

ANSI/AWS D14.6-96
An American National Standard

Specification for Welding of Rotating Elements of Equipment



American Welding Society

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rotating equipment, welding
fabrication, welding inspection,
weld modification and repair

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Specification for Welding of Rotating Elements of Equipment

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Prepared by
AWS Committee on Machinery and Equipment

Under the Direction of
AWS Technical Activities Committee

Approved by
AWS Board of Directors

Abstract

Establishes material and workmanship standards, for use by manufacturers and purchasers of rotating equipment. Also included are sections defining process qualifications, quality control and repair requirements.



American Welding Society

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Foreword

(This Foreword is not a part of ANSI/AWS D14.6-96, *Specification for Welding of Rotating Elements of Equipment*, but is included for information purposes only.)

Until a few years ago, specifications for welded fabrication were published just for “stationary” structures—boilers, bridges, and buildings. Machinery and equipment specifications now consider structures with “dynamic” applications—earthmovers and cranes.

This specification pertains to another major dynamic category—rotating elements of equipment. In this present case, the link of similarity is shape more than application, i.e., round shapes from a few inches to 200 inches in diameter, with a variety of uses involving power generation, propulsion, and material processing.

It was evident from the outset that all types of rotating equipment could not be covered effectively. There already had been expressed a need for welding specifications for major industrial rotating equipment such as large mechanical draft fans, centrifuges, pumps and compressors as used in power plants, paper making, steel production, etc. It was voted to leave for future publications such special characteristic items as jet engines and steam turbines.

Experience had been similar among the companies represented on this subcommittee. Equipment had been produced successfully for tens of years without specifications or restraints. But operating requirements for the equipment were growing so severe that engineering firms and ultimate users were becoming very concerned about safety and liability. Some specifiers had begun to require implementation of the *ASME Boiler and Pressure Vessel Code* in part or in whole, and others invoked the *AWS Structural Welding Code*. Arguments about interpretation and compliance were widespread. It was evident that the most useful document would be a set of rules and definitions to communicate before and after fabrication just what the user and supplier have agreed upon for structural integrity within the economic restraints of competitive bid purchasing.

With that objective, the subcommittee developed this specification, adopting the premise that many wise and experienced man-years have gone into the *AWS Structural Welding Code* and the *ASME Boiler and Pressure Vessel Code*. Also, the specifiers and manufacturers most likely to use this specification have built up documentation that complies with those two codes. Hence, each section of this specification started with an attempt to use information from those codes. For instance, procedure and performance qualification methods have been kept more nearly like the *Pressure Vessel Code* because the manufacturers and engineering firms represented on the subcommittee are ruled by it on their projects more often than by the *Structural Code*. A large amount of test documentation then will continue to be useful. However, it was voted to entirely omit a section on design. It was felt there is needed a separate study of how practices do or should differ in design of welded rotating equipment from those published for stationary structures. Such a study was beyond the scope of this subcommittee.

A table of approximate conversions from U.S. customary units to SI units for dimensions found in the Figures and Tables of this specification can be found following the Annexes.

Comments or inquiries pertaining to this specification are welcome. They should be addressed to: Secretary, AWS Committee on Machinery and Equipment, American Welding Society, 550 N.W. LeJeune Road, Miami, FL 33126.

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

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Specification for Welding of Rotating Elements of Equipment

1. General Provisions

1.1 Scope. This specification applies to the fabrication, by welding, of wrought or cast material used in the manufacture of the rotating elements of equipment, such as fans, pumps, compressors, etc.

1.2 Manufacturer's Responsibility. The manufacturer's responsibility shall include the following:

- (1) Review purchaser's specifications and advise of any exceptions (e.g., nonspecification materials).
- (2) Ensure that all welds are in conformance to this specification (see 7.1.4).
- (3) Designate welds on drawings by appropriate AWS symbols and notes.
- (4) Detail joint preparation and ensure joint compatibility with applied processes.
- (5) Select the weld process(es) for each weld joint.
- (6) Qualify, maintain, and use welding procedure specifications (WPS) and performance records that meet the requirements of this specification for the welding process(es) selected.
- (7) Maintain records of tests and procedures relating to welding and forward copies to the buyer, when required in the contract (see 7.1.4).

1.3 Purchaser's Responsibility. The purchaser's responsibility shall include the following:

- (1) Resolve, prior to purchase, the manufacturer's exceptions to the specification.
- (2) Specify, in writing, prior to purchase and manufacture, special test procedures required (see 5.9 and 7.4).
- (3) Specify, in writing, mutually agreed conditions under which the purchaser may conduct in-plant or on-site inspection of the product to meet this specification.
- (4) When inspectors are provided, they shall meet the personnel requirements of section 7, Inspection and Quality Control.

1.4 Definitions. Welding terms used in this specification shall be interpreted in conformance to ANSI/AWS A3.0, *Standard Welding Terms and Definitions*.

1.5 Symbols. Welding symbols shown on manufacturer's and purchaser's drawings shall be in conformance to ANSI/AWS A2.4, *Standard Symbols for Welding, Brazing, and Nondestructive Examination*.

2. Base Metals

2.1 Materials selected for use in welded fabrication of rotating elements shall conform to the specifications established by a recognized material specifying organization (i.e., ASTM, ASME, API, etc.). Materials, other than those so covered, may be used upon agreement between purchaser and manufacturer.

2.2 Table 1 groups base metals for welding procedure and performance qualification on the basis of mechanical properties, chemical composition, and metallurgical compatibility to minimize the number of welding qualifications where this can logically be done. Base metals have been divided into general categories (e.g., Material numbers M-1, M-1A, M-2, M-2A, M-3, etc.) and further subdivided into groups. The grouping does not imply that base metals may be indiscriminately substituted for a base metal that was used in the qualification test without consideration of the compatibility from the standpoint of metallurgical properties, postweld heat treatment, design, mechanical properties, and service requirements.

In addition to the material and group number, a "standard" column is provided which denotes the material specification for each listed metal. "P" denotes American Society of Mechanical Engineers (ASME) materials, "S" denotes American Society for Testing and Materials (ASTM) materials, "Q" denotes materials which do not fall into either "P" or "S" categories.

2.3 Materials not listed in Table 1, but which are nominally identical in mechanical properties and chemical composition to a material listed, may be classified using the M-number of the listed material when agreed upon between purchaser and manufacturer. Other materials not listed in Table 1 shall require a separate welding procedure qualification.

Table 1
Grouping of Base Metals for Procedure Qualification

Mat'l No.	Group No.	Std.	Base Metal Specification	Minimum Tensile/ Yield ksi	Base Metal			
Steel and Steel Alloys								
1	1	PS	A31	Grade A	45/23	Rivets (C)		
				Grade B	58/29	Rivets (C)		
		PS	A36	for thk ≤ 8 in.	58/36	Plate (C-Mn-Si)		
				for thk > 8 in.	58/32			
		PS	A53	Type F	45/25	Pipe		
				Type E, Gr. A	48/30	Pipe		
				Type E, Gr. B	60/35	Pipe		
				Type S, Gr. A	48/30	Pipe		
				Type S, Gr. B	60/35	Pipe		
				Grade B	60/35	Pipe		
				PS	A106	Grade A	48/30	Pipe (C-Si)
						Grade B	60/35	Pipe (C-Si)
		S	A131	Grade A	58/34	Structural		
				for thk > 1 in.	58/32			
				Grade B	58/34	Structural		
				Grade CS	58/34	Structural		
				Grade D	58/34	Structural		
				Grade DS	58/34	Structural		
				Grade E	58/34	Structural		
						Pipe of A283 and A285		
		PS	A134					
		PS	A135	Grade A	48/30	ERW Pipe (C)		
				Grade B	60/35	ERW Pipe (C-Mn)		
		S	A139	Grade A	48/30	Pipe		
				Grade B	60/35	Pipe		
				Grade C	60/42	Pipe		
		S	A161	Low Carbon	47/26	Low C Tube		
				Grade T1	55/30	C-Mo Tube		
		PS	A178	Grade A	47/26	ERW Tube (C)		
				Grade C	60/37	ERW Tube (C)		
		PS	A179			Seamless Tube (Low C)		
		PS	A181	Class 60	60/30	Pipe Flange (C-Si)		
		PS	A192		47/26	Seamless Tube (C-Si)		
		PS	A210	Grade A-1	60/37	Tube (C)		
		PS	A214		*	ERW Tube (C)		
		PS	A216	Grade WCA	60/30	Castings (C-Si)		
		PS	A226		47/26	ERW Tube (C-Si)		
		PS	A234	WPB	60/35	Pipe Fitting (C-Mn)		
		PS	A266	Class 1	60/30	Seamless Forging (C-Si)		
		PS	A283	Grade A	45/24	Plate (C-Si)		
				Grade B	50/27	Plate (C-Si)		
				Grade C	55/30	Plate (C)		
				Grade D	60/33	Plate (C)		
				Grade C	60/30	Plate (C-Si)		
		S	A284	Grade D	60/33	Plate (C-Si)		
				Grade A	45/24	Plate (C)		
				Grade B	50/27	Plate (C)		
		PS	A285	Grade C	55/30	Plate (C)		
				Grade 1	55/30	Plate (C-Mn)		
				Grade 6	60/35	Pipe (C-Mn)		
		PS	A333	Grade 1	55/30	Tube (C-Mn)		
				Grade 6	60/35	Tube (C-Mn-Si)		
		PS	A334	Grade 1	55/30	Tube (C-Mn)		
Grade 6	60/35			Tube (C-Mn-Si)				

(continued)

Table 1 (Continued)

Mat'l No.	Group No.	Std.		Base Metal Specification	Minimum Tensile/ Yield ksi	Base Metal		
1	1	PS	A350	Grade LF1	60/30	Forging (C-Mn)		
		PS	A352	Grade LCA	60/30	Casting (C)		
				Grade LCB	65/35	Casting (C-Si)		
		PS	A369	Grade FPA	48/30	Forging (C)		
				Grade FPB	60/35	Forging (C)		
		PS	A372	Type I	60/35	Forging (C)		
		S	A381	Class Y35	60/35	Pipe		
				Class Y42	63/42	Pipe		
		PS	A414	Grade A	45/25	Sheet (C)		
				Grade B	50/30	Sheet (C)		
				Grade C	55/33	Sheet (C)		
				Grade D	60/35	Sheet (C-Mn)		
				Grade E	65/38	Sheet (C-Mn)		
		PS	A420	Grade WPL6	60/35	Pipe Fitting (C-Mn-Si)		
		PS	A442	Grade 55	55/30	Plate (C-Mn-Si)		
				Grade 60	60/32	Plate (C-Mn-Si)		
		S	A500	Grade A	45/33	Tube		
				Grade B	58/42	Tube		
		S	A501		58/36	Tube		
		S	A512					
						Grade 1008	*	Mechanical Tube
						Grade 1010	*	Mechanical Tube
						Grade MT1010	*	Mechanical Tube
						Grade 1012	*	Mechanical Tube
						Grade 1015	*	Mechanical Tube
						Grade MT1015	*	Mechanical Tube
						Grade MTX1015	*	Mechanical Tube
						Grade 1016	*	Mechanical Tube
						Grade 1018	*	Mechanical Tube
						Grade 1019	*	Mechanical Tube
						Grade 1020	*	Mechanical Tube
						Grade MT1020	*	Mechanical Tube
						Grade MTX1020	*	Mechanical Tube
						Grade 1021	*	Mechanical Tube
						Grade 1025	*	Mechanical Tube
						Grade 1026	*	Mechanical Tube
						Grade 1110	*	Mechanical Tube
						Grade 1115	*	Mechanical Tube
						Grade 1117	*	Mechanical Tube
				A513		Grade 1008	*	ERW Tube
						Grade 1010	*	ERW Tube
						Grade MT1010	*	ERW Tube
						Grade 1015	*	ERW Tube
						Grade MT1015	*	ERW Tube
						Grade MTX1015	*	ERW Tube
						Grade 1016	*	ERW Tube
						Grade 1017	*	ERW Tube
						Grade 1018	*	ERW Tube
						Grade 1019	*	ERW Tube
						Grade 1020	*	ERW Tube
						Grade MT1020	*	ERW Tube
						Grade MTX1020	*	ERW Tube
				Grade 1021	*	ERW Tube		

