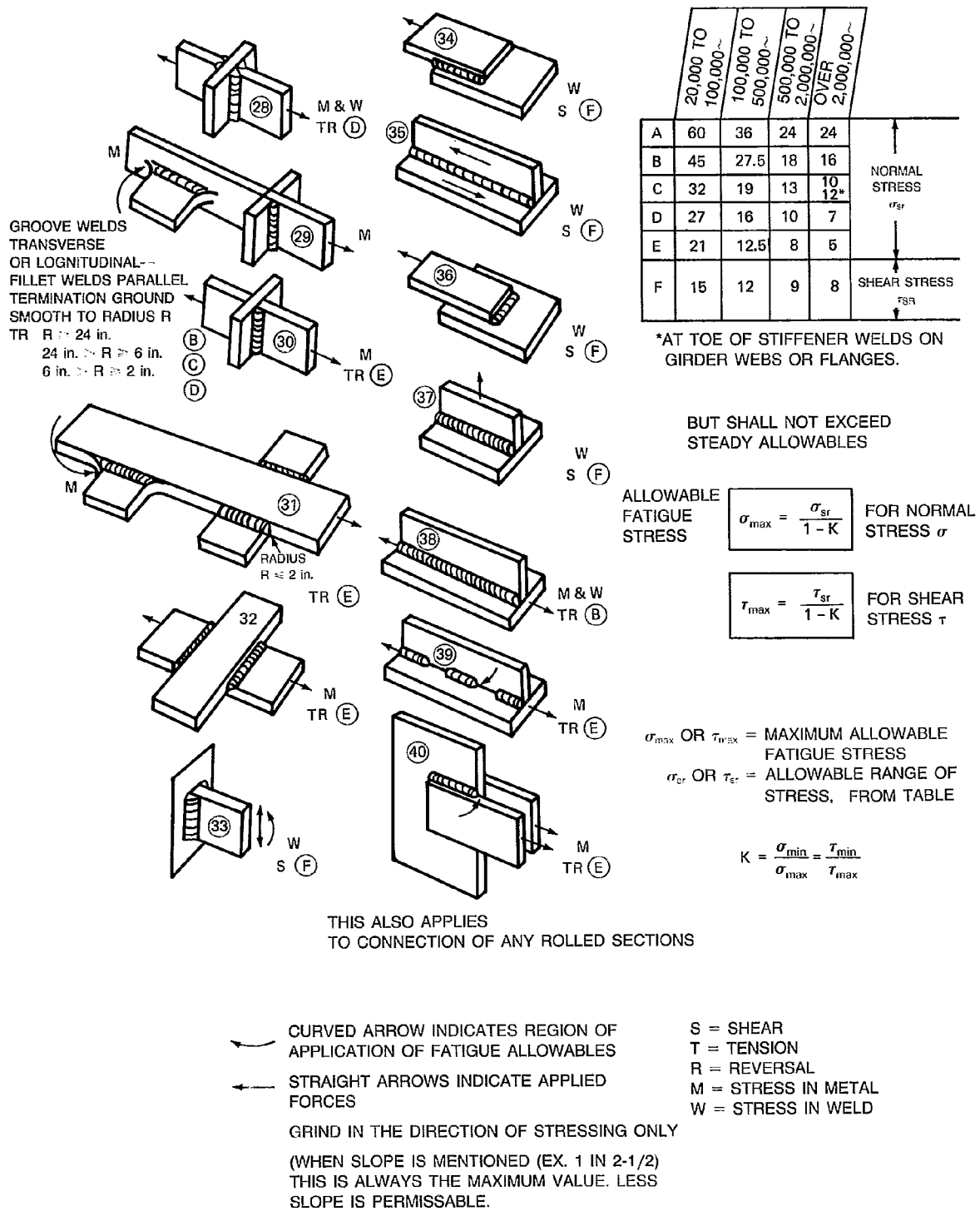


Figure 3 (Continued) — Allowable Fatigue Stress (KIPS)

Table 4
Size of Full-Strength Fillet Welds

Thinner Plate Thickness (t)		Full Strength Weld Size $\mu = 3/4 t^*$		Thinner Plate Thickness (t)		Full Strength Weld Size $\mu = 3/4 t^*$	
in.	mm	in.	mm	in.	mm	in.	mm
1/4	6.4	3/16	4.8	1-3/8	34.9	1	25.4
5/16	7.9	1/4	6.4	1-1/2	38.1	1-1/8	28.6
3/8	9.5	5/16	7.9	1-5/8	41.3	1-1/4	31.8
7/16	11.1	3/8	9.5	1-3/4	44.4	1-3/8	34.9
1/2	12.7	3/8	9.5	2	50.8	1-1/2	38.1
9/16	14.3	7/16	11.1	2-1/8	54.0	1-5/8	41.3
5/8	15.9	1/2	12.7	2-1/4	57.2	1-3/4	44.4
3/4	19.1	9/16	14.3	2-3/8	60.3	1-3/4	44.4
7/8	22.2	5/8	15.9	2-1/2	63.5	1-3/4	44.4
1	25.4	3/4	19.1	2-5/8	66.7	1-7/8	47.6
1-1/8	28.6	7/8	22.2	2-3/4	69.9	2	50.8
1-1/4	31.8	1	25.4	3	76.2	2-1/4	57.2

* μ - leg size of fillet weld.

as shown in Table 1.⁴ Minimum weld size is determined by the thickness of the two parts joined, except that the weld size need not exceed the thickness of the thinner part joined.

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

(1) Along edges less than 1/4 in. (6.4 mm) thick, the maximum size may be equal to the thickness of the material.

(2) Along edges 1/4 in. (6.4 mm) or more in thickness, the maximum size shall be 1/16 in. (1.6 mm) less than the thickness of the material unless the drawings specify that the weld is to be built out to obtain full throat thickness as illustrated in Figure 6(A) or (B).

4.4.6 The minimum effective length of a fillet weld shall be 4 times its size and in no case less than 1-1/2 in. (38.1 mm).

4. The size of a fillet weld is not controlled by the thickness of material as is the size of a groove weld. Experience and engineering judgement, however, show that smaller fillet welds than those in the table, when used on thick material, may crack because of hardening of the heat-affected zone created by rapid chilling, or because of the disproportionate restraint of the thick material. The limits specified are those developed by practical welding experience and represent the smallest single pass fillet welds that should be used on various thicknesses of steel when requirements of calculated stress do not require large welds.

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

4.4.8 Fillet welds in holes or slots may be used to transmit shear in lap joints, or to prevent the buckling or separation of lapped parts. Fillet welds in a hole or slot may overlap, subject to the provisions of 4.4.3 and 4.4.12.

4.4.9 Seal welding shall be accomplished by a continuous weld around the joint to form a leak-tight structure.

4.4.10 Fillet welds may be used in skewed joints that have an acute angle of not less than 60 degrees. Permitted forms of such joints are detailed in Figure 6(C) and (D).

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

4.4.12 The effective length of a straight fillet weld shall be the overall length of the full-size fillet, in-

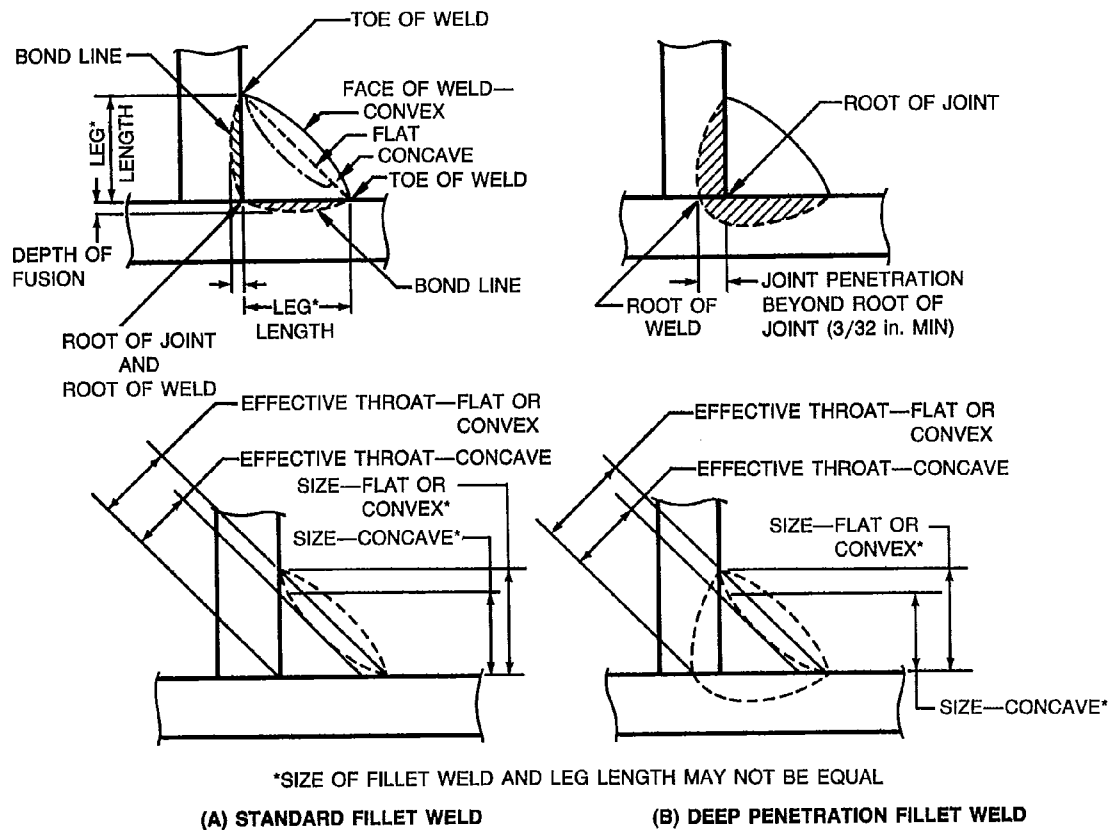


Figure 4 — Fillet Weld Types and Nomenclature

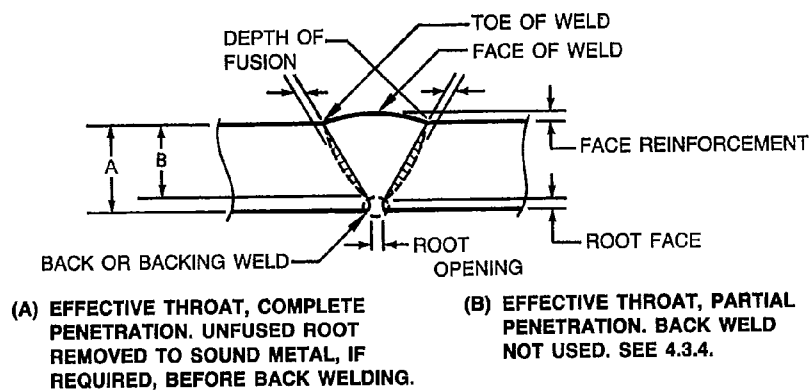


Figure 5 — Nomenclature for Single-V-Groove Weld in a Butt Joint

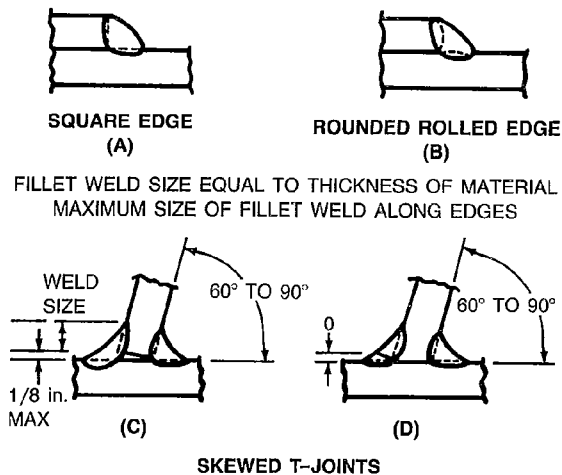


Figure 6 — Details for Fillet Welds

cluding end returns. The effective length of a curved fillet weld shall be the length of the line generated by the center-point of the effective throat thickness. For a fillet weld in a hole or slot, if the weld area computed from this length is greater than the area found by 4.4.14, this latter area shall be used as the effective area of the fillet weld.⁵

4.4.13 The effective throat thickness shall be the shortest distance from the root of the weld to the diametric face of the weld (see Figure 4).

4.4.14 Plug and Slot Welds. The effective area shall be the nominal area of the hole or slot in the plane of the faying surface. These welds shall be computed to resist shear stresses only on this effective area.

4.4.15 Filling of plug welds flush is not required.

4.4.16 Requirements for intermittent fillet welds for primary weldments are as follows (see 1.3.6):

(1) Minimum length of each weld shall be 1-1/2 in. (38.1 mm).

(2) At least 25 percent of the joint shall be welded.

(3) Maximum clear spacing, end to end, of welds shall be 12 times the thickness of the thinner part, but not more than 8 in. (203.2 mm).

(4) An intermittent fillet weld shall terminate with welds at each end of the joint.

5. Note differentiation between plug or slot welds and fillet welds in holes or slots.

4.5 Recommended Proportions of Weld Joint Geometry

4.5.1 Figures 7, 8, 9, 10, and 11 show recommended weld joint geometry to use with various welding processes.

4.5.2 In reference to Figure 11, the corner-to-corner joint (A) is difficult to assemble and weld because neither plate can be supported by the other. A small electrode with low current should be used to prevent melt-through, and a large amount of weld metal is required. The joint (B) requires half as much weld metal as (A). The joint (C) requires half the weld metal of (A), but will have the same throat section when the inside weld is made the same size as the outside weld. The joint (D) makes an economical joint, and the weld is invisible from one direction.

For thin plates, 1/4 in. (6.4 mm) max, joint (E) may be used. When heavier plates are used, a partial-joint-penetration weld may be used as shown in (F). If machining is required, it should be done on the unwelded face if possible (G). If machining is required on the welded face, the weld should be increased to provide finish allowance (F). Care should be taken when making welds close to the edges of plates to prevent excessive burning or "scallop" of edges unless the edge is to be ground. A weld size slightly smaller, 1/16 in. (1.6 mm), than the outstanding leg(s) of plate will result in a smoother appearing weld (see 4.4.5).

5. Workmanship

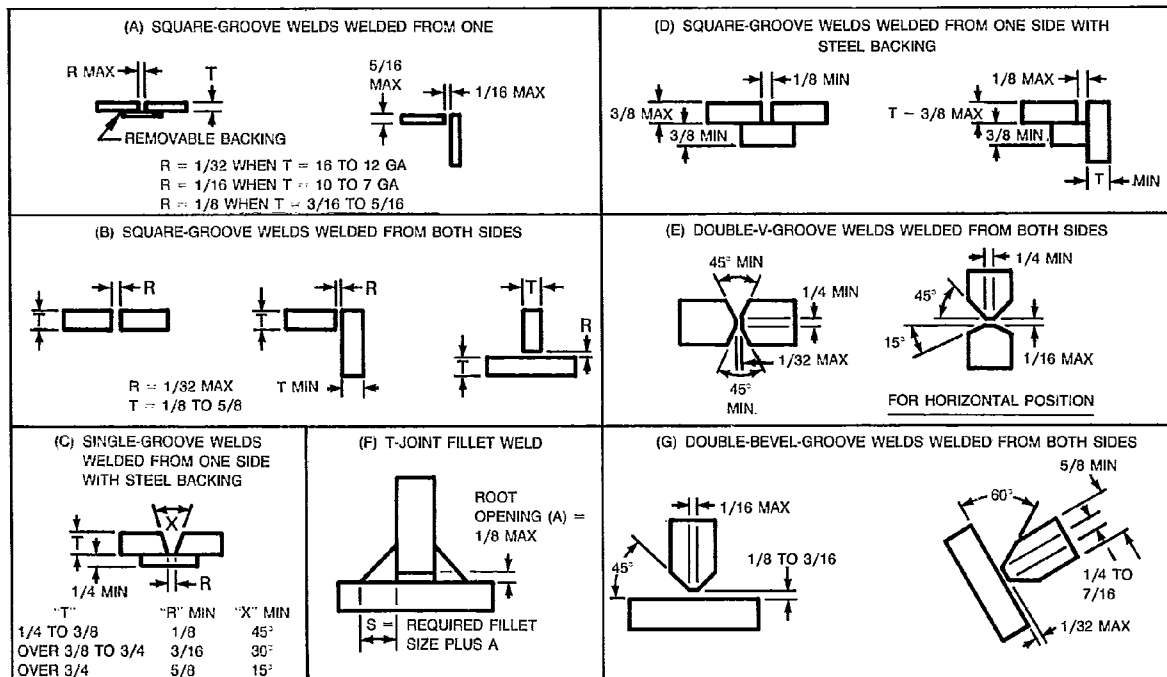
5.1 Introduction

5.1.1 This section describes the workmanship criteria that shall be required in the production and inspection of weldments.

5.1.2 The sizes and length of welds shall not be less than those specified on the detail drawings, nor shall they be in excess of the design tolerances. The location of welds shall not be changed without written approval from the designer.

5.2 Qualification

5.2.1 Qualification of welding procedures and welder performance, when specified by the designer, shall be in accordance with the latest edition of ANSI/AWS D1.1, *Structural Welding Code—Steel* or B2.1, *Welding Procedure and Performance Qualification* or other nationally recognized standard.



(ALL DIMENSIONS ARE IN INCHES. FOR METRIC CONVERSION, SEE APPENDIX C)

Figure 7 — Recommended Grooves for Submerged Arc Welding

5.2.2 Welding qualifications for pressure vessels attached to or incorporated into machine tools, shall comply with Section IX, *ASME Boiler and Pressure Vessel Code—Steel*.

5.3 Preparation of Material

5.3.1 Surfaces to be welded and any adjacent surfaces within 2 in. (50.8 mm) of the weld shall be free from slag, grease, moisture, or other material that will interfere with proper welding.

5.3.2 Stock used for weldment members shall be free of nicks, burrs, bends, warpage, and gouges, except those not exceeding 5 percent of stock thickness and those that will be removed when machining.

5.3.3 All bends shall be free of ruptures in grain fibers. Sharp impressions or markings caused by forming shall not exceed 5 percent of stock thickness.