(continued)

Table 1 (Continued)

Mat'l No.	Group No.	Std.		Base Metal Specification	Minimum Tensile/ Yield ksi	Base Metal
1	1	S	513	Grade 1022	*	ERW Tube
				Grade 1023	*	ERW Tube
				Grade 1024	*	ERW Tube
				Grade 1025	*	ERW Tube
				Grade 1026	*	ERW Tube
				Grade 1027	*	ERW Tube
		PS	A515	Grade 55	55/30	Plate (C-Si)
				Grade 60	60/32	Plate (C-Si)
				Grade 65	65/35	Plate (C-Si)
		PS	A516	Grade 55	55/30	Plate (C-Si)
				Grade 60	60/32	Plate (C-Si)
				Grade 65	65/35	Plate (C-Mn-Si)
		S	A519	Grade 1008	*	Mechanical Tube
				Grade 1010	*	Mechanical Tube
				Grade MT1010	*	Mechanical Tube
				Grade 1012	*	Mechanical Tube
				Grade 1015	*	Mechanical Tube
				Grade MT1015	*	Mechanical Tube
				Grade MTX1015	*	Mechanical Tube
				Grade 1016	*	Mechanical Tube
				Grade 1017	*	Mechanical Tube
				Grade 1018	*	Mechanical Tube
				Grade 1019	*	Mechanical Tube
				Grade 1020	*	Mechanical Tube
				Grade MT1020	*	Mechanical Tube
				Grade MTX1020	*	Mechanical Tube
				Grade 1021	*	Mechanical Tube
				Grade 1022	*	Mechanical Tube
				Grade 1025	*	Mechanical Tube
				Grade 1026	*	Mechanical Tube
		S	A523	Grade A	48/30	Pipe
				Grade B	60/35	Pipe
		PS	A524	Grade I	60/35	Pipe (C-Mn-Si)
				Grade II	55/30	Pipe (C-Mn-Si)
		S	A529		60/42	Structural
		S	A539		45/35	Coiled Tube
		PS	A556	Grade A2	47/26	Smls. Tube
				Grade B2	60/37	Smls. Tube
		PS	A557	Grade A2	47/26	ERW Tube
				Grade B2	60/37	ERW Tube
		PS	A562		55/30	Plate (C-CU-Ti)
		S	A569	Grade 30	49/30	Sheet & Strip
				Grade 33	52/33	Sheet & Strip
				Grade 36	53/36	Sheet & Strip
				Grade 40	53/40	Sheet & Strip
		S	A570	Grade 30	49/30	Sheet & Strip
				Grade 33	52/33	Sheet & Strip
				Grade 36	53/36	Sheet & Strip
				Grade 40	55/40	Sheet & Strip
		S	A572	Grade 42	60/42	HSLA, Cb-V Steel
		S	A573	Grade 58	58/32	Plate, Improved Toughness
				Grade 65	65/35	Plate, Improved Toughness

(continued)

Table 1 (Continued)

Mat'l No.	Group No.	Std.	Base Metal Specification	Minimum Tensile/ Yield ksi	Base Metal
1	1	S	A575	Grade 1008	* Bar
				Grade 1010	* Bar
				Grade 1012	* Bar
				Grade 1015	* Bar
				Grade 1017	* Bar
				Grade 1020	* Bar
				Grade 1023	* Bar
				Grade 1025	* Bar
		PS	A587	48/30	Pipe (Low C)
		S	A611	42/25	Sheet
				Grade B	45/30 Sheet
				Grade C	48/33 Sheet
				Grade D	52/40 Sheet
		PS	A620	40/20	Drawing Quality Sheet
		PS	A660	60/30	Pipe (C)
		PS	A662	58/40	Plate (C-Mn)
				Grade B	65/40 Plate (C-Mn)
		S	A663	45/22.5	Bar (C)
				Grade 50	50/25 Bar (C)
				Grade 55	55/27.5 Bar (C)
				Grade 60	50/30 Bar (C)
				Grade 65	65/36 Bar (C)
		PS	A671	55/30	Pipe (C)
				Grade CA55	55/30 Pipe (C)
				Grade CE55	60/32 Pipe (C-Si)
				Grade CB60	65/35 Pipe (C-Si)
				Grade CB65	60/32 Pipe (C-Si)
				Grade CC60	65/35 Pipe (C-Mn-Si)
				Grade CC65	60/32 Pipe (C-Mn-Si)
		PS	A672	45/24	Pipe (C)
				Grade A45	50/27 Pipe (C)
				Grade A50	55/30 Pipe (C)
				Grade A55	55/30 Pipe (C-Si)
				Grade B55	60/30 Pipe (C-Si)
				Grade B60	65/35.5 Pipe (C-Si)
				Grade B65	55/30 Pipe (C-Si)
				Grade C55	60/32 Pipe (C-Si)
				Grade C60	65/35 Pipe (C-Mn-Si)
				Grade C65	55/30 Pipe (C-Mn-Si)
				Grade E55	60/32 Pipe (C-Mn-Si)
				Grade E60	
		PS	A675	45/22.5	Bar (C)
				Grade 50	50/25 Bar (C)
				Grade 55	55/27.5 Bar (C)
				Grade 60	60/30 Bar (C)
				Grade 65	65/32.5 Bar (C)
		PS	A695	60/35	Bar (C-Si)
		PS	A696	60/35	Bar (C)
		S	A709	58/36	Sheet
		PS	A727	60/36	Forging
		PS	A765	60/36	Forging
		Q	ABS	58/34	Structural
				Grade B	58/34 Structural

(continued)

Table 1 (Continued)

Mat'l No.	Group No.	Std.	Base Metal Specification	Minimum Tensile/ Yield ksi	Base Metal
1	1	Q	ABS	Grade D	58/34 Structural
				Grade E	58/34 Structural
				Grade CS	58/34 Structural
				Grade DS	58/34 Structural
		Q	API 5L	Grade A25	45/25 Pipe
				Grade A	48/30 Pipe
				Grade B	60/35 Pipe
				Grade X42	60/42 Pipe
		Q	API 5LS	Grade A	48/30 Pipe
				Grade B	60/35 Pipe
				Grade X42	60/42 Pipe
		Q	1005	*	Steel Compositions
		Q	1006	*	Steel Compositions
		Q	1008	*	Steel Compositions
		Q	1009	*	Steel Compositions
		Q	1010	*	Steel Compositions
		Q	1011	*	Steel Compositions
		Q	1012	*	Steel Compositions
		Q	1013	*	Steel Compositions
		Q	1015	*	Steel Compositions
		Q	1016	*	Steel Compositions
		Q	1017	*	Steel Compositions
		Q	1018	*	Steel Compositions
		Q	1019	*	Steel Compositions
		Q	1020	*	Steel Compositions
		Q	1021	*	Steel Compositions
		Q	1022	*	Steel Compositions
		Q	1023	*	Steel Compositions
		Q	1025	*	Steel Compositions
		Q	1026	*	Steel Compositions
1	2	PS	A105	70/36	Pipe Flanges (C-Si)
		PS	A106	Grade C	70/40 Pipe (C-Si)
		S	A131	Grade AH32	68/45.5 Structural
				Grade DH32	68/45.5 Structural
				Grade EH32	68/45.5 Structural
				Grade AH36	71/50 Structural
				Grade DH36	71/50 Structural
				Grade EH36	71/50 Structural
		S	A139	Grade D	60/46 Pipe
				Grade E	66/52 Pipe
		P	A155	Grade KC70	70/38 Pipe (C-Si)
				Grade KCF70	70/38 Pipe (C-Mn-Si)
		PS	A181	Class 70	70/36 Pipe Flange (C-Si)
		PS	A210	Grade C	70/40 ERW Tube (C-Si)
		PS	A216	Grade WCB	70/36 Casting (C-Si)
				Grade WCC	70/40 Casting (C-Mn-Si)
		PS	A234	WPC	70/40 Pipe Fitting (C-Mn)
		S	A242	Type 1	70/50 HSLA, Structural
				.75 in. < thk ≤ 1.5 in.	67/46
				1.5 in. < thk ≤ 4.0 in.	63/42
			A242	Type 2	70/50 HSLA, Structural
				.75 in. < thk ≤ 1.5 in.	67/46
				1.5 in. < thk ≤ 4.0 in.	63/42

(continued)

Table 1 (Continued)

Mat'l No.	Group No.	Std.	Base Metal Specification	Minimum Tensile/ Yield ksi	Base Metal
1	2	PS	A266	Class 2 Class 3 Class 4	70/36 75/37.5 75/37.5 Seamless Forging (C-Si) Seamless Forging (C-Si) Seamless forging (C-Si)
		PS	A299	75/42	Plate (C-Mn-Si)
		PS	A350	70/36	Forging (C-Mn-Si)
		PS	A352	70/40	Casting (C-Mn)
		PS	A372	70/45	Forging (C)
		S	A381	72/52	Pipe
				75/56	Pipe
		PS	A414	70/42	Sheet
				75/45	Sheet
		S	A441	70/50	HSLA Steel
				.75 in. < thk ≤ 1.5 in. 1.5 in. < thk ≤ 4.0 in. 4.0 in. < thk ≤ 8.0 in.	67/46 63/42 60/40
		PS	A455	75/35	Plate (C-Mn)
		PS	A487	70/30	Casting (C)
				70/36	Casting (C)
				70/40	Casting (C)
				70/40	Casting
		S	A500	62/46	Structural Tubing
		PS	A508	70/36	Forging (0.35 max. C-Si)
				70/36	Forging (0.30 max. C-Si)
		S	A512	*	Mechanical Tube
				*	Mechanical Tube
		S	A513	*	Mechanical Tube
				*	Mechanical Tube
		PS	A515	70/38	Plate (C-Si)
		PS	A516	70/38	Plate (C-Mn-Si)
		S	A519	*	Mechanical Tube
				*	Mechanical Tube
		PS	A537	70/50	Plate (C-Mn-Si)
		PS	A541	70/36	Forging
				70/36	Forging
		PS	A556	70/40	Tubes Seamless (C-Mn)
		S	A557	70/40	ERW Tube (C-Mn)
		S	A569	60/45	Sheet & Strip
				65/50	Sheet & Strip
		S	A570	60/45	Sheet & Strip
				65/50	Sheet & Strip
				75/60	Sheet & Strip
				80/65	Sheet & Strip
		S	A572	65/50	HSLA, Cb, V, Steel
				75/60	HSLA, Cb, V, Steel
		S	A573	65/35	Imp. Tough. Plate
				70/42	Imp. Tough. Plate
		S	A588	70/50	HSLA Structural
				70/50	HSLA Structural
				70/50	HSLA Structural
				70/50	HSLA Structural
				70/50	HSLA Structural
				70/50	HSLA Structural

(continued)

Table 1 (Continued)

Mat'l No.	Group No.	Std.	Base Metal Specification	Minimum Tensile/ Yield ksi	Base Metal
1	2	S	A588	Grade H Grade J Grade K All Grades: 4.0 in. < thk ≤ 5.0 in. thk > 5.0 in.	70/50 70/50 70/50 HSLA Structural HSLA Structural HSLA Structural
		S	A595	Grade A Grade B Grade C	67/46 63/42 65/55 Tapered Tube Tapered Tube Tapered Tube
		S	A606		70/60 Tapered Tube
		S	A607		70/60 Tapered Tube
		S	A618	Grade 45 Grade 50 Grade 55 Grade 60 Grade 1a Grade 1b Grade II Grade III	65/45 60/45 65/50 70/55 75/60 70/50 70/50 70/50 HSLA Sheet and Strip Sheet and Strip Sheet and Strip Sheet and Strip HSLA Tube HSLA Tube HSLA Tube
		S	A633	Grade A Grade C 2.5 in. < thk ≤ 4.0 in. Grade D 2.5 in. < thk ≤ 4.0 in.	65/50 63/42 70/50 65/46 70/50 65/46 HSLA Steel HSLA Steel
		PS	A660	Grade WCB Grade WCC	70/36 70/40 Pipe (C) Pipe (C-Mn-Si)
		S	A662	Grade C	70/43 Plate (C-Mn)
		PS	A671	Grade CB70 Grade CC70 Grade CD70 Grade CK75	70/38 70/38 70/46 75/40 Pipe Pipe Pipe Pipe
		PS	A672	Grade B70 Grade C70 Grade D70 Grade N75	70/38 70/38 70/46 75/40 Pipe Pipe Pipe Pipe
		PS	A675	Grade 70 Grade 75	70/35 75/37.5 Bar Bar
		PS	A691	Gr. CMSH-70 Gr. CMS-75	70/50 75/40 Pipe Pipe
		S	A695	Grade 40 Grade 45	70/40 80/45 Bar Bar
		S	A696	Grade C	70/40 Bar
		S	A709	Grade 50 Grade 50W	65/50 70/50 Structural Structural
		PS	A737	Grade B	70/50 Plate
		PS	A738	Grade A	75/45 Plate
		PS	A765	Grade II	70/36 Forging
		Q	ABS	Grade AH32 Grade DH32 Grade EH32 Grade AH36 Grade DH36 Grade EH36	68/45 68/45 68/51 71/51 71/51 71/51 Hull Steel Hull Steel Hull Steel Hull Steel Hull Steel Hull Steel

(continued)

Table 1 (Continued)

Mat'l No.	Group No.	Std.	Base Metal Specification	Minimum Tensile/ Yield ksi	Base Metal
1	2	Q	API 2H	62/42	
			API 5LS	63/46	Pipe
			Grade X46	66/52	Pipe
		Q	Grade X60	75/60	Pipe
			Grade X46	63/46	Pipe
			Grade X52	66/52	Pipe
1	3	S	API 5L	75/60	Pipe
			Grade X46	63/46	Pipe
			Grade X52	66/52	Pipe
		PS	Class 60	78/60	Pipe
			Class 65	80/65	Pipe
			Class BQ	80/36	Casting (C)
		PS	Class CQ	80/40	Casting (C)
			Class 2	80/60	C-Mn-Si-Plate
			2.5 in. < thk ≤ 4.0 in.	75/55	
		S	4.0 in. < thk ≤ 6.0 in.	70/46	
			Grade 65	80/65	HSLA, Cb, V Steel
			Grade 65	80/65	Sheet, HSLA Cb-V
		S	Grade 70	85/70	Sheet, HSLA Cb-V
			Grade A	81/50	Plate, HSLA
			Grade E	80/60	HSLA Steel
		S	4.0 in. < thk ≤ 6.0 in.	75/55	
			Grade 70	70/35	Bar
			Grade 75	75/41	Bar
		PS	Grade 80	80/44	Bar
			Grade CD80	80/60	Pipe (C-Mn-Si)
			Grade D80	80/65	Pipe (C-Mn-Si)
		PS	Grade 80	80/40	Bar
			Grade 90	90/55	Bar
			Grade CMSH-80	80/60	Pipe
		PS	Grade C	80/60	Plate
			Grade B	85/60	Plate
			Grade X65	82/65	Pipe
		Q	Grade X70	77/70	Pipe
			Grade X65	77/65	Pipe
			Grade X70	82/70	Pipe
1	4	S	API 5L	82/80	Sheet and Strip
			Grade E	90/80	HSLA (Ni-Cu-Cr-Mo-Cb)
			Grade A C1.1	72/65	HSLA (Ni-Cu-Cr-Mo-Cb)
		S	Grade A C1.2	85/75	HSLA (Ni-Cu-Cr-Mo-Cb)
			Grade A C1.3	90/80	HSLA (Ni-Cu-Cr-Mo-Cb)
			Grade B	100/90	HSLA (Ni-Cu-Cr-Mo-Cb)
		PS	Grade C C1.1	95/85	HSLA (Ni-Cu-Cr-Mo-Cb)
			Grade C C1.3	90/70	Plate
			Grade A	95/75	Plate
		PS	Grade B	90/70	Plate
			Grade C	90/80	HSLA Plate (Ni-Cu-Cr-Mo-Cb)
			Grade A C1.1	72/65	HSLA Plate (Ni-Cu-Cr-Mo-Cb)
		PS	Grade A C1.2	85/75	HSLA Plate (Ni-Cu-Cr-Mo-Cb)
			Grade A C1.3	100/90	HSLA Plate (Ni-Cu-Cr-Mo-Cb)
			Grade C C1.1	95/85	HSLA Plate (Ni-Cu-Cr-Mo-Cb)
		PS	Grade C1.3	65/37	Plate (C-1/2 Mo)
			Grade A	55/30	Tube (C-1/2 Mo)
			Grade T1a	60/32	Tube (C-1/2 Mo)

(continued)

Table 1 (Continued)

Mat'l No.	Group No.	Std.		Base Metal Specification	Minimum Tensile/ Yield ksi	Base Metal
3	1	PS	A209	Grade T1b	53/28	Tube (1/2 Cr-1/2 Mo)
		PS	A213	Grade T2	60/30	Tube (1/2 Cr - 1/2 Mo)
		PS	A217	Grade WC1	65/35	Casting (C-1/2 Mo)
		PS	A234	Marking WPI	55/30	Pipe Fitting (C-1/2 Mo)
		PS	A250	Grade T1	55/30	Tube (C-1/2 Mo)
				Grade T1a	60/32	Tube (C-1/2 Mo)
				Grade T1b	53/28	Tube (C-1/2 Mo)
		PS	A335	Grade P1	55/30	Pipe (C-1/2 Mo)
				Grade P2	55/30	Pipe (1/2 Cr-1/2 Mo)
				Grade P15	60/30	Pipe (1-1/2 Si - 1/2 Mo)
		PS	A352	Grade LC1	65/35	Casting (C-1/2 Mo)
		PS	A369	Grade FP1	55/30	Pipe (C-1/2 Mo)
				Grade FP2	55/30	Pipe (1/2 Cr-1/2 Mo)
		PS	A387	Grade 2, Class 1	55/33	Plate (1/2 Cr-1/2 Mo)
		PS	A426	Grade CP1	55/35	Cast Pipe (C-1/2 Mo)
				Grade CP2	55/30	Cast Pipe (1/2 Cr-1/2 Mo)
				Grade CP15	60/30	Cast Pipe (C-Si-Mo)
		PS	A672	Grade L65	65/37	Pipe (C-1/2 Mo)
		PS	A691	Grade CM-65	65/37	Pipe (C-1/2 Mo)
		3	2	S	A155	Grade 1/2 CR
				Grade CM70	70/40	Pipe (C-1/2 Mo)
				Grade CM75	75/43	Pipe (C-1/2 Mo)
PS	A182			Grade F1	70/40	Pipe Flange (C-1/2 Mo)
				Grade F2	70/40	Pipe Flange (1/2 Cr-1/2 Mo)
PS	A204			Grade B	70/40	Plate (C-1/2 Mo)
				Grade C	75/43	Plate (C-1/2 Mo)
PS	A302			Grade A	75/45	Plate (Mn-Mo)
PS	A336			Class F1	70/40	Forging (C-Mo)
PS	A387			Gr. 2, Class 2	70/45	Plate (Cr-Mo)
PS	A672			Grade L70	70/40	Pipe (C-1/2 Mo)
				Grade L75	75/43	Pipe (C-1/2 Mo)
				Grade H75	75/45	Pipe (1 Mn-1/2 Mo)
PS	A691			Gr. CM-70	70/40	Pipe (C-1/2 Mo)
				Gr. CMSH-70	70/50	Pipe (C-Mo)
				Gr. CM-75	75/43	Pipe (C-1/2 Mo)
		Gr. CMS-75	75/40	Pipe (C-Mo)		
3	3	PS	A302	Grade B	80/50	Plate (Mn-Mo)
				Grade C	80/50	Plate (Mn-Mo-Ni)
				Grade D	80/50	Plate (Mn-Mo-Ni)
		PS	A508	Class 2	80/50	Forging (3/4 Ni-Mo-Cr-V)
				Class 2a	90/65	Forging (1/2 Ni-Cr-Mo)
				Class 3	80/50	Forging (1/2 Ni-Cr-Mo-V)
				Class 3a	90/65	Forging (3/4 Ni-Cr-Mo-V)
				Class 4b	90/70	Forging (3-1/2 Ni-Cr-Mo-V)
		PS	A533	Type A, Class 1	80/50	Plate (Mn-Mo)
				Type B, Class 1	80/50	Plate (Mn-Mo-Ni)
				Type C, Class 1	80/50	Plate (Mn-Mo-Ni)
				Type D, Class 1	80/50	Plate (Mn-Mo-Ni)
				Type A, Class 2	90/70	Plate (Mn-Mo)
				Type B, Class 2	90/70	Plate (Mn-Mo-Ni)
				Type C, Class 2	90/70	Plate (Mn-Mo-Ni)
				Type D, Class 2	90/70	Plate (Mn-Mo-Ni)

(continued)

Table 1 (Continued)