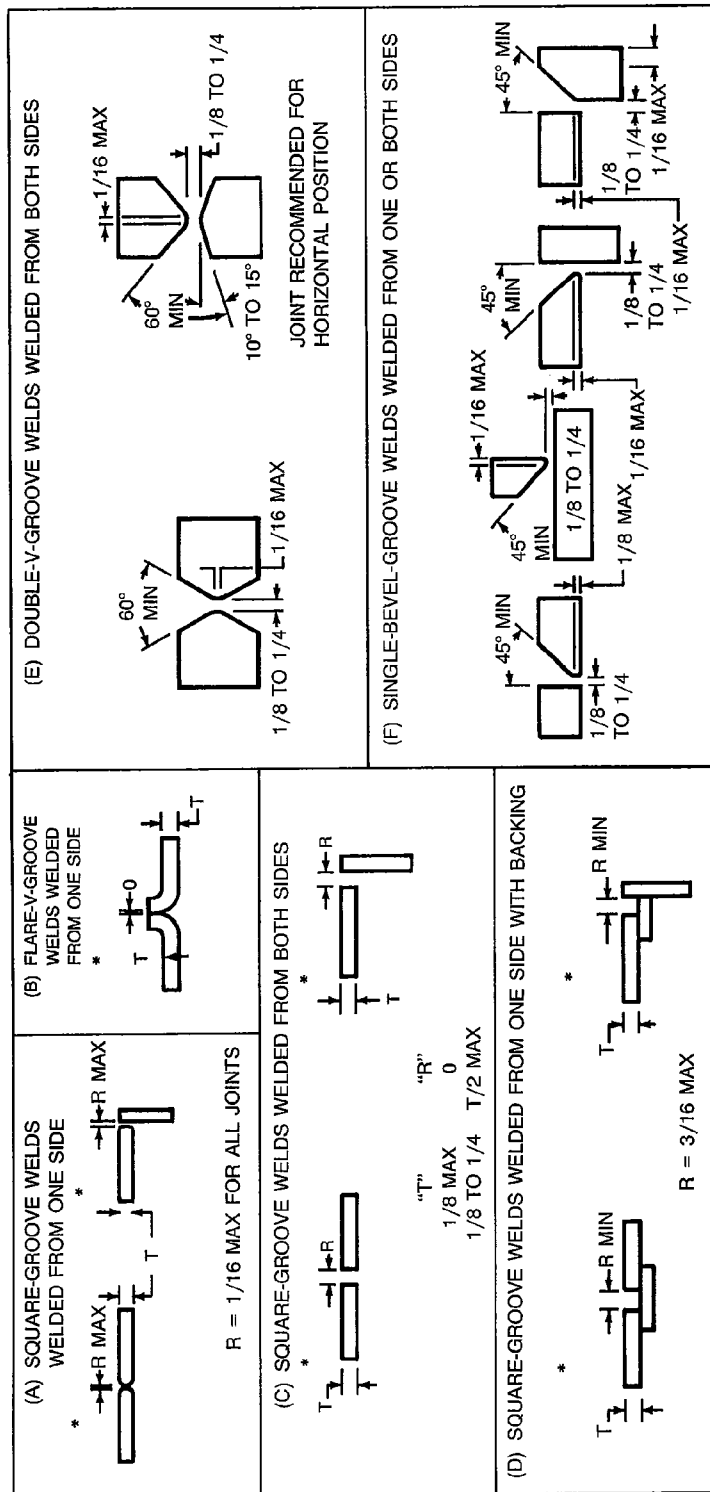
5.3.4 All cut surfaces on external areas shall have a smooth and regular surface, free of cracks and notches.

5.4 Assembly

5.4.1 Parts to be joined by fillet welds shall be brought into as close contact as practicable, but a small gap, 1/32 in. (0.8 mm), shall remain to permit movement of the parts as the weld contracts upon solidification.

5.4.2 Members to be welded shall be brought into correct alignment and held in position by suitable devices, or by tack welds, until welding has been completed. Jigs and fixtures should be used where practicable.

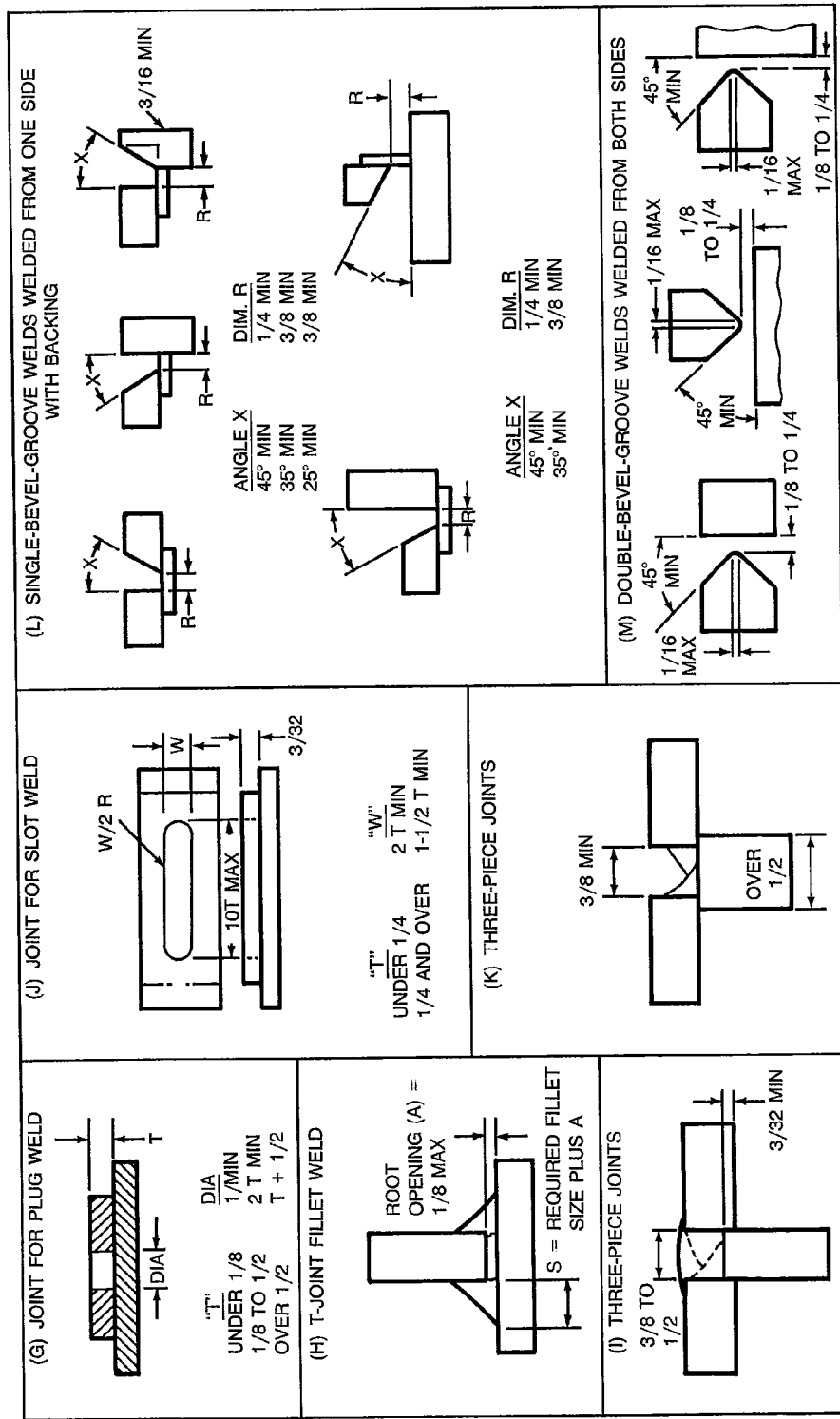
5.4.3 Tack welds shall be subject to the same quality requirements as final welds except that visible external tack welds not incorporated into the final weld shall be removed, and the surface shall be made flush with the original surface. Tack welds incorporated into the final weld shall be thoroughly cleaned before welding over. Multiple-pass tack welds shall have cascaded ends.



(ALL DIMENSIONS ARE IN INCHES. FOR METRIC CONVERSION, SEE APPENDIX C)

NOTE: FIGURES DESIGNATED * MAY BE USED WITH GAS METAL ARC WELDING PROCESS AS WELL AS OTHER PROCESSES MENTIONED.

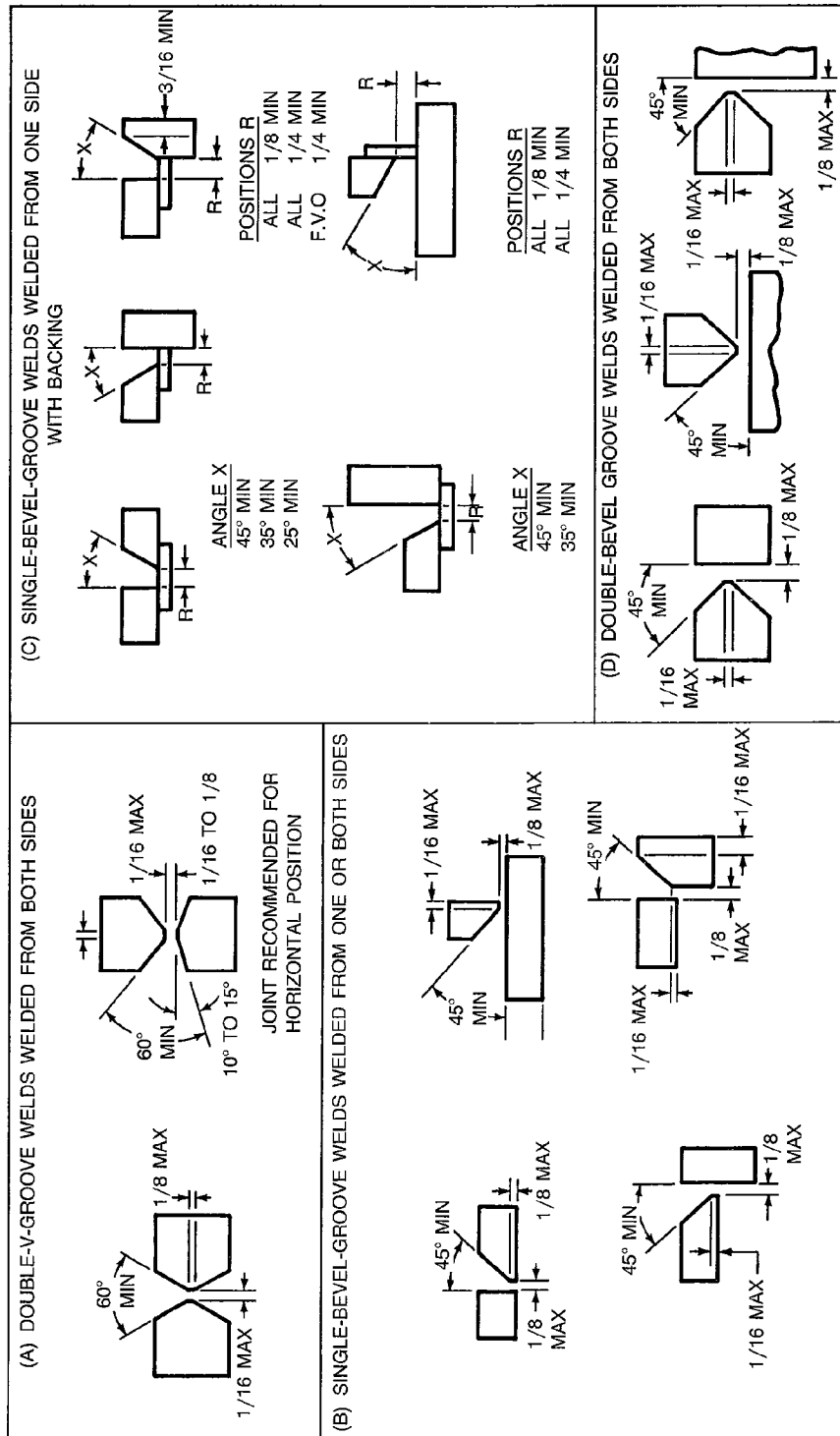
Figure 8—Recommended Grooves for Shielded Metal Arc, Gas Tungsten Arc, Flux Cored Arc, Oxyfuel gas, and Plasma Arc Welding Processes