Mat'l No.	Group No.	Std.	Base Metal Specification	Minimum Tensile/ Yield ksi	Base Metal
3	3	PS	A541	Class 2	80/50 Forging (3/4 Ni-Cr-Mo-V)
				Class 2A	90/65 Forging (1/2 Ni-Cr-Mo)
		PS	A672	Class 3	80/50 Forging (1/2 Ni-Mo-V)
				Class 3A	90/65 Forging (1/2 Ni-Mo-V)
4	1	S	A155	Grade H80	80/50 Pipe (Mn-Mo)
				Grade J80	80/50 Pipe (Mn-Mo-Ni)
				Grade J90	90/70 Pipe (Mn-Mo-Ni)
				Grade 1CR	55/33 Pipe (1 Cr-1/2 Mo)
		PS	A182	Grade 1-1/4 CR	60/35 Pipe (1 Cr-1/2 Mo-Si)
				Grade F11	70/40 Pipe Flange (1-1/4 Cr-1/2 Mo-Si)
				Grade F11a	75/45 Pipe Flange (1-1/4 Cr-1/2 Mo-Si)
				Grade F11b	60/30 Pipe Flange (1-1/4 Cr-1/2 Mo-Si)
		PS	A199	Grade F12	70/40 Pipe Flange (1 Cr - 1/2 Mo)
				Grade F12b	60/30 Pipe Flange (1 Cr - 1/2 Mo)
				Grade T3b	60/25 Smls. Tube (2 Cr - 1/2 Mo)
				Grade T11	60/25 Smls. Tube (2 Cr - 1/2 Mo)
		PS	A202	Grade A	75/45 Plate (1/2 Cr - 1/4 Mo-Si)
				Grade B	85/47 Plate (1/2 Cr - 1/4 Mn-Si)
				Grade T3b	60/30 Tube (2Cr-1/2 Mo)
				Grade T11	60/30 Tube (1-1/4 Cr-1/2 Mo-Si)
		PS	A213	Grade T12	60/30 Tube (2 Cr-1/2 Mo)
				Grade WC4	70/40 Casting (1 Ni-Cr-1/2 Mo)
				Grade WC5	70/40 Casting (3/4 Ni-Mo-3/4 Cr)
				Grade WC6	70/40 Casting (1-1/4 Cr-1/2 Mo)
		PS	A234	WP11	60/30 Pipe Fitting (1-1/4 Cr-1/2 Mo-Si)
				WP12	60/30 Pipe Fitting (1 Cr-1/2 Mo)
		PS	A333	Grade G-4	60/30 Pipe
				Grade P11	60/30 Pipe (1-1/4 Cr-1/2 Mo-Si)
				Grade P12	60/30 Pipe (1 Cr-1/2 Mo)
				Class F11	70/40 Forging (1 Cr-1/2 Mo)
		PS	A182	Class F11a	75/45 Forging (1 Cr-1/2 Mo)
				Class F11b	60/30 Forging (1-1/4 Cr-1/2 Mo)
				Class F12	70/40 Forging (1 Cr-1/2 Mo)
		PS	A369	Grade FP3b	60/30 Pipe (2 Cr-Mo)
				Grade FP11	60/30 Pipe (1-1/4 Cr-Mo-Si)
				Grade FP 12	60/30 Pipe (1 Cr-Mo)
		PS	A387	Gr. 11, Class 1	60/35 Plate (1-1/4 Cr-1/2 Mo-Si)
				Gr. 11, Class 2	75/45 Plate (1-1/4 Cr-1/2 Mo-Si)
				Gr. 12, Class 1	55/33 Plate (1 Cr-1/2 Mo)
				Gr. 12, Class 2	65/40 Plate (1 Cr-1/2 Mo)
		S	A389	Grade C23	70/40 Casting
				Grade C24	80/50 Casting
		PS	A405	Grade P24	60/30 Pipe
				Grade CP11	70/40 Cast Pipe (1-1/4 Cr-Mo)
		PS	A426	Grade CP12	60/30 Cast Pipe (2 Cr-Mo)
				Gr. 1 Cr, CL1	55/33 Pipe (1 Cr-1/2 Mo)
				Gr. 1 Cr, CL2	65/45 Pipe (1 Cr-1/2 Mo)
				Gr. 1-1/4 Cr., CL1	60/35 Pipe (1-1/4 Cr-1/2 Mo-Si)
		PS	A691	Gr. 1-1/4 Cr, CL2	75/45 Pipe (1-1/4 Cr-1/2 Mo-Si)
				Grade B11	70/45 Bar (1-1/4 Cr-1/2 Mo)
		PS	A739	Grade 4	60/35 Pipe (Cr-Ni-Cu-Al)
				Grade 1	60/37 Tube (Cr-Ni-Cu)
				Grade 2	60/37 Tube (Ni-Cu-Mo)
		PS	A423	Grade 1	60/37 Tube (Ni-Cu-Mo)
				Grade 2	60/37 Tube (Ni-Cu-Mo)

(continued)

Table 1 (Continued)

Mat'l No.	Group No.	Std.		Base Metal Specification	Minimum Tensile/ Yield ksi	Base Metal		
5	1	S	A155	Gr. 2-1/4 Cr	60/35	Pipe (2-1/4 Cr-Mo)		
				PS	A182	Grade F21	75/45	Pipe Flange (3 Cr-Mo)
						Grade F22	75/45	Pipe Flange (2-1/4 Cr-Mo)
		Grade F22a	60/30			Pipe Flange (2-1/4 Cr-Mo)		
		PS	A199	Grade T4	60/25	Smls. Tube (Cr-Mo-Si)		
				Grade T21	60/25	Smls. Tube (3 Cr-Mo)		
				Grade T22	60/25	Tube (2-1/4 Cr-Mo)		
		S	A200	Grade T4	60/25	Tube (Cr-Mo)		
				Grade T21	60/25	Tube (Cr-Mo)		
				Grade T22	60/25	Smls. Tube (2-1/4 Cr-Mo)		
		PS	A213	Grade T21	60/30	Tube (3 Cr-Mo)		
				Grade T22	60/30	Tube (2-1/4 Cr-Mo)		
				Grade WC9	70/40	Casting (2-1/4 Cr-Mo)		
		PS	A217	WP22	60/30	Pipe Fitting (2-1/4 Cr-Mo)		
		PS	A234	Grade P21	60/30	Pipe (3 Cr-Mo)		
		PS	A335	Grade P22	60/30	Pipe (2-1/4 Cr-1 Mo)		
				PS	A336	Class F21	75/45	Forging (3 Cr-Mo)
						Class F21a	60/30	Forging (3 Cr-Mo)
		Class F22	75/45			Forging (2-1/4 Cr-1 Mo)		
		PS	A369	Class F22a	60/30	Forging (2-1/4 Cr-Mo)		
				Grade FP21	60/30	Pipe (3 Cr-Mo)		
				Grade FP22	60/30	Pipe (2-1/4 Cr-Mo)		
		PS	A387	Gr. 21, Class 1	60/30	Plate (3 Cr-Mo)		
				Gr. 21, Class 2	75/45	Plate (3 Cr-Mo)		
				Gr. 22, Class 1	60/30	Plate (2-1/4 Cr-Mo)		
		PS	A426	Gr. 22, Class 2	75/45	Plate (2-1/4 Cr-Mo)		
				Grade CP 21	60/30	Cast Pipe (3 Cr-Mo)		
				Grade CP 22	70/40	Cast Pipe (2-1/4 Cr-1 Mo)		
		PS	A691	Gr. 2-1/4 Cr, CL.1	60/30	Pipe (2-1/4 Cr-1 Mo)		
				Gr. 2-1/4 Cr, CL.2	75/45	Pipe (2-1/4 Cr-1 Mo)		
				Gr. 3Cr, Class 1	60/30	Pipe (3 Cr-1 Mo)		
		PS	A739	Gr. 3 Cr, Class 2	75/45	Pipe (3 Cr-1 Mo)		
Grade B22	75/45			Bar (2-1/4 Cr - 1 Mo)				
PS	A182			Grade F5	70/40	Pipe Flange (5 Cr-1/2 Mo)		
		Grade F5a	90/65	Pipe Flange (5 Cr-Mo)				
		Grade F7	70/40	Pipe Flange (7 Cr-Mo)				
PS	A199	Grade F9	85/55	Pipe Flange (9 Cr-Mo)				
		Grade T5	60/30	Smls. Tube (5 Cr-Mo)				
		Grade T7	60/30	Smls. Tube (7 Cr-Mo)				
S	A200	Grade T9	60/30	Smls. Tube (9 Cr-Mo)				
		Grade T5	60/30	Alloy Tube				
		Grade T7	60/30	Alloy Tube				
PS	A213	Grade T9	60/30	Alloy Tube				
		Grade T5	60/30	Alloy Tube (5 Cr-Mo)				
		Grade T5b	60/30	Alloy Tube (5 Cr-Mo-Si)				
PS	A217	Grade T5c	60/30	Alloy Tube (5 Cr-Mo-Ti)				
		Grade T7	60/30	Tube (7 Cr-Mo)				
		Grade T9	60/30	Tube (9 Cr-Mo)				
PS	A234	Grade C5	90/60	Casting (5 Cr-Mo)				
		Grade C12	90/60	Casting (9 Cr-Mo)				
		Grade WP5	60/30	Pipe Fitting (5 Cr-1/2 Mo)				
			Grade WP7	60/30	Pipe Fitting (7 Cr-1/2 Mo)			

(continued)

Table 1 (Continued)

Mat'l No.	Group No.	Std.	Base Metal Specification	Minimum Tensile/ Yield ksi	Base Metal
5	2	PS	A234	Grade WP9	Pipe Fitting (9 Cr-1/2 Mo)
		PS	A335	Grade P5	Pipe (5 Cr-1/2 Mo)
				Grade P5b	Pipe (5 Cr-1/2 Mo-Si)
				Grade P5c	Pipe (5 Cr-1/2 Mo-Ti)
				Grade P7	Pipe (7 Cr-1/2 Mo)
				Grade P9	Pipe (9 Cr-1/2 Mo)
		PS	A336	Class F5	Forging (5 Cr-1/2 Mo)
				Class F5a	Forging (5 Cr-1/2 Mo)
				Class F9	Forging (9 Cr-1 Mo-3/4 Si)
		PS	A369	Grade FP5	Pipe (5 Cr-1/2 Mo)
				Grade FP7	Pipe (7 Cr-1/2 Mo)
				Grade FP9	Pipe (9 Cr-1/2 Mo)
		PS	A387	Gr. 5, Class 1	Plate (5 Cr-1/2 Mo)
				Gr. 5, Class 2	Plate (5 Cr-1/2 Mo)
		PS	A426	Grade CP5	Cast Pipe (5 Cr-1/2 Mo)
				Grade CP5b	Cast Pipe (5 Cr-1-1/2 Si-1/2 Mo)
				Grade CP7	Cast Pipe (7 Cr-1/2 Mo)
				Grade CP9	Cast Pipe (9 Cr-1 Mo)
		PS	A487	Grade 8N	Casting (2-1/4 Cr-Mo)
		PS	A691	Gr. 5 Cr, Class 1	Pipe (5 Cr-1/2 Mo)
				Gr. 5 Cr, Class 2	Pipe (5 Cr-1/2 Mo)
6	1	PS	A182	Gr. F6A, Class 1	Flange (13 Cr)
		PS	A240	Type 410	Plate (13 Cr)
		PS	A268	Grade TP 409	Tube (13 Cr)
				Grade TP 410	Tube (13 Cr)
		S	A473	Type 403	Forging
				Type 410	Forging
				Type 414-T	Forging
		PS	A479	Type 403, CL.1	Bar & Shapes
				Type 410, CL.1	Bar & Shapes
6	2	PS	A182	Grade F429	Flange (15 Cr)
		PS	A240	Type 429	Plate (15 Cr)
		PS	A268	Grade TP429	Tube (15 Cr)
		S	A473	Type 405	Forging
				Type 420	Forging
				Type 429	Forging
6	3	PS	A182	Gr. F6a, Class 2	Forging (13 Cr)
				Gr. F6a, Class 3	Forging (13 Cr)
				Gr. F6a, Class 4	Forging (13 Cr)
				Grade F6b	Forging (13 Cr-1/2 Mo)
		PS	A217	Grade CA-15	Casting (13 Cr-Mo)
		PS	A336	Class F6	Forging (13 Cr)
		PS	A426	Grade CPCA15	Cast Pipe (13 Cr-Mo)
		PS	A479	Type 414, tempered	Bar & Shapes
		PS	A487	Class CA15M	Casting (13 Cr)
		PS	A182	Grade F6NM	Flange (13 Cr-4 Ni)
		PS	A352	CA6NM	Casting (13 Cr-4 Ni)
6	4	PS	A479	Type 414	Bar (Cr-Ni)
		PS	A487	Grade CA6NM	Casting (13 Cr-4 Ni)
		PS	A240	Type 405	Plate (12 Cr-Al)
				Type 409	Plate (11 Cr)
7	1	PS	A240	Type 410S	Plate (13 Cr)

(continued)

Table 1 (Continued)