NOTE: FIGURES DESIGNATED * MAY BE USED WITH GAS METAL-ARC WELDING PROCESS AS WELL AS THE OTHER PROCESSES MENTIONED.

(ALL DIMENSIONS ARE IN INCHES. FOR METRIC CONVERSION, SEE APPENDIX C)

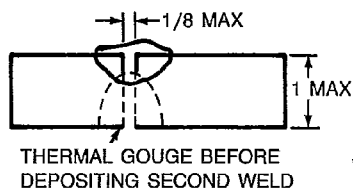
Figure 8 (Continued) — Recommended Grooves for Shielded Metal Arc, Gas Tungsten Arc, Flux Cored Arc, Oxyfuel gas, and Plasma Arc Welding Processes



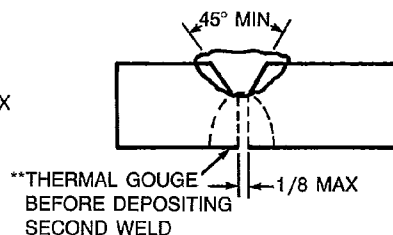
(ALL DIMENSIONS ARE IN INCHES. FOR METRIC CONVERSION, SEE APPENDIX C)

Figure 9 — Alternative Recommended Grooves for Gas Metal Arc Welding and Gas Tungsten Arc Welding

(A) MODIFIED SQUARE GROOVE

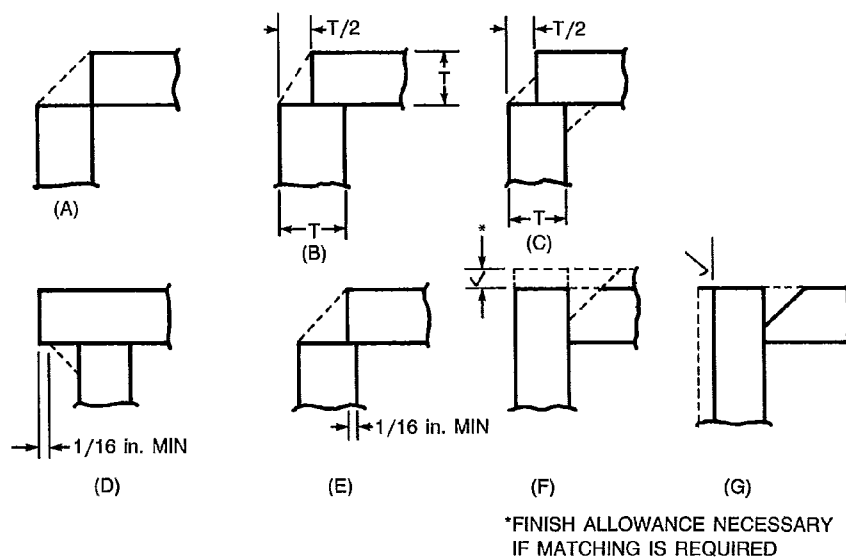


(B) MODIFIED SINGLE-V GROOVE



NOTE: **ONLY IF REQUIRED FOR STRENGTH

(ALL DIMENSIONS ARE IN INCHES. FOR METRIC CONVERSION, SEE APPENDIX C)

Figure 10 — Recommended Mixed Grooves for All Arc Welding Processes

(ALL DIMENSIONS ARE IN INCHES. FOR METRIC CONVERSION, SEE APPENDIX C)

Figure 11 — Recommended Welded Corner Joints for Shielded Metal Arc, Gas Tungsten Arc and Flux Cored Arc Welding, Oxyfuel Gas Welding, Gas Metal Arc Welding and Plasma Arc Welding Processes

5.4.4 Where the design shows a continuous, unbroken surface, the welding together of several pieces to make this surface should be avoided, especially for external members.

5.5 Control of Distortion and Shrinkage Stresses. In assembling and joining parts of a weldment, the procedure and sequence should be designed to minimize distortion and shrinkage. Insofar as practicable, all welds shall be deposited in a sequence that will balance the shrinkage as welding progresses.

5.6 Quality of Welds

5.6.1 Welds shall have no cracks as revealed by the inspection method specified by the designer (see 7.5).

5.6.2 There shall be complete fusion between weld and base metal and between successive passes in the weld.

5.6.3 All craters shall be filled to within + 10 percent of the full cross section of the weld.

5.6.4 Weld overlap shall not exceed 1/16 in. (1.6 mm) beyond the fusion line of the weld.

5.6.5 Undercut shall not exceed the lesser of 5 percent of the base metal thickness, or 1/32 in. (0.8 mm).

5.6.6 All weld joints shall be in accordance with applicable paragraphs of 4, Weld Joint Design.

5.7 Fabricator Identification. Fabricators shall identify all major assemblies or parts that they have fabricated with a distinguishing mark on a surface where it will be retained after machining and will be visible in normal use.

5.8 Finish Standards for Steel Weldments

5.8.1 No. 1 Finish – Premium Weldment Quality. (Only employed on machine parts requiring superior appearance.) All external weld spatter shall be removed. All external welds shall be ground removing lumps and projections; external butt joint welds shall be ground flush, except on machined surfaces and underside of bottom. All nicks and imperfections in cut surfaces shall be repaired. All edges of electrical conduit passages shall be broken to a smooth, slightly rounded contour. All scars, arc strikes, and imperfections on outside plate surfaces shall be repaired, except on machined surfaces and underside of bottom.

5.8.2 No. 2 Finish – Good Weldment Quality. (Used on machinery parts requiring a good commercial appearance.)

All external weld spatter shall be removed. External welds shall be ground, removing lumps and other objectionable discontinuities. No attempt should be made to make corners entirely smooth. Serious nicks and defects in cut surfaces shall be repaired. All edges of electrical conduit passages shall be broken. Scars on outside of plate shall be repaired, except surfaces to be machined and underside of bottom.

5.8.3 No. 3 Finish – Utility Weldment Quality. Weld spatter shall be removed; do not break edges or grind welds.

5.8.4 All Finishes. All finishes shall be descaled by abrasive blasting or other methods as specified, and primed as specified by the designer. The inside surfaces of weldments which are not accessible to the blasting do not have to be free of scale, slag, or other foreign material. All openings shall be covered during blasting to exclude stray blasting material. Loose scale, stray shot, and foreign material shall be removed from compartments where specified.

5.8.5 Any weldment within the scope of piping or pressure vessel codes listed in 1.6 shall be treated according to the requirements of those codes.

5.9 Dimensional Tolerances. The dimensions of weldments shall be within the tolerances listed, or as agreed between the designer and fabricator.

5.10 Flatness. Flatness is the condition of a surface having all elements in one plane. A flatness tolerance zone is confined by two parallel planes within which

Table 5
Surface Flatness Tolerances

Surface Area		Surface Flatness 2*			
		To be Machined		Not to be Machined	
sq.ft	sq.m	in.	mm	in.	mm
Up to 4	0.4	0.12	3.2	0.16	4.0
Up to 8	0.7	0.16	4.0	0.19	4.8
Up to 16	1.5	0.19	4.8	0.25	6.4
Up to 32	3	0.25	6.4	0.31	7.9
Up to 64	6	0.31	7.9	0.38	9.5
Up to 128	12	0.38	9.5	0.44	11.1
Over 128	---	0.44	11.1	0.50	12.7

*Dimension is distance between planes defining the surface.

the surface should lie. Table 5 gives surface flatness tolerances.

5.11 Squareness and Parallelism. Square and parallel surfaces should lie within their flatness tolerance zones, as shown in Table 5, and also within their location tolerances as shown in Table 6.

5.12 Location of Welded Members and Overall Size. The dimensions of the fabrication (including overall size, hole diameters, location dimensions, etc.) shall agree with the design dimensions subject to the tolerances given in Table 6.