Mat'l No.	Group No.	Std.		Base Metal Specification	Minimum Tensile/ Yield ksi	Base Metal		
7	1	PS	A268	Grade TP 405	60/30	Tube (12 Cr-Al)		
				Grade TP 409	60/30	Plate (11 Cr-Ti)		
		S	A473	Type 405	60/30	Forging		
				Type 410S	65/35	Forging		
				Type 414, tempered	115/90	Forging		
	2	PS	A479	Type 431, tempered	115/90	Forging		
				Type 405	60/25	Bar & Shapes		
		S	A176	UNS S44600	65/40	Plate (Cr-N)		
				PS	A182	Grade F430	60/35	Pipe Flange (17 Cr)
						PS	A240	Type XM-8
UNS S44400	60/40	Plate (18 Cr-2 Mo-Ti)						
7				Type 430	65/30	Plate (17 Cr)		
				Type XM-27	65/40	Plate (26 Cr-1/2 Mo)		
				Type XM-33	68/45	Plate (26 Cr-1-1/4 Mo - 1/2 Ti)		
				Type 430	60/35	Tube (17 Cr)		
				Gr. TPXM-8	60/30	Tube (18 Cr-Ti)		
				Type (18 Cr - 2 Mo)	60/45	Tube (18 Cr - 2 Mo-Ti)		
				UNS S44600	65/40	Forging (Cr-N)		
				Type 430	70/35	Forging		
				PS	A479	Type XM-8	70/40	Bar & Shapes
						Type XM-27	65/40	Bar & Shapes
					Type XM-30	70/40	Bar & Shapes	
					Type 430	70/40	Bar & Shapes (17 Cr)	
					Type 18 Cr- 2 Mo	60/40	Smls. and Welded Pipe	
					TPXM-8	60/30	Smls. and Welded Pipe	
					Type 301	75/30	Plate	
					Type 302	75/30	Plate	
					Type 302B	75/30	Plate	
					Type 304	75/30	Plate	
					Type 304L	70/25	Plate	
					Type 304LN	75/30	Plate	
8	1	S	A167	Type 305	70/25	Plate		
				Type 308	75/30	Plate		
				Type 309	75/30	Plate		
				Type 309S	75/30	Plate		
				Type 309Cb	75/30	Plate		
				Type 310	75/30	Plate		
				Type 310S	75/30	Plate		
				Type 310Cb	75/30	Plate		
				Type 316	75/30	Plate		
				Type 316L	70/25	Plate		
				Type 316LN	75/30	Plate		
				Type 316Cb	75/30	Plate		
				PS	A182	Type 317	75/30	Plate
						Type 317L	75/30	Plate
				Type 321	75/30	Plate		
				Type 321H	75/30	Plate		
				Type 347	75/30	Plate		
				Type 348	75/30	Plate		
				Type XM-15	75/30	Plate		
				Grade F304	75/30	Pipe Flange (Cr-Ni)		
Grade F304H	75/30	Pipe Flange (Cr-Ni)						

(continued)

Table 1 (Continued)

Mat'l No.	Group No.	Std.	Base Metal Specification	Minimum Tensile/ Yield ksi	Base Metal	
8	1	PS	A182	Grade F304L	70/25	Pipe Flange (Cr-Ni)
				Grade F304N	80/35	Pipe Flange (Cr-Ni-N)
				Grade F304LN	75/30	Pipe Flange (Cr-Ni-N)
				Grade F316	75/30	Pipe Flange (Cr-Ni-Mo)
				Grade 316H	75/30	Pipe Flange (Cr-Ni-Mo)
				Grade 316L	70/25	Pipe Flange (Cr-Ni-Mo)
				Grade 316LN	75/30	Pipe Flange (Cr-Ni-Mo-N)
				Grade F316N	80/35	Pipe Flange (Cr-Ni-Mo-N)
				Grade F321	75/30	Pipe Flange (Cr-Ni-Ti)
				Grade F321H	75/30	Pipe Flange (Cr-Ni-Ti)
				Grade F347	75/30	Pipe Flange (Cr-Ni-Cb)
				Grade 347H	75/30	Pipe Flange (Cr-Ni-Cb)
				Grade F348	75/30	Pipe Flange (Cr-Ni-Cb)
				Grade F348H	75/30	Pipe Flange (Cr-Ni-Cb)
		PS	A213	Grade TP304	75/30	AISI Smls. Tube (Cr-Ni)
				Grade TP304H	75/30	AISI Smls. Tube (Cr-Ni)
				Grade TP304L	70/25	AISI Smls. Tube (Cr-Ni)
				Grade TP304N	80/35	Alloy Smls. Tube (Cr-Ni-N)
				Grade TP316	75/30	AISI Smls. Tube (Cr-Ni-Mo)
				Grade TP316H	75/30	AISI Smls. Tube (Cr-Ni-Mo)
				Grade TP316L	70/25	AISI Smls. Tube (Cr-Ni-Mo)
				Grade TP316N	80/35	Alloy Smls. Tube (Cr-Ni-Mo-N)
				Grade TP321	75/30	AISI Smls. Tube (Cr-Ni-Ti)
				Grade TP321H	75/30	AISI Smls. Tube (Cr-Ni-Ti)
				Grade TP347	75/30	AISI Smls. Tube (Cr-Ni-Cb)
				Grade TP347H	75/30	AISI Smls. Tube (Cr-Ni-Cb)
				Grade TP348	75/30	AISI Smls. Tube (Cr-Ni-Cb)
				Grade TP348H	75/30	AISI Smls. Tube (Cr-Ni-Cb)
		PS	A240	Grade XM-15	75/30	Alloy Smls. Tube (Cr-Ni-Si)
				Type 302	75/30	Plate (Cr-Ni)
				Type 304	75/30	AISI Plate (Cr-Ni)
				Type 304H	75/30	AISI Plate (Cr-Ni)
				Type 304L	70/25	AISI Plate (Cr-Ni)
				Type 304LN	75/30	AISI Plate (Cr-Ni-N)
				Type 304N	80/35	AISI Plate (Cr-Ni-N)
				Type 316	75/30	AISI Plate (Cr-Ni-Mo)
				Type 316H	75/30	AISI Plate (Cr-Ni-Mo)
				Type 316L	70/25	AISI Plate (Cr-Ni-Mo)
				Type 316LN	75/30	AISI Plate (Cr-Ni-Mo-N)
				Type 316N	80/35	AISI Plate (Cr-Ni-Mo-N)
				Type 316Cb	75/30	AISI Plate (Cr-Ni-Mo)
				Type 316Ti	75/30	AISI Plate (Cr-Ni-Mo)
				Type 317	75/30	AISI Plate (Cr-Ni-Mo)
				Type 317L	75/30	AISI Plate (Cr-Ni-Mo)
				Type 321	75/30	AISI Plate (Cr-Ni-Ti)
				Type 321H	75/30	AISI Plate (Cr-Ni-Ti)
				Type 347	75/30	AISI Plate (Cr-Ni-Cb)
				Type 347H	75/30	AISI Plate (Cr-Ni-Cb)
				Type 348	75/30	AISI Plate (Cr-Ni-Cb)
				Type 348H	75/30	AISI Plate (Cr-Ni-Cb)
				Type XM-15	75/30	Plate (Cr-Ni-Si)
				Type XM-21	85/40	Plate (Cr-Ni-N)

(continued)

Table 1 (Continued)

Mat'l No.	Group No.	Std.	Base Metal Specification	Minimum Tensile/ Yield ksi	Base Metal			
8	1	PS	A249	Grade TP304	75/30	AISI Welded Tube (Cr-Ni)		
				Grade TP304H	75/30	AISI Welded Tube (Cr-Ni)		
				Grade TP304L	70/25	AISI Welded Tube (Cr-Ni)		
				Grade TP304LN	75/30	AISI Welded Tube (Cr-Ni-N)		
				Grade TP304N	80/35	Welded Tube (Cr-Ni-N)		
				Grade TP316	75/30	AISI Welded Tube (Cr-Ni-Mo)		
				Grade TP316H	75/30	AISI Welded Tube (Cr-Ni-Mo)		
				Grade TP316L	70/25	AISI Welded Tube (Cr-Ni-Mo)		
				Grade TP316LN	75/30	AISI Welded Tube (Cr-Ni-Mo-N)		
				Grade TP316N	80/35	AISI Welded Tube (Cr-Ni-Mo-N)		
				Grade TP317	75/30	AISI Welded Code (Cr-Ni-Mo)		
				Grade TP321	75/30	AISI Welded Code (Cr-Ni-Ti)		
				Grade TP321H	75/30	AISI Welded Tube (Cr-Ni-Ti)		
				Grade TP347	75/30	AISI Welded Tube (Cr-Ni-Cb)		
				Grade TP347H	75/30	AISI Welded Tube (Cr-Ni-Cb)		
				Grade TP348	75/30	AISI Welded Tube (Cr-Ni-Cb)		
				Grade TP348H	75/30	AISI Welded Tube (Cr-Ni-Cb)		
				Grade TPXM-15	75/30	Welded Tube (Cr-Ni-Si)		
		S	A269	Grade TP304	*	Tubing		
				Grade TP304L	*	Tubing		
				Grade TP304LN	*	Tubing		
				Grade TP316	*	Tubing		
				Grade TP316L	*	Tubing		
				Grade TP316LN	*	Tubing		
				Grade TP317	*	Tubing		
				Grade TP321	*	Tubing		
				Grade TP347	*	Tubing		
				Grade TP348	*	Tubing		
		S	A270	Type 304	70/30	Tubing		
		S	A271	Grade TP304	75/30	Tubing		
				Grade TP304H	75/30	Tubing		
				Grade TP316	75/30	Tubing		
				Grade TP316H	75/30	Tubing		
				Grade TP321	75/30	Tubing		
				Grade TP321H	75/30	Tubing		
				Grade TP347	75/30	Tubing		
				Grade TP347H	75/30	Tubing		
				PS	A312	Grade TP304	75/30	Pipe (Cr-Ni)
						Grade TP304H	75/30	Pipe (Cr-Ni)
		Grade TP304L	70/25			Pipe (Cr-Ni)		
		Grade TP304LN	75/30			Pipe (Cr-Ni-N)		
		Grade TP304N	80/35			Pipe (Cr-Ni-No)		
		Grade TP316	75/30			Pipe (Cr-Ni-Mo)		
		Grade TP316H	75/30			Pipe (Cr-Ni-Mo)		
		Grade TP316L	70/25			Pipe (Cr-Ni-Mo)		
		Grade TP316LN	75/30			Pipe (Cr-Ni-Mo-N)		
		Grade TP316N	80/35			Pipe (Cr-Ni-Mo-N)		
		Grade TP317	75/30			Pipe (Cr-Ni-Mo)		
		Grade TP321	75/30			Pipe (Cr-Ni-Ti)		
		Grade TP321H	75/30			Pipe (Cr-Ni-Ti)		
		Grade TP347	75/30			Pipe (Cr-Ni-Cb)		
		Grade TP347H	75/30	Pipe (Cr-Ni-Cb)				

(continued)

Table 1 (Continued)

Mat'l No.	Group No.	Std.		Base Metal Specification	Minimum Tensile/ Yield ksi	Base Metal
8	1	PS	A312	Grade TP348	75/30	Pipe (Cr-Ni-Cb)
				Grade TP348H	75/30	Pipe (Cr-Ni-Cb)
				Grade TPXM-15	75/30	Pipe (Cr-Ni)
		PS	A336	Class F304	70/30	Forging (Cr-Ni)
				Class F304H	70/30	Forging (Cr-Ni)
				Class F304L	65/25	Forging (Cr-Ni)
				Class F304N	80/35	Forging (Cr-Ni)
				Class F316	70/30	Forging (Cr-Ni-Mo)
				Class F316H	70/30	Forging (Cr-Ni-Mo)
				Class F316L	65/25	Forging (Cr-Ni-Mo)
				Class F316N	80/35	Forging (Cr-Ni-Mo)
				Class F321	70/30	Forging (Cr-Ni-Ti)
				Class F321H	70/30	Forging (Cr-Ni-Ti)
				Class F347	70/30	Forging (Cr-Ni-Cb)
				Class F347H	70/30	Forging (Cr-Ni-Cb)
				Class F348	70/30	Forging (Cr-Ni-Cb)
				Class 348H	65/25	Forging (Cr-Ni-Cb)
		PS	A351	Grade CF3	70/30	Casting (Cr-Ni)
				Grade CF3A	77/35	Casting (Cr-Ni)
				Grade CF3M	70/30	Casting (Cr-Ni-Mo)
				Grade CF8	70/30	Casting (Cr-Ni)
				Grade CF8A	77/35	Casting (Cr-Ni)
				Grade CF8C	70/30	Casting (Cr-Ni-Cb)
				Grade CF8M	70/30	Casting (Cr-Ni-Mo)
				Grade CF10	70/30	Casting (Cr-Ni-Mo)
				Grade CF10M	70/30	Casting (Cr-Ni-Mo)
				Grade CG8M	75/35	Casting (Cr-Ni-Mo)
		PS	A358	Grade 304	75/30	AISI Pipe (Cr-Ni)
				Grade 304H	70/30	AISI Pipe (Cr-Ni)
				Grade 304L	65/25	AISI Pipe (Cr-Ni)
				Grade 304N	80/35	AISI Pipe (Cr-Ni-N)
				Grade 316	75/30	AISI Pipe (Cr-Ni-Mo)
				Grade 316L	65/25	AISI Pipe (Cr-Ni-Mo)
				Grade 316N	80/35	AISI Pipe (Cr-Ni-Mo)
				Grade 321	75/30	AISI Pipe (Cr-Ni-Ti)
				Grade 347	75/30	AISI Pipe (Cr-Ni-Cb)
				Grade 348	75/30	AISI Pipe (Cr-Ni-Cb)
		PS	A376	Grade TP304	75/30	AISI Smls. Tube (Cr-Ni)
				Grade TP304H	75/30	AISI Smls. Tube (Cr-Ni)
				Grade TP304N	80/35	Smls. Tube (Cr-Ni-N)
				Grade TP316	75/30	AISI Smls. Tube (Cr-Ni-Mo)
				Grade TP316H	75/30	AISI Smls. Tube (Cr-Ni-Mo)
				Grade TP316N	80/35	Smls. Tube (Cr-Ni-Mo-N)
				Grade TP321	75/30	AISI Smls. Tube (Cr-Ni-Ti)
				Grade TP321H	75/30	AISI Smls. Tube (Cr-Ni-Ti)
				Grade TP347	75/30	AISI Smls. Tu7be (Cr-N-Cb)
				Grade TP347H	75/30	AISI Smls. Tube (Cr-Ni-Cb)
				Grade TP348	75/30	AISI Smls. Tube (Cr-Ni-Cb)
				Grade TP348H	75/30	AISI Smls. Tube (Cr-Ni-Cb)
		PS	A403	WP304	75/30	Pipe Fitting
				WP304H	75/30	Pipe Fitting
				WP304HF	75/30	Pipe Fitting

(continued)

Table 1 (Continued)

Mat'l No.	Group No.	Std.	Base Metal Specification	Minimum Tensile/ Yield ksi	Base Metal
8	1	PS	A403	WP304L	Pipe Fitting
				WP304N	Pipe Fitting
				WP316	Pipe Fitting
				WP316H	Pipe Fitting
				WP316HF	Pipe Fitting
				WP316L	Pipe Fitting
				WP316N	Pipe Fitting
				WP317	Pipe Fitting
				WP321	Pipe Fitting
				WP321H	Pipe Fitting
				WP321HF	Pipe Fitting
				WP347	Pipe Fitting
				WP347H	Pipe Fitting
				WP348	Pipe Fitting
				WP348H	Pipe Fitting
		PS	A409	TP304	Welded Pipe
				TP304L	Welded Pipe
				TP316	Welded Pipe
				TP316L	Welded Pipe
				TP317	Welded Pipe
				TP321	Welded Pipe
				TP347	Welded Pipe
				TP348	Welded Pipe
		PS	A430	Grade FP304	Pipe (Cr-Ni)
				Grade FP304H	Pipe (Cr-Ni)
				Grade FP304N	Pipe (Cr-Ni-N)
				Grade FP316	Pipe (Cr-Ni-Mo)
				Grade FP316H	Pipe (Cr-Ni-Mo)
				Grade FP316N	Pipe (Cr-Ni-Mo-N)
				Grade FP321	Pipe (Cr-Ni-Ti)
				Grade FP321H	Pipe (Cr-Ni-Ti)
				Grade FP347	Pipe (Cr-Ni-Cb)
				Grade FP347H	Pipe (Cr-Ni-Cb)
				Gr. FP16-8-2H	Pipe (Cr-Ni-Mo)
		PS	A451	Grade CPF3	Casting (Cr-Ni)
				Grade CPF3H	Casting (Cr-Ni)
				Grade CPF3M	Casting (Cr-Ni)
				Grade CPF8	Casting (Cr-Ni)
				Grade CPF8A	Casting (Cr-Ni, Ferrite)
				Grade CPF8M	Casting (Cr-Ni-Mo)
				Grade CPF8C	Casting (Cr-Ni-Cb)
				Gr. CPF10MC	Casting (Cr-Ni-Mo-Cb)
		PS	A452	Grade TP304H	Cast Pipe (Cr-Ni)
				Grade TP316H	Cast Pipe (Cr-Ni-Mo)
				Grade TP347H	Cast Pipe (Cr-Ni-Cb)
		S	A473	Type 302	Forging
				Type 302B	Forging
				Type 303	Forging
				Type 303Se	Forging
				Type 304	Forging
				Type 304L	Forging
				Type 305	Forging

(continued)

Table 1 (Continued)

Mat'l No.	Group No.	Std.	Base Metal Specification	Minimum Tensile/ Yield ksi	Base Metal
8	1	S	A473	Type 308	75/30 Forging
				Type 314	75/30 Forging
				Type 316	75/30 Forging
				Type 316L	65/25 Forging
				Type 317	75/30 Forging
				Type 321	75/30 Forging
				Type 347	75/30 Forging
				Type 348	75/30 Forging
				Type XM-10	90/50 Forging
				Type XM-11	90/50 Forging
		PS	A479	Type 302	75/30 Bar & Shapes (Cr-Ni)
				Type 304	75/30 Bar & Shapes (Cr-Ni)
				Type 304H	75/30 Bar & Shapes (Cr-Ni)
				Type 304L	70/30 Bar & Shapes (Cr-Ni)
				Type 304N	80/35 Bar & Shapes (Cr-Ni-N)
				Type 316	75/30 Bar & Shapes (Cr-Ni-Mo)
				Type 316H	70/25 Bar & Shapes (Cr-Ni-Mo)
				Type 316L	70/25 Bar & Shapes (Cr-Ni-Mo)
				Type 316N	80/35 Bar & Shapes (Cr-Ni-Mo-N)
				Type 321	75/30 Bar & Shapes (Cr-Ni-Ti)
				Type 321H	75/30 Bar & Shapes (Cr-Ni-Ti)
				Type 347	75/30 Bar & Shapes
				Type 347H	75/30 Bar & Shapes (Cr-Ni-Cb)
				Type 348	75/30 Bar & Shapes (Cr-Ni-Cb)
				Type 348H	75/30 Bar & Shapes (Cr-Ni-Cb)
		PS	A688	Grade TP304	75/30 Welded Tube (Cr-Ni)
				Grade TP304L	70/25 Welded Tube (Cr-Ni)
				Grade TP316	75/30 Welded Tube (Cr-Ni-Mo)
				Grade TP316L	70/25 Welded Tube (Cr-Ni-Mo)
				Grade F10	80/30 Pipe Flange (Cr-Ni)
8	2	PS	A182	Grade F45	87/45 Pipe Flange (Cr-Ni)
				Grade F310	75/30 Pipe Flange (Cr-Ni)
				Grade TP310	75/30 AISI Smls. Tube (Cr-Ni)
		PS	A213	Type 309s	75/30 AISI Plate (Cr-Ni)
			A240	Type 309 Cb	75/30 Plate (Cr-Ni-Cb)
				Type 310s	75/30 Plate (Cr-Ni)
		PS		Type 310Cb	75/30 Plate (Cr-Ni-Cb)
				UNS S30815	87/45 Plate (Cr-Ni-Si-N)
			A249	Grade TP309	75/30 Tube (Cr-Ni)
				Grade TP310	75/30 Tube (Cr-Ni)
		PS	A312	Grade TP309	75/30 Pipe (Cr-Ni)
				Grade TP310	75/30 Pipe (Cr-Ni)
				UNS S30815	87/45 Pipe (Cr-Ni-Si-N)
		PS	A336	Class F310	75/30 Forging (Cr-Ni)
				Class FXM-11	90/50 Forging (Cr-Ni)
				Class FXM-19	100/55 Forging (Cr-Ni)
		PS	A351	Grade CH8	65/28 Casting (Cr-Ni)
				Grade CH10	70/30 Casting (Cr-Ni)
				Grade CH20	70/30 Casting (Cr-Ni)
				Grade CK20	65/28 Casting (Cr-Ni)
				Grade CN7M	65/25 Casting (Cr-Ni-Mo)
		PS	A358	Grade 309	75/30 Pipe (Cr-Ni)
				Grade 310	75/30 Pipe (Cr-Ni)

(continued)

Table 1 (Continued)

Mat'l No.	Group No.	Std.	Base Metal Specification	Minimum Tensile/ Yield ksi	Base Metal
8	2	PS	A403	WP309	Pipe Fitting (Cr-Ni)
				WP310	Pipe Fitting (Cr-Ni)
		PS	A409	Grade TP309	Pipe (Cr-Ni)
				Grade TP310	Pipe (Cr-Ni)
		PS	A451	Grade CPH8	Casting (Cr-Ni)
				Grade CPH20	Casting (Cr-Ni)
				Grade CPK20	Casting (Cr-Ni)
		S	A473	Type 309	Forging
				Type 309s	Forging
				Type 310	Forging
				Type 310s	Forging
				UNS S30815	Forging (Cr-Ni-Si-N)
				Type 310S	Bar & Shapes (Cr-Ni)
		PS	A479	Type 309S	Bar & Shapes (Cr-Ni)
				UNS S30815	Bar (Cr-Ni-Si-N)
8	3	PS	A182	Grade FXM-19	Pipe Flange (Cr-Ni-Mn-Mo-Cb-N-V)
				Grade FXM-11	Pipe Flange (Cr-Ni-Mo)
				Grade F44	Pipe Flange (Cr-Ni-Mo-Low C)
				Grade FR	Pipe Flange (Ni-Cu)
			A240	Type 201	Plate (Cr-Mn-Ni-N)
				Type 202	Plate (Cr-Mn-Ni-N)
				Type XM-17	Plate (Cr-Ni-Mn-Mo-N)
				Type XM-17	Sheet and Strip (Cr-Ni-Mn-Mo-N)
				Type XM-18	Plate (Low C-Cr-Ni-Mn-Mo)
					Sheet and Strip (Cr-Ni-Mn-Mo-N-Cb-V)
				Type XM-19	Plate (Cr-Ni-Mn-Mo-N-Cb-V)
					Sheet and Strip (Cr-Ni-Mn-Mo-N-Cb-V)
				Type XM-29	Plate (Cr-Ni-Mn-N)
		PS	A249	Gr. TPXM-19	Welded Tubes (Cr-Ni-Mn-Mo-Cb-N-V)
				Gr. TPXM-29	Welded Tubes (Cr-Ni-Mn-N)
		S	A269	Gr. TPXM-10	Tubing
				Gr. TPXM-11	Tubing
				Gr. TPXM-15	Tubing
				Gr. TPXM-19	Tubing
				Gr. TPXM-29	Tubing
				Type XM-11	Pipe (Cr-Ni-Mn-N)
		PS	A336	Type TPXM-19	Pipe (Cr-Ni-Mn-Mo-Cb-N-V)
				Type XM-29	Pipe (Cr-Ni-Mn-N)
				Class XM-11	Forging (Cr-Ni-Mn)
				Class FXM-19	Forging (Cr-Ni-Mn)
		PS	A351	Grade CG6MMN	Casting (Cr-Ni-Mn-Cb-N-V)
		PS	A358	Grade XM-19	Pipe (Cr-Ni-Mn)
				Grade XM-29	Pipe (Cr-Ni-Mn-N)
		PS	A403	Marking WPXM-19	Pipe Fitting
		PS	A412	Type 201	Plate, Sheet, Strip
				Type XM-11	Plate, Sheet, Strip
				Type XM-19	Plate
					Sheet and Strip