6. Stress Relief and Heat Treating

6.1 Introduction. This section describes the various methods used to increase the stability of a machine tool weldment. Additional helpful information may be found in Appendix A3.

6.2 Stress Relief Heat Treatment

6.2.1 Stresses created during the manufacture of a weldment, or which were residual in the raw material, may be reduced by stress relief heat treatment. This is a process which:

- (1) Raises the temperature of a weldment at a controlled rate to a level near the lower critical temperature for that metal (heating cycle)
- (2) Maintains that elevated temperature for a specified time period (holding cycle)
- (3) Lowers the temperature at a controlled rate (cooling cycle)

6.2.2 The furnace work supports shall be "leveled out" so that they are within 1/8 in. (3.2 mm) of each other.

6.2.3 When two or more items are heated at the same time, they shall be spaced so that all pieces will heat uniformly.

6.2.4 Baffles shall be placed to protect the work from direct impingement of the flame of furnace burners.

6.2.5 The furnace temperature shall be controlled and recorded from a thermocouple placed in the arch of the furnace, above and close to the work. On large weldments and other important structures, the recorder(s), shall also read and record the true work temperature from thermocouples placed within the weldment and shielded from direct impingement of the flame. These charts shall show the location of each thermocouple, the chart temperature scale, weldment

Table 6
Location And Overall Size Tolerances

Design Dimension		Tolerances (+) (Plus or Minus)			
		To be Machined		No to be Machined	
in.	mm	in.	mm	in.	mm.
Up to 24	0.6	0.06	1.5	0.06	1.5
Up to 48	1.2	0.12	3.2	0.12	3.2
Up to 72	1.8	0.18	4.7	0.25	6.4
Up to 96	2.4	0.25	6.4	0.38	9.5
Over 96	---	0.38	9.5	0.50	12.7

name, part number, and serial number. These data shall become a part of the weldment history folder and shall be available for at least 5 years. See Appendix A3 for additional information.

6.2.6 Heating Cycle. The proper heat treatment of a weldment requires that it be loaded into a furnace with a temperature below 200°F (93°C). The furnace temperature shall then be raised at a rate that will not cause cracking or warpage during the heating cycle. After the furnace temperature reaches 600°F (316°C), the furnace temperature should be elevated at a rate not exceeding 200°F (93°C) per hour until the weldment reaches the holding temperature.

6.2.7 Holding Cycle. The holding cycle is the period during which the weldment is held at the specified temperature. Unless otherwise specified, the holding time shall be 1 hour, plus 1 additional hour for each inch of thickness of the thickest section of the fabrication.

When the weldment is fabricated from low carbon steel, its holding temperature shall not be less than 1200°F (649°C), nor more than 1300°F (704°C); the exact range depends on the shape and size of the work. See Appendix A3 for additional information.

The weldment temperature for the holding cycle should be specified on the drawing. If not specified, a 1200°F (649°C) to 1250°F (677°C) range is satisfactory.

6.2.8 Cooling Cycle. The weldment shall be cooled at a rate not to exceed 200°F (93°C) per hour until the temperature is below approximately 600°F (316°C), when the furnace door may be opened. The weldment temperature shall be below 300°F (149°C) before it is removed from the furnace.

Blowers shall not be used to increase the rate of temperature reduction during the cooling cycle.

6.3 Other Methods of Stress Relief. If other methods of stress relief, such as peening or vibration, are to be employed, they shall be used only with the approval of the designer.

7. Inspection and Quality Control

7.1 Introduction

7.1.1 This section describes the inspection and quality control procedures that apply to metal cutting machine tool weldments.

7.1.2 When required by the contract, the inspector designated by the designer shall ascertain that all fabrication is performed in accordance with the requirements of this specification and the designer's specification.

7.1.3 The inspector shall be furnished with complete detailed drawings, specifications, or data showing the size, length, type, and location of all welds to be made.

7.2 Inspection of Materials. The inspector shall determine that only materials conforming to the specification of the designer are used.

7.3 Inspection of Work and Records

7.3.1 The inspector shall ascertain that the size, length, and location of welds conform to the requirements of this specification and to the detail drawings, that no specified welds are omitted, and that any unspecified welds are acceptable to the designer.

7.3.2 The inspector may, at suitable intervals, observe the technique and performance of each welder and welding operator to make certain that the applicable requirements of 5, Workmanship, are met.

7.3.3 The inspector shall examine the work to make certain that it meets the requirements of 5, Workmanship. Size and contour of welds shall be measured with suitable gages. Welds shall show no indication of cracks, as revealed by the inspection method specified by the designer (see 7.5).

7.3.4 The inspector shall identify with a distinguishing mark, in an accessible area not to be subsequently machined, all fabrications that the inspector has inspected and accepted.

7.3.5 The inspector shall determine that the fabricator's mark is in accordance with 5.7.

7.4 Obligation of the Fabricator

7.4.1 The fabricator shall correct improper workmanship and correct or replace all welds that do not comply with the contract drawings and specifications or with this specification.

7.4.2 All changes and corrective work shall be made in accordance with the applicable paragraphs of 8, Modification and Repair.

7.5 Inspection. When inspection is required, it shall be so stated in the information furnished to the fabricator. This information shall designate the welds to be examined, the extent and method of examination, and the acceptance criteria for each weld.

8. Modification and Repair

8.1 Introduction

8.1.1 This section describes criteria for modifying and repairing new and existing metal cutting machine tool weldments.

8.1.2 The term *modify* shall be interpreted as any addition or reconstruction of fabrication due to a change by the designer during fabrication or in use.

8.1.3 The term *repair* shall be interpreted as any necessary correction.

8.1.4 Modification and repair work shall conform to all applicable sections of this specification.

8.1.5 No deviations from design drawings and specifications shall be made without the designer's concurrence. Modifications should be accompanied by design drawings. In lieu of revised drawings, when time or other factors are problematic, the fabricator should record instructions, time, and source of authorization and provide a copy of same to the designer.

8.1.6 Repairs shall be made only with the designer's concurrence.

8.2 Changes During Fabrication Prior to Stress Relief

8.2.1 Modifying, by additions of material, may be done at any time, provided additions do not inhibit inspection.

8.2.2 When modification is accomplished by removal of material, the designer shall determine if adequate design strength is maintained to satisfy the requirements of the structure.

8.2.3 Plug or slot welds are permissible when access to work is from one side, or when plates are to be held flat to the base metal.

8.2.4 No additional member shall be welded on the fillet weld of a previous joint.

8.2.5 Repairs shall conform to all applicable sections of this specification.

8.2.6 Repair of excess warpage of weldments may be done by heating or peening influential sections while properly supporting the structure in a free state (see 6.3).

8.3 Changes After Stress Relief

8.3.1 Modifications which do not affect dimensional stability do not require additional stress relief.

8.3.2 Modifications which do affect dimensional stability shall require additional stress relief.

8.3.3 Partial removal of an area for clearances, etc. should be by machining to avoid or minimize distortion. Grinding or hand filing may also be used.

8.3.4 Where dimensional stability may be affected, attachments such as brackets, shelves, or extensions should be bolted rather than welded.

8.3.5 Repair workmanship shall conform to all applicable sections of this specification.

8.4 Changes After Machining and In Use

8.4.1 All changes to the fabrication during this period shall be done in a way that will avoid or minimize distortion and loss of structural strength.

8.4.2 It is preferable to make additions by bolting or clamping, rather than by welding.

8.4.3 Where welded attachments are unavoidable, temperature controlling practices shall be employed; for example, the use of a small diameter electrode in intermittent short-run beads, alternate cooling and welding, application of water-soaked padding, etc.

8.4.4 Peening of welds and the surrounding area may be used to restore alignment (see 6.3).

8.4.5 Removal of material before or after any repair welding should be done by machining.

8.4.6 Repair workmanship shall conform to all applicable sections of this specification.

8.4.7 For areas where incorrect machining has affected strength, necessitating the removal and re-

placement of members, procedures for repair shall be in accordance with the applicable sections of this specification.

8.4.8 Repair of a machining error, other than those of 8.4.7, should generally be accomplished by non-welded additions, or the altering of mating units.

9. Special Requirements – Stainless Steel

9.1 Introduction

9.1.1 This section describes the required design data, workmanship, heat treatment, and procedures that are necessary to insure satisfactory performance of stainless steels. Any changes from those specified shall be approved by the designer.

9.1.2 The use of stainless steel in the fabrication of electrochemical machining equipment demands careful handling, special techniques, and procedures not required for low carbon steels. Omission of the following requirements of this section can lead to serious corrosion problems in major investment equipment.

9.2 Designing for Corrosion Resistance

9.2.1 Under certain conditions, stainless steel does corrode and precautions shall be taken to minimize the extent of possible damage.

9.2.2 Equipment shall be designed to eliminate, when possible, sharp corners and internal braces that act as traps for suspended solids, and to reduce the number of welds to a minimum.

9.2.3 Corrosion caused by a metallic junction between stainless steel and a metal of different galvanic potential, such as copper, can cause equipment failure. An electrically insulated joint shall be used when two such metals must be used. All insulated washers, sleeves, separators, etc., used for this purpose shall have minimum water absorption. Washers used under the bolt head and nut shall seal completely without producing crevices that may cause corrosion problems.

9.2.4 After all fabrication has been completed, stainless steel surfaces shall be thoroughly cleaned and nitric-acid treated as described in A2.2, unless alternate methods are specified or approved by the designer. Large structures such as tanks need to be treated only on surfaces which contact the electrolyte.

9.2.5 The designer shall specify location of marks and the method used for marking stainless steel fabrications for identification purposes.