(continued)

Table 1 (Continued)

Mat'l No.	Group No.	Std.		Base Metal Specification	Minimum Tensile/ Yield ksi	Base Metal		
8	3	S	A473	Type 201	90/30	Forging (Cr-Mn-Ni-N)		
				Type 202	90/38	Forging (Cr-Mn-Ni-N)		
				Type XM-10	90/50	Forging		
				Type XM-11	90/50	Forging		
		PS	A479	Type XM-11	90/50	Bar and Shapes (Cr-Ni-Mn)		
				Type XM-18	90/50	Bar and Shapes (Cr-Mn-Ni-Mo)		
				Type XM-19	100/60	Bar and Shapes (Cr-Ni-Mn)		
				Type XM-29	100/55	Bar and Shapes (Cr-Ni-Mn-N)		
				UNS S21800	95/50	Bar and Shapes (Cr-Ni-Mn-Si)		
				Type XM-29	100/55	Tube (Cr-Ni-Mn-N)		
8	4	PS	A688	Type XM-29	100/55	Tube (Cr-Ni-Mn-N)		
		PS	A240	UNS S31254	94/44	Plate (Cr-Ni-Mo-Cu-N)		
		PS	A249	UNS S31254	94/44	Tube (Cr-Ni-Mo-Cu-N)		
		PS	A312	UNS S31254	94/44	Pipe (Cr-Ni-Mo-Cu-N)		
9A	1	PS	A182	Grade FR	63/46	Forging (2Ni-1Cr)		
				PS	A203	Grade A	65/37	Plate (2-1/2 Ni)
						Grade B	70/40	Plate (2-1/2 Ni)
				PS	A234	Grade WPR	63/46	Pipe Fitting
		PS	A333			Grade 7	65/35	Pipe (2-1/2 Ni)
				Grade 9	63/46	Pipe (2 Ni - 1 Cu)		
		PS	A350	Grade 7	65/35	Tube (2-1/2 Ni)		
				Grade 9	63/46	Tube (2 Ni - 1 Cu)		
		PS	A352	Grade LF9	63/46	Forging (2 Ni - 1 Cu)		
				Grade LC2	70/40	Casting (2-1/2 Ni)		
		PS	A420	Grade WPL9	63/46	Pipe Fitting (2 Ni - 1 Cu)		
				PS	A203	Grade D	65/37	Plate (3-1/2 Ni)
		PS	A333			Grade E	70/40	Plate (3-1/2 Ni)
				PS	A334	Grade F	75/50	Plate (3-1/2 Ni)
PS	A350	Grade 3	65/35			Pipe (3-1/2 Ni)		
		PS	A352	Grade 3	65/35	Tube (3-1/2 Ni)		
PS	A420			Grade LF3	70/37.5	Forging (3-1/2 Ni)		
		PS	A765	Grade LC3	70/40	Casting (3-1/2 Ni)		
9C	1			PS	A352	Grade WPL3	65/37	Pipe Fitting (3-1/2 Ni)
		10A	1			PS	A225	Grade III
PS	A268			LC4	70/40			Casting (4 Ni)
		PS	A487	Grade C	105/70	Plate (Mn-V)		
PS	A487			Grade D	75/55	Plate (Mn-V)		
		PS	A487	Class 1N	85/55	Casting (Mn-V)		
PS	A487			Class 1Q	90/65	Casting (Mn-V)		
		PS	A487	Grade T17	60/30	Tube (1 Cr-V)		
PS	A487			Type 329	81/50	Plate (C-Mn-Si)		
		PS	A487	Grade TP446	90/70	Plate (Cr-Ni-Mo)		
PS	A487			Grade TP329	70/40	Tube (27 Cr)		
		PS	A487	Class 2N	90/70	Tube (Cr-Ni-Mo)		
PS	A487			Class 2Q	85/53	Casting (Mn-Mo)		
		PS	A487	Class 4N	90/65	Casting (Mn-Mo)		
PS	A487				90/65	Casting (Ni-Cr-Mo-V)		
		PS	A487		65/35	Plate (36 Ni)		
PS	A487			Grade F50	100/65	Forging (Cr-Ni-Mo-N)		
		PS	A487	Grade F51	90/65	Forging (Cr-Ni-Mo-N)		
PS	A487			UNS S32550	110/80	Plate (Cr-Ni-Mo-Cu)		
		PS	A487	Grade CD4MCu	100/70	Casting (Cr-Ni-Cu-Mo)		
PS	A487			UNS S32550	110/80	Bar and Shape (Cr-Ni-Mo-Cu)		

(continued)

Table 1 (Continued)

Mat'l No.	Group No.	Std.		Base Metal Specification	Minimum Tensile/ Yield ksi	Base Metal
10H	1	PS	A789	UNS S32550	110/80	Tube (Cr-Ni-Mo-Cu)
		PS	A790	UNS S32550	110/80	Pipe (Cr-Ni-Mo-Cu)
10I	1	PS	A182	Grade FXM-27	60/35	Forging (27 Cr- 1 Mo)
		PS	A240	Grade XM-27	65/40	Plate (26 Cr- 1 Mo - Ti)
				Type XM-33	68/45	Plate (26 Cr - 1 Mo - Ti)
		PS	A268	Gr.1 TPXM-27	65/40	Tube (26 Cr - 1 Mo)
				Gr. TPXM-33	68/45	Tube (26 Cr - 1 Mo - Ti)
		PS	A336	Class FXM-27Eb	60/35	Forging (26 Cr - 1 Mo)
		PS	A479	Grade XM-27	65/40	Bar and Shapes (26 Cr - 1 Mo)
		PS	A731	Type XM-27	65/40	Pipe (Cr- Mo)
				Type XM-33	65/40	Pipe (Cr - Mo - Ti)
				UNS S44700	80/60	Plate (29 Cr - 4 Mo)
10J	1	PS	A240	UNS S44700	80/60	Tube (29 Cr - 4 Mo)
		PS	A268	UNS S44700	80/60	Plate (29 Cr - 4 Mo)
		PS	A479	UNS S44700	80/60	Plate (29 Cr - 4 Mo)
10K	1	PS	A240	UNS S44800	80/60	Plate (29 Cr- 2 Ni - 4 Mo)
		PS	A268	UNS S44800	80/60	Tube (29 Cr- 2 Ni - 4 Mo)
		PS	A479	UNS S44800	80/60	Plate (29 Cr - 2 Ni - 4 Mo)
11A	1	PS	A333	Grade 8	100/75	Pipe (9 Ni)
		PS	A334	Grade 8	100/75	Tube (9 Ni)
		PS	A353		100/75	Plate (9 Ni)
		PS	A420	Grade WPL8	100/75	Pipe Fitting (9 Ni)
		PS	A522	Type I	100/75	Forging (9 Ni)
				Type II	100/75	Forging (8 Ni)
		PS	A553	Type I	100/85	Plate (9 Ni)
				Type II	100/85	Plate (8 Ni)
11A	2	PS	A645		95/65	Plate (5 Ni - Mo)
11A	3	PS	A487	Class 4Q	105/85	Casting (Ni-Cr-Mo-V)
			Class 4QA	115/95	Casting (Ni-Cr-Mo)	
11A	4	PS	A533	Class 3, Grade A	100/82.5	Plate (Mn-Mo)
				Class 3, Grade B	100/82.5	Plate (Mn-Mo-Ni)
				Class 3, Grade C	100/82.5	Plate (Mn-Mo-Ni)
				Class 3, Grade D	100/82.5	Plate (Mn-Mo-Ni)
				Grade J100	100/83	Pipe
11A	5	PS	A672	Grade LC2-1	105/80	Casting (Ni-Cr-Mo)
		PS	A352	Class 4	105/85	Forging (Ni-Cr-Mo-V)
		PS	A508	Class 4a	115/100	Forging (Ni-Cr-Mo-V)
				Class 5	105/85	Forging (Ni-Cr-Mo-V)
				Class 5a	115/100	Forging (Ni-Cr-Mo-V)
11A	6	PS	A542	Class 1	105/85	Plate (2-1/4 Cr-Mo)
				Class 2	115/100	Plate (2-1/4 Cr - 1 Mo)
				Class 3	99/75	Plate (2-1/4 Cr-Mo)
				Class 4	85/60	Plate (2-1/4 Cr - Mo)
				Type B, Class 1	105/85	Plate (Ni-Cr-Mo)
				Type B, Class 2	115/100	Plate (Ni-Cr-Mo)
				Type B, Class 3	90/70	Plate (Ni-Cr-Mo)
		S	A543	Type C, Class 1	105/85	Plate (Ni-Cr-Mo)
				Type C, Class 2	115/100	Plate (Ni-Cr-Mo)
				Type C, Class 3	90/70	Plate (Ni-Cr-Mo)
				Grade A	110/100	Alloy Steel Plate
				Grade A	115/100	Alloy Steel Plate
				Grade E	110/100	Alloy Steel Plate
				Grade E	115/100	Alloy Steel Plate
11B	1	S	A514			
		PS	A517			
	2	S	A514			
		PS	A517			

(continued)

Table 1 (Continued)

Mat'l No.	Group No.	Std.	Base Metal Specification	Minimum Tensile/ Yield ksi	Base Metal
11B	3	S	A514	Grade F	110/100 Alloy Steel Plate
		PS	A517	Grade F	115/100 Alloy Steel Plate
11B	4	S	A514	Grade B	110/100 Alloy Steel Plate
		PS	A517	Grade B	115/100 Alloy Steel Plate
11B	5	S	A514	Grade D	110/100 Alloy Steel Plate
		PS	A517	Grade D	115/100 Alloy Steel Plate
11B	6	S	A514	Grade J	110/100 Alloy Steel Plate
		PS	A517	Grade J	115/100 Alloy Steel Plate
11B	7	S	A514	Grade M	110/100 Alloy Steel Plate
		PS	A517	Grade M	115/100 Alloy Steel Plate
11B	8	S	A514	Grade C	110/100 Alloy Steel Plate
		PS	A517	Grade C	115/100 Alloy Steel Plate
11B	9	S	A514	Grade G	110/100 Alloy Steel Plate
		PS	A517	Grade G	115/100 Alloy Steel Plate
11B	10	S	A514	Grade H	110/100 Alloy Steel Plate
		PS	A517	Grade H	115/100 Alloy Steel Plate
11B	11	S	A514	Grade K	110/100 Alloy Steel Plate
		PS	A517	Grade K	115/100 Alloy Steel Plate
11B	12	S	A514	Grade L	110/100 Alloy Steel Plate
		PS	A517	Grade L	115/100 Alloy Steel Plate
11B	13	S	A514	Grade N	110/100 Alloy Steel Plate
11B	14	S	A514	Grade P	110/100 Alloy Steel Plate
		PS	A517	Grade P	115/100 Alloy Steel Plate
11B	15	S	A514	Grade Q	110/100 Alloy Steel Plate
		PS	A517	Grade Q	115/100 Alloy Steel Plate
11B	16	S	A514	Grade R	110/100 Alloy Steel Plate
		PS	A517	Grade R	115/100 Alloy Steel Plate
11B	17	S	A514	Grade S	110/100 Alloy Steel Plate
		PS	A517	Grade S	115/100 Alloy Steel Plate
11B	18	S	A514	Grade T	110/100 Alloy Steel Plate
		PS	A517	Grade T	115/100 Alloy Steel Plate
11B	20	S	A709	Grade 100 & 100W	110/100 Alloy Steel Plate

*By agreement with material producer.

Table 1 (Continued)

Mat'l No.	Std.	Base Metal Specification	Thickness in.	Minimum Tensile/ Yield ksi	Type of Base Metal	Notes
Aluminum and Aluminum-Base Alloys						
21	PS	B209	0.051-3.000	8/2.5	1060 Sheet, Plate	
			0.051-3.000	11/3.5	1100 Sheet, Plate	
			0.051-3.000	14/5.0	3003 Sheet, Plate	
			0.051-0.499	13/4.5	Alclad 3003 Sheet, Plate	(1)
			0.500-3.000	14/5.0	Alclad 3003 Plate	(2)
	PS	B210	All	8.5/2.5	1060 Bar, Rod, Shapes, Tube	
			Up to 0.500	13/4.5	Alclad 3003 Seamless Tube	
			All	14/5	3003 Seamless Tube	
	PS	B211	0.125 and over	8/2.5	1060 Bar, Rod, Wire	
			0.125 and over	11/3	1100 Bar, Rod, Wire	
			All	14/5	3003 Bar, Rod, Wire	
	PS	B221	All	8.5/2.5	1060 Bar, Rod, Shapes	
			All	11/3	1100 Bar, Rod, Shapes	
			All	14/5	3003 Bar, Rod, Shapes	
	PS	B234	0.010-0.200	12/10	1060 Seamless Tube	
	PS	B241	All	8.5/2.5	1060 Seamless Pipe, Tube	
			All	11/3	1100 Seamless Pipe, Tube	
			All	14/5	3003 Seamless Pipe, Tube	
22	PS	B247	Up thru 4.000	14/5	3003 Die Forging	
	PS	B209	0.050-3.000	22/8.5	3004 Sheet, Plate	
			0.051-0.499	21/8.0	Alclad 3004 Sheet, Plate	(1)
			0.500-3.000	22/8.5	Alclad 3004 Plate	(2)
			0.051-3.000	25/9.5	5052 Sheet, Plate	
			0.051-3.000	30/11	5254 Sheet, Plate	
			0.020-3.000	30/11	5154 Sheet, Plate	
			0.020-3.000	31/12	5454 Sheet, Plate	
			0.051-3.000	25/9.5	5652 Sheet, Plate	
	PS	B210	0.018-0.450	25/10	5052 Seamless Tube	
			All	30/11	5154 Bar, Rod, Shapes, Tube	
	PS	B221	All	23/8.5	3004 Bar, Shapes, Pipe, Tube	
			All	30/11	5154 Bar, Rod, Shapes, Pipe, Tube	
			All	31/12	5454 Bar, Rod, Shapes, Tube	
	PS	B234	All	36/26	5454 Bars, Rod, Shapes, Tube	
	PS	B241	All	31/12	5052 Tube	
			All	30/11	5254 Seamless Pipe & Extruded Tube	
			All	31/14	5454 Seamless Pipe & Extruded Tube	
			All	25/10	5652 Seamless Pipe & Extruded Tube	
23	PS	B209	Up to 0.499	27/14	Alclad 6061-T4 Sheet, Plate	
			0.5 to 3.0	30/16	Alclad 6061-T4 Sheet, Plate	(1)
			0.051-6.000	30/16	6061-T4 Sheet, Plate	(1)
			0.051-5.000	27/14	Alclad 6061 Sheet, Plate	
			Up to 4 in.	42/35	6061-T6, T651 Sheet, Plate	
	PS	B210	All	30/16	6061-T4 Tube	
			All	33/28	6063-T6 Tube	
	PS	B211	All	42/35	6061-T6 Bar, Rod	
	PS	B221	All	16/8	6063 Bar, Rod, Shapes	
			All	26/16	6061 Bar, Rod, Shapes	
	PS	B234	All	42/35	6061-T6 Seamless Tube	
	PS	B241	All	16/8	6063-T6 Seamless Pipe & Extruded Tube	
			All	26/16	6061-T4 Pipe, Tube	

(continued)

Table 1 (Continued)

Mat'l No.	Std.	Base Metal Specification	Thickness in.	Minimum Tensile/ Yield ksi	Type of Base Metal	Notes
25	23PS	B247	Up thru 4.000	38/35	6061-T6 Forgings	
	PS	B308	All	38/35	6061-T6 Structural Shapes	
	PS	B209	0.051-1.500	40/18	5083 Sheet, Plate	
			1.501-3.000	39/17	5083 Plate	
			3.001-5.000	38/16	5083 Plate	
			5.001-7.000	37/15	5083 Plate	
			7.001-8.000	36/14	5083 Plate	
			0.020-2.000	35/14	5086 Plate, Sheet	
			0.051-1.500	42/19	5456 Sheet, Plate	
			1.501-3.000	41/18	5456 Plate	
			3.001-5.000	40/17	5456 Plate	
			5.001-7.000	39/16	5456 Plate	
			7.001-8.000	38/15	5456 Plate	
	PS	B221	Up thru 5.000	35/14	5086 Bar, Rod, Shapes	
			Up thru 5.000	39/16	5083 Bar, Rod, Shapes	
			Up thru 5.000	41/19	5456 Bar, Rod, Shapes	
	PS	B241	Up thru 5.000	35/14	5086 Smls. Pipe, Tube	
			Up thru 5.000	41/19	5456 Smls. Pipe, Tube	
			Up thru 5.000	39/16	5083 Smls. Pipe, Tube	
	PS	B247	Up thru 4.000	39/16	5083 Forging	

(1) Specified tensile properties are for full thickness specimens which include cladding.

(2) Specified tensile properties are for specimens taken from the core.

(continued)

Table 1 (Continued)

Mat'l No.	Std.	Base Metal Specification	Condition	Size(s) or Thickness	Minimum Tensile/ Yield ksi	Type of Base Metal
31	PS	B11	—	—	30/10	C11000, C12200, C12500 Plate
				—	31/10	C14200 Plate
	PS	B42	Drawn	1/8 in.-2 in.	45/40	C10200, C12000, C12200 Pipe
			Drawn	2-1/2 in.-12 in.	36/30	C10200, C12000, C12200 Pipe
	PS	B75	Annealed	—	30/9	C10200, C12000, C12200, C14200 Smls. Tube
			Light Drawn	—	36/30	C10200, C10300, C12000, C12200 C12200, C12400 Smls. Tube
			Hard Drawn	—	45/40	C10200, C10300, C12000, C12200 C14200 Smls. Tube
			—	—	—	C10200, C12000, C12200, C14200 Smls. Tube
	PS	B111	Light Drawn	—	36/30	C10200, C12000, C12200, C14200 Smls. Tube
			Hard Drawn	—	45/40	C10200, C12000, C12200, C14200 Smls. Tube
			Annealed	—	38/12	C19200 Smls. Tube
	S	B133	Hard Drawn	—	48/43	C19200 Smls. Tube
			Annealed	—	30/-	C10200, C11000, C12000, C12200 C12500, C14200 Rod & Bar
	PS	B152	Annealed	—	30/10	C10200, C10400, C10500, C10700 C12200, C12300, Sheet, Strip, Plate, Bar
						C10200, C12000, C12200, C14200 Finned Tube
	PS	B359	Annealed	—	30/9	C10200, C12000, C12200, C14200 Finned Tube
			Light Drawn	—	36/30	C10200, C12000, C12200, C14200 Finned Tube
			Annealed	—	38/12	C19200 Finned Tube
	PS	B395	Light Drawn	—	36/30	C10200, C12000, C12200, C14200 Smls. Tube
			Annealed	—	38/12	C19200 Smls. Tube
			Annealed	—	32/15	C12200 Welded Tube
	PS	B543	Annealed	—	45/22	C19400 Welded Tube
			Annealed	—	50/20	C46200
32	S	B21	Extruded	—	50/20	C46400
			Soft	—	50/20	C46400
	PS	B43	Annealed	—	40/12	C23000 Smls. Pipe
	PS	B111	Annealed	—	40/12	C23000 Tube
			Annealed	—	50/20	C28000 Muntz Metal, Tube
			Annealed	—	45/15	C44300 Admiralty, Tube
			Annealed	—	45/15	C44400 Admiralty, Tube
			Annealed	—	45/15	C44500 Admiralty, Tube
			Annealed	—	50/18	C68700 Smls. Tube
			Annealed	—	40/12	C23000 Smls. Tube
	PS	B135	Annealed	—	40/12	C23000 Smls. Tube
	PS	B171	Annealed	2 in. and under	50/20	C36500, C36600, C36700, C36800 Muntz Metal Plate
			Annealed	4 in. and under	45/15	C44300, C44400, C44500 Plate
			Annealed	to 5 in.	50/20	C46400, C46500, C46600 Plate
			Annealed	—	40/12	C23000 Smls. Tube
			Annealed	—	40/15	C44300, C44400, C44500 Tube
			Annealed	—	50/18	C68700 Smls. Tube
			Annealed	—	40/12	C23000 Smls. Tube
	S	B395	Annealed	—	45/15	C44300, C44400, C44500 Tube
			Annealed	—	50/18	C68700 Smls. Tube
			Annealed	—	40/12	C23000 Smls. Tube
	PS	B543	Annealed	—	50/18	C68700 Smls. Tube
			Annealed	—	40/12	C23000 Welded Tube

(continued)

Table 1 (Continued)

Mat'l No.	Std.	Base Metal Specification	Condition	Size(s) or Thickness	Minimum Tensile/ Yield ksi	Type of Base Metal
32	PS	B543	Annealed	—	45/15	C44300, C44400, C44500 Welded Tube
33	PS	B96 B98	Annealed	—	50/18	C68700 Welded Tube
			Annealed	—	50/18	C65500 Cu-Si Plate, Sheet
			Soft	—	40/12	C65100 Cu-Si Rod, Bar, Shapes
			Half Hard	Up to 2 in.	55/20	C65100 Cu-Si Rod, Bar, Shapes
			Soft	—	52/15	C65500, C66100 Rod, Bar, Shapes
34	PS	B315 B111	Quarter Hard	—	55/24	C65500, C66100 Rod, Bar, Shapes
			Half Hard	Up to 2 in.	70/38	C65500, C66100 Rod, Bar, Shapes
			Annealed	—	50/15	C65500 Cu-Si Pipe and Tube
			Annealed	—	38/12	C70400 Cu-Ni Tube
			Light Drawn	—	40/30	C70400 Cu-Ni Tube
			Annealed	—	40/15	C70600 Cu-Ni Tube
			Light Drawn	—	45/35	C70600 Cu-Ni Tube
			Annealed	—	45/16	C71000 Cu-Ni Tube
			Annealed	—	52/18	C71500 Cu-Ni Tube
			Drawn, Stress Relvd.	—	72/50	C71500 Cu-Ni Tube
			Soft	—	38/15	C70600 Cu-Ni Rod & Bar
			Annealed	2.5 in. & under	40/15	C70600 Cu-Ni Plate
			Annealed	2.5 in. & under	50/20	C71500 Cu-Ni