9.3 Welding of Stainless Steels

9.3.1 The presence of chlorine and chlorides during the welding of stainless steel shall be avoided to prevent serious stress-corrosion cracking.

9.3.2 Joint preparation for welding solid stainless steel stock is similar to that for welding carbon steel. (See A2.2.1.)

9.3.3 Cracks or crevices in the weld zone, or porosity in the weld surface, are not acceptable.

9.3.4 Procedures for welding stainless steel clad stock should be those recommended by the manufacturer of the clad stock.

9.3.5 Undercutting of the clad surface should be avoided. However, should this defect develop, the undercut area shall be restored with stainless steel weld metal.

9.3.6 Prior to welding, all surface contaminants such as oil, grease, scale, oxide, paint, zinc, copper, iron, sulfur, and lead shall be removed as described in A2.2.

9.3.7 The removal of weld reinforcements or ripples, when specified, should be accomplished as described in A2.3.

9.3.8 A welded attachment to the stainless steel that is exposed intermittently or continuously to the electrolyte shall be completely welded on every edge interface between attachment and the main structure.

9.3.9 Where possible, all weld joints or beads that are normally immersed in the electrolyte shall be ground smooth, but not necessarily flush (unless specified), by methods described in A2.3.

9.4 Thermal Stress Relief

9.4.1 Parts or components of stainless steel in which dimensional stability is a critical factor shall be stress relieved after welding and prior to rough machining.

The corrosion resistance of stainless steel is influenced to a large extent by previous thermal treatment. Recommendations for thermal stress relief are given in A2.6.

9.4.2 Prior to any heating, the stainless steel shall be cleaned of all surface contamination, including oxides and scales, by degreasing and acid treatment as described in A2.2.

9.4.3 Scale and oxides may also be removed and a matte finish produced by abrasive blasting per the latest edition of ASTM specification A380, or by the use of glass bead blasting as described in A2.5.

Appendix A

Processes

(This Appendix is not a part of ANSI/AWS D14.2-93, *Specification for Metal Cutting Machine Tool Weldments*, but is included for information only.)

The joining of parts to form and the subsequent stress relieving or heat treatment of various machine tool weldments can entail the use of a variety of processes. The purpose of this Appendix is to provide useful information on these processes.

A1. Processes

A1.1 Applicable Welding Processes. The following welding processes may be encountered in the construction of machine tool weldments:

- (1) Arc welding
- (2) Oxyfuel (gas) welding
- (3) Friction welding
- (4) Resistance welding
- (5) Electron beam welding
- (6) Electroslag welding
- (7) Electrogas welding
- (8) Plasma arc welding
- (9) Stud welding

Joining processes other than those mentioned above may be used if they provide equivalent weld properties, as determined by the designer.

A1.2 Arc Welding

A1.2.1 Shielded Metal Arc Welding (SMAW). An arc welding process utilizing an arc between a covered electrode and the weld pool. The process is used with shielding from the decomposition of the electrode covering, without the application of pressure, and with filler metal from the electrode.

A1.2.2 Stud Welding. A general term for joining of a metal stud or similar part to a workpiece. Weld-

ing may be accomplished by arc, resistance, friction, or other processes with or without external gas shielding.

A1.2.3 Gas Tungsten Arc Welding (GTAW). An arc welding process that uses an arc between a tungsten electrode (non-consumable) and the weld pool. The process is used with shielding gas and without the application of pressure.

A1.2.4 Gas Metal Arc Welding (GMAW). An arc welding process that uses an arc between a continuous filler metal electrode and the weld pool. The process is used with shielding from an externally supplied gas and without the application of pressure.

A1.2.5 Submerged Arc Welding (SAW). An arc welding process that uses an arc or arcs between a bare metal electrode or electrodes and the weld pool. The arc and molten metal are shielded by a blanket of granular flux on the workpieces. The process is used without pressure and with filler metal from the electrode and sometimes from a supplemental source (welding rod, flux, or metal granules).

A1.2.6 Flux Cored Arc Welding (FCAW). An arc welding process that uses an arc between a continuous filler metal electrode and the weld pool. The process is used with shielding gas from a flux contained within the tubular electrode, with or without additional shielding from an externally supplied gas, and without the application of pressure.

A1.3 Oxyfuel Gas Welding (OFW). A group of welding processes that produces coalescence of work-

pieces by heating them with an oxyfuel gas flame. The processes are used with or without the application of pressure and with or without filler metal.

A1.4 Friction Welding (FRW). A solid-state welding process that produces a weld under compressive force contact of workpieces rotating or moving relative to one another to produce heat and plastically displace material from the faying surfaces.

A1.5 Resistance Welding (RW). A group of welding processes that produces coalescence of the faying surfaces with the heat obtained from resistance of the workpieces to the flow of the welding current in a circuit of which the workpieces are a part, and by the application of pressure.

A1.6 Electron Beam Welding (EBW). A welding process that produces coalescence with a concentrated beam, composed primarily of high-velocity electrons, impinging on the joint. The process is used without shielding gas and without the application of pressure.

A1.7 Electroslag Welding (ESW). A welding process that produces coalescence of metals with molten slag that melts the filler metal and the surfaces of the workpieces. The weld pool is shielded by this slag, which moves along the full cross section of the joint as welding progresses. The process is initiated by an arc that heats the slag. The arc is then extinguished by the conductive slag, which is kept molten by its resistance to electric current passing between the electrode and the workpieces.

A1.8 Electrogas Welding (EGW). An arc welding process that uses an arc between a continuous filler metal electrode and the weld pool, employing vertical position welding with backing to confine the molten weld metal. The process is used with or without an externally supplied shielding gas and without the application of pressure.

A1.9 Plasma Arc Welding (PAW). An arc welding process that uses a constricted arc between a nonconsumable electrode and the weld pool (transferred arc) or between the electrode and the constricting nozzle (nontransferred arc). Shielding is obtained from the ionized gas issuing from the torch, which may be supplemented by an auxiliary source of shielding gas. The process is used without the application of pressure.

A2. Stainless Steel Processing Recommendations

A2.1 Stainless Steel Weld Defects

A2.1.1 The corrosion-resistant properties required of a solid or clad surface and the necessary mechanical

properties of welds and welded joints demand high-quality welds. Defects regarded as of little importance in ordinary mild steel fabrication may be of major concern with clad or solid corrosion-resistant materials. Many of the most common defects result from incorrect joint preparation and fit-up. Departure from correct procedures will result in welds of poor mechanical and chemical properties.

A2.1.2 Undercut of clad surfaces will reduce or eliminate the protection of the cladding. All undercut sections on the corrosion-resistant side should be covered with weld metal of the same material used for welding.

A2.1.3 Adequate penetration and complete fusion of the weld metal in all joints should be assured to prevent the initiation of cracks and crevices in flawed areas which may furnish channels for corrosive action.

A2.1.4 As porosity on the weld surface will be a focal point for corrosion, this condition should be avoided. Starting porosity from stainless steel electrodes may be eliminated by the use of a T-start, or by rebaking the electrodes at the temperature recommended by the supplier. The T-start is made by beginning the weld approximately 1/4 in. (6.4 mm) ahead of the last bead. The electrode is manipulated back over the crater of the last bead and then moved forward to continue the weld.

A2.2 Surface Contamination of Stainless Steel

A2.2.1 Prior to welding or heating, films of oil, grease, and shop dirt should be removed. Scale and oxide from heat treatment or thermal cutting should also be removed. Other contaminants, such as zinc (present in some cutting oils), should be avoided. Stainless steel cleaning tools which have not been contaminated with carbon steels should be used. After welding, the weld areas should be thoroughly cleaned of slag, weld spatter, and scale.

A2.2.2 Oils, grease, or other organic contaminants may be removed by solvents such as 1,1,1-trichloroethane or trichlorethylene, or by alkaline cleaning.¹ Metallic films or embedded particles such as iron, zinc, cadmium, copper, etc. should be removed. This is

1. **WARNING:** A characteristic, objectionable, irritating odor of decomposed chlorinated solvents (such as trichlorethylene and perchlorethylene), which include highly toxic phosgene gas and other irritating decomposition products, occurs when such vapors enter into the atmosphere of an arc welding operation. See Z49.1, *Safety in Welding and Cutting*, latest edition, available from AWS.

best accomplished by immersion in a nitric acid solution of the following composition:

Nitric acid (38° Be)	20 parts by volume
Water	80 parts by volume
Immersion time	15–20 minutes minimum
Operating temperature	120° – 140°F (49° – 60°C)

After the acid treatment has been completed, the part should be rinsed thoroughly with clean, warm water, then swabbed with a 2 percent-by-volume ammonia solution followed by an additional water rinse. Stainless steel clad steel stock may also be treated by this method; however, precautions should be observed to prevent excessive attack on the steel backing.

A2.2.3 Surface scale or oxides may be removed by a solution having the following composition:

Nitric acid (38° Be)	10 parts by volume
Hydrofluoric acid (40 percent)	2–3 parts by volume
Water to make	100 parts by volume
Operating temperature	110°–120°F (43°–49°C)
Immersion time	2–20 minutes

Brushing with a stainless steel or nylon brush may be required, as well as additional immersion periods. After the part has been descaled, it should be rinsed-neutralized-rinsed as described above.

A2.2.4 Proper procedures should be employed in the use and disposal of all hazardous chemicals.

A2.3 Finishing Stainless Steel Welded Beads

A2.3.1 When weld beads are to be ground flush or ripples removed, the initial grinding is normally done using a rubber Bakelite-bonded aluminum oxide wheel of 16–36 grit operated at 5000–6000 linear feet per minute (25–30 m/s). Wheels used for grinding stainless steel should not be used on metals other than stainless steel.

A2.3.2 Edges of the wheel should be rounded, and grinding should proceed along the bead, taking care not to tilt the wheel. The wheel should be allowed to ride the work in the interest of efficiency and should not be held too long at one place because of danger of overheating the surface. Heat tinting will appear at approximately 400°F (204°C). When grinding clad stock, care should be taken to prevent a serious reduction in clad thickness or cutting through.

A2.3.3 Where finer finishes are required than those produced with a 36 grit, it is customary to use 40–60 (or even finer) grit wheels. If it is necessary to match

a No. 4 plate finish, the weld should not be ground level with the plate, or a depression may appear when polishing. It should also be noted that in finishing light-gage clad stock, the bead should not be ground flush; it is best to first grind off the top of the weld bead and then round off by fine grinding and polishing to make the weld free of pits or crevices. A sanitary surface can be made in this manner. Improvements in blending and finish, above that produced by grinding, if required, may be obtained by a polishing operation similar to that described in A2.4.

A2.4 Polishing Stainless Steel

A2.4.1 Polishing or buffing differs from grinding only in that finer grit sizes (100 and up) are used. The abrasive materials should be iron-free. Manufactured types such as silicon carbide and aluminum oxide are preferred. The latter is the common type in use for stainless steel. It is customary to reduce grit sizes in steps of forty. For example, if 100 grit is used in the first operation, it would be followed by 140 grit and then 180 grit.

A2.4.2 Several types of polishing equipment are available. For blending the surface of weld beads to the surface of polished clad or solid plate, the air-inflated rubber wheel with an abrasive cloth sleeve has proved useful. There are also fabric polishing wheels of various types. Cloth wheels made of 18 to 20 sewn sections of unbleached muslin of 64/68 to 84/92 count are quite common as are wheels made of glued or mechanically-held strips of abrasive cloth. It is customary to change direction of the wheel 90 degrees after each change in grit size in order to help eliminate wheel marks in the plate surface.

A2.5 Abrasive-Cleaning of Stainless Steel. Glass bead blasting may also be used for finishing the stock. There is some evidence that the peening action of this process improves corrosion resistance and imparts a compressive stress that strengthens the joint. A final acid wash treatment should be used after the glass bead blasting operation.

A2.6 Thermal Stress Relief of Stainless Steel

A2.6.1 There are two basic thermal treatments that may be used for stress relief.² One is performed at

2. These treatments are in contrast to the solution anneal treatment that is given to nonstabilized or the normal carbon content grades of stainless steel after welding, which is necessary to insure normal corrosion resistance. The solution anneal treatment consists of heating the stainless steel to approximately 1900°F (1038°C), holding for sufficient time to dissolve precipitated carbides and then water quenching to 700°F (371°C) or below. An air quench may be substituted for the water quench when the section size is thin.

relatively low temperatures, and the second at elevated temperatures. The selection of a treatment depends upon the critical nature of the part application, its geometry, and the type of stainless steel.

A2.6.2 Stainless parts that require only a low order of stress relief to perform satisfactorily may be heated to 775°F (413°C) and held at temperature for a minimum of 12 hours. This treatment relieves no more than 30 percent of the total stresses and should not be specified for parts requiring very low residual stress levels. The advantage of this treatment is that it has no adverse effect on the (general) corrosion resistance of stainless steel and increases the metal's resistance to stress corrosion cracking.

A2.6.3 Parts that must be stable require a relatively high-temperature treatment. Types 304L and 316L stainless steels may be heated to 1650°F (899°C) and held at temperature for 1 hour, plus 1 hour per inch of thickness of maximum cross section. Cooling may be in still air; in the event that such a rate would cause warpage, furnace cooling may be used.

A2.6.4 Whatever method is used, the part should be thoroughly solvent-degreased or alkaline cleaned prior to heat treatment to remove any oil or other organic material from the surface to prevent carbon pickup. The furnace atmosphere used should not carburize, nitride, or in any way detrimentally affect the corrosion resistance of the stainless steel.

A2.6.5 Parts fabricated from unstabilized grades of stainless steel should not be heated and held in the range of 800–1625°F (427° – 885° C) for even short periods of time. This range of temperature causes precipitation of carbides which depletes the chromium in areas around the grain boundaries. This effect seriously reduces the corrosion resistance of the stainless steel. Parts that have been inadvertently exposed to temperatures in this range shall be given a full solution anneal.

A3. Stress Relief and Heat Treatment

A3.1 Need for Stress Relief. In the fabrication of chip-making machine tool weldments, adequate stress relief is necessary to attain the proper level of stability

during machining, assembly, run-off, shipping, and in use.

A3.2 Level of Relief. The purpose of stress relief heat treatment is to lower the yield point of the metal to a predetermined level. When the weldment is held at the proper temperature for a suitable time, the approximate maximum residual stress level may be determined from established experimental data.

A3.3 Preheat and Postheat. Preheating and postheating may be useful to minimize cracking when welding very heavy sections, close fitting details, or steels chosen for their hardenability.

A3.4 Verified Need for Relief. Before specifying stress relief, determine whether the weldment really requires it. Many do not require stress relief to function properly in machine tools. Thermal stress relief in a weldment is necessary only when accuracy must be achieved in its manufacture and be retained throughout its useful life. Small detail parts, guards, brackets, frames, etc., normally do not require stress relief.

A3.5 Controlled Sequences. Weldments may not require stress relief for adequate stability when a balanced design, incorporating controlled welding sequence and extent of welding, is combined with a controlled machining sequence. These procedures are rather sophisticated and should be undertaken only after considering all problems involved.

A3.6 Thermal-Hardened Surfaces. During a thermal shape-cutting operation, the cut surfaces may be hardened and very high local internal stresses may be set up. Cutting tools will wear rapidly when cutting through such surfaces. A heat treatment, at stress relief temperatures, softens the cut surfaces and improves cutting tool life.

A3.7 Temperature Variations. The temperature during the holding cycle of the stress relief treatment has a greater effect in reducing stresses than the length of time the part is held at that temperature. The closer the temperature is to the critical temperature, [e.g., 1333°F (722°C) for AISI 1020 steel], the more effective it is in lowering the stress level. Temperatures above the critical temperature will tend to cause severe warpage.

A3.8 Unusual Weldments. All unusual weldments should be studied and adjustments made to the stress relief cycle to assure adequate stress relief.

A3.9 Residual Stress Ranges. None of the stress relief methods presently known removes all stresses. A

residual stress range of 3000 to 6000 psi (21 to 41 kPa) remains after thermal stress relief at 1200 to 1250°F (649 to 677°C) for the usual holding time given in 6, Stress Relief and Heat Treating. This is considered an acceptable level for most structures. However, some weldments, such as long, thin ones and large flat plates, require lower stress levels [1000 to 3000 psi (7 to 21 kPa)] when stability during machining is especially desirable. Under these circumstances, more time, higher temperature, or both, may be required during the holding portion of the stress relief cycle.

A3.10 Dissimilar Metal Parts. Thermal stress relief of weldments made of materials with significantly different coefficients of expansion is not advisable. For example, cast iron, high-carbon steel, or bronze should not be welded to low-carbon steel and then heat treated.

A3.11 Water or Oil Quenching. Water or oil quenching of weldments is not recommended. Such treatment will frequently result in cracking.

A3.12 Thickness Differences. When there is a great difference in the thickness of the welded elements,

distortion or failure may occur during thermal stress relief unless proper precautions are taken; for example, shielding the thin material from rapid heating, or thinning some of the heavy sections by premachining.

A3.13 Stainless Steel. See A2, Stainless Steel Processing Recommendations.

A3.14 Hardenable Components. The incorporation of hardenable steel components into low-carbon steel machine tool weldments is not recommended. Weld joint failure may be anticipated, either in fabrication, stress relieving, or during local hardening.

A3.15 Age-Hardening Alloys. Thermal stress relief of machine tool weldments made of precipitation-hardening alloys, such as aluminum, will over-age the material.

A3.16 Thin Panels. Thermal stress relief treatment for weldments fabricated from large panels of 20 through 7 gage stock may cause severe buckling.

A3.17 Shot or Sand Blasting. Shot blasting of large thin panels to remove scale or paint will usually cause buckling; sand blasting may cause buckling, but to a lesser degree.

Appendix B

Welding Safety Considerations

(This Appendix is not a part of ANSI/AWS D14.2-93, *Specification For Metal Cutting Machine Tool Weldments*, but is included for information only.)

It is important, when constructing machine tool weldments that appropriate safety measures be followed. While all safety considerations may be impossible to assemble, and certainly would be too involved to be of practical use, it is hoped that the following list will be informative of those principles that need to be observed.

B1. Electric Shock Can Kill

B1.1 The electrode and work (or ground) circuits are electrically "hot" when the welding machine is turned on. Do not touch these "hot" parts with your bare skin or wet clothing. Wear dry, hole-free gloves to insulate hands.

B1.2 In semiautomatic, automatic or machine welding, the electrode, electrode reel, welding head, nozzle or semiautomatic welding gun are also electrically "hot."

B1.3 Insulate yourself from work or ground using dry insulation. When welding in damp locations, on metal framework such as floors, gratings or scaffolds, and when in positions such as sitting or lying, make certain the insulation is large enough to cover your full area of physical contact with work and ground.

B1.4 Always be sure the work cable makes a good electrical connection with the metal being welded. The connection should be as close as possible to the area being welded.

B1.5 Ground the work or metal to be welded to a good electrical (earth) ground.

B1.6 Maintain the electrode holder, work clamp, welding cable and welding machine in good, safe operating condition. Replace damaged insulation.

B1.7 Never dip the electrode or electrode holder in water for cooling.

B1.8 Never simultaneously touch electrically "hot" parts of electrode holders connected to two welding machines because voltage between the two can be the total of the open circuit voltage of both welding machines.

B1.9 When working above floor level, protect yourself from a fall should you get a shock.

B1.10 Also see Items B4.3 and B6.

B2. Arc Rays Can Burn

B2.1 Use a shield with the proper filter and cover plates to protect your eyes from sparks and the rays of the arc when welding or observing open arc welding. Headshield and filter lens should conform to ANSI Z87.1 standards.

B2.2 Use suitable clothing made from durable flame-resistant material to protect your skin and that of your helpers from the arc rays.

B2.3 Protect other nearby personnel with suitable nonflammable screening or warn them not to watch the arc nor expose themselves to the arc rays or to hot spatter or metal.

B3. Fumes and Gases Can Be Dangerous

B3.1 Welding may produce fumes and gases hazardous to health. Avoid breathing these fumes and gases. When welding, keep your head out of the fumes. Use enough ventilation or exhaust, or both, at the arc to keep fumes and gases away from the breathing zone. When welding on galvanized, lead, or cadmium plated steel and other metals which produce toxic fumes, even greater care must be taken.

B3.2 Do not weld in locations near chlorinated hydrocarbon vapors coming from degreasing, cleaning or spraying operations. The heat and rays of the arc can react with solvent vapors to form phosgene, a highly toxic gas, and other irritating products.

B3.3 Shielding gases used for arc welding can displace air and cause injury or death. Always use enough ventilation, especially in confined areas, to insure breathing air is safe.

B3.4 Read and understand the manufacturer's instructions for the equipment and the consumables to be used, including the material safety data sheet (MSDS) and follow your employer's safety practices.

B3.5 See item B7.2.

B4. Welding Sparks Can Cause Fire or Explosion

B4.1 Remove fire hazards from the welding area. If this is not possible, cover them to prevent the welding sparks from starting a fire. Remember that welding sparks and hot materials from welding can easily go through small cracks and openings to adjacent areas. Have a fire extinguisher readily available.

B4.2 Where compressed gases are to be used at the job site, special precautions should be used to prevent hazardous situations. Refer to ANSI/ASC, *Safety in Welding and Cutting* and the operating information for the equipment being used.

B4.3 When not welding, make certain no part of the electrode circuit is touching the work or ground. Accidental contact can cause overheating and create a fire hazard.

B4.4 Do not heat, cut or weld tanks, drums or other containers until the proper steps have been taken to insure that such procedures will not cause flammable or toxic vapors from substances inside. They can cause an explosion even though the containers have been

"cleaned." For information, obtain ANSI/AWS F4.1, *Recommended Safe Practices for the Preparation for Welding and Cutting of Containers and Piping That Have Held Hazardous Substances*, latest edition, from the American Welding Society.

B4.5 Vent hollow castings or containers before heating, cutting, or welding. They may explode.

B4.6 Sparks and spatter are thrown from the welding arc. Wear oil-free protective garments such as leather gloves, heavy shirt, cuffless trousers, high shoes, and a cap over your hair. Wear ear plugs when welding out of position or in confined places. Always wear safety glasses with side shields when in a welding area.

B4.7 Connect the work cable to the work as close to the welding area as practical. Work cables connected to the building framework or other locations away from the welding area increase the possibility of the welding current passing through lifting chains, crane cables or other alternate circuits. This can create fire hazards or overheat lifting chains or cables until they fail.

B4.8 See item B7.3.

B5. Cylinders May Explode if Damaged

B5.1 Use only compressed gas cylinders containing the correct shielding gas for the process used and properly operating regulators designed for the gas and pressure used. All hoses, fittings, etc. should be suitable for the application, and maintained in good condition.

B5.2 Always keep cylinders in an upright position, securely chained to an undercarriage or fixed support.

B5.3 Cylinders should be located: away from areas where they may be struck or subjected to physical damage, or at a safe distance from arc welding or cutting operations and any other source of heat, sparks, or flame.

B5.4 NEVER allow the electrode, electrode holder, or any other electrically "hot" parts to touch a cylinder.

B5.5 Keep your head and face away from the cylinder valve outlet when opening the cylinder valve.

B5.6 Valve protection caps should always be in place and handtight except when the cylinder is in use or connected for use.

B5.7 Read and follow the instructions on compressed gas cylinders, associated equipment, and CGA publication P-1, *Precautions for Safe Handling of Compressed Gases in Cylinders*, available from the Compressed Gas Association.

B6. Electrically Powered Equipment Can Be Dangerous

B6.1 Turn OFF input power using the disconnect switch at the fuse box before working on the equipment.

B6.2 Install equipment in accordance with the National Electrical Code, all local codes, and the manufacturer's recommendations.

B6.3 Ground the equipment in accordance with the latest version of the National Electrical Code and the manufacturer's recommendations.

B7. Engine-Powered Equipment Can Create a Hazard

B7.1 Turn the engine OFF before troubleshooting and maintenance work unless the maintenance work requires it to be running.

B7.2 Operate engines in open, well-ventilated areas or vent the engine exhaust fumes outdoors.

B7.3 Do not add the fuel near an open flame, welding arc, or when the engine is running. Stop the engine and allow it to cool before refueling to prevent spilled fuel from vaporizing on contact with hot engine parts and igniting. Do not spill fuel when filling tank. If fuel is spilled, wipe it up, and do not start engine until fumes have been eliminated.

B7.4 Keep all equipment safety guards, covers and devices in position and in good repair. Keep hands,

hair, clothing and tools away from V-belts, gears, fans and all other moving parts when starting, operating or repairing equipment.

B7.5 In some cases, it may be necessary to remove safety guards to perform required maintenance. Remove guards only when necessary, and replace them when the maintenance requiring their removal is complete. Always use the greatest care when working near moving parts.

B7.6 Do not put your hands near the engine fan. Do not attempt to override the governor or idler by pushing on the throttle control rods while the engine is running.

B7.7 To prevent accidentally starting gasoline engines while turning the engine or welding generator during maintenance work, disconnect the spark plug wires, distributor cap or magneto wire as appropriate.

B7.8 To avoid scalding, do not remove the radiator pressure cap when the engine is hot.

B8. An Unsafe Work Environment Can Cause Injury

B8.1 To prevent accidental cuts and abrasions, remove from the work area all sharp-edged debris such as metal chips and stringers created by previous metal cutting operations.

B8.2 Ensure that the floor or other supporting surfaces are free of oil spills or other slippery materials.

B8.3 When performing operations on machinery or machine mounted parts, ensure that the machine is deenergized, tagged out, and in a safe condition. Also remove or cover sharp edged tooling that may interfere with a safe welding environment.

Appendix C: Commonly Used Metric Conversions

Inch-millimeter conversion
1 in. = 25.4 mm exactly

To convert inches to millimeters, multiply the inch value by 25.4

To convert millimeters to inches, divide the millimeter value by 25.4

Inch and Millimeter Decimal Equivalents of Fractions of an Inch

Inch		Millimeter	Inch		Millimeter
Fraction	Decimal		Fraction	Decimal	
1/64	0.015	0.396	33/64	0.515	13.096
1/32	0.031	0.793	17/32	0.531	13.493
3/64	0.046	1.190	35/64	0.546	13.890
1/16	0.062	1.587	9/16	0.562	14.287
5/64	0.078	1.984	37/64	0.578	14.684
3/32	0.093	2.381	19/32	0.593	15.081
7/64	0.109	2.778	39/64	0.609	15.478
1/8	0.125	3.175	5/8	0.625	15.875
9/64	0.140	3.571	41/64	0.640	16.271
5/32	0.156	3.968	21/32	0.656	16.668
11/64	0.171	4.365	43/64	0.671	17.065
3/16	0.187	4.762	11/16	0.687	17.462
13/64	0.203	5.159	45/64	0.703	17.859
7/32	0.218	5.556	23/32	0.718	18.256
15/64	0.234	5.953	47/64	0.734	18.653
1/4	0.250	6.350	3/4	0.750	19.050
17/64	0.265	6.746	49/64	0.765	19.446
9/32	0.281	7.143	25/32	0.781	19.843
19/64	0.296	7.540	51/64	0.796	20.240
5/16	0.312	7.937	13/16	0.812	20.637
21/64	0.328	8.334	53/64	0.828	21.034
11/32	0.343	8.731	27/32	0.843	21.431
23/64	0.359	9.128	55/64	0.859	21.828
3/8	0.375	9.525	7/8	0.875	22.225
25/64	0.390	9.921	57/64	0.890	22.621
13/32	0.406	10.318	29/32	0.906	23.018
27/64	0.421	10.715	59/64	0.921	23.415
7/16	0.437	11.112	15/16	0.937	23.812
29/64	0.453	11.509	61/64	0.953	24.209
15/32	0.468	11.906	31/32	0.968	24.606
31/64	0.484	12.303	63/64	0.984	25.003
1/2	0.500	12.700	1	1.000	25.400

AWS Documents on Machinery and Equipment

Document Code	Title
D14.1	Specification for Welding of Industrial and Mill Cranes and Other Material Handling Equipment
D14.2	Specification for Metal Cutting Machine Tool Weldments
D14.3	Specification for Welding of Earthmoving and Construction Equipment
D14.4	Classification and Application of Welded Joints for Machinery and Equipment
D14.5	Specification for Welding of Presses and Press Components
D14.6	Specification for Welding of Rotating Elements of Equipment

For ordering information, contact the Order Department, American Welding Society, 550 N. W. LeJeune Road, P. O. Box 351040, Miami, Florida 33135 (phone) 1-800-443-9353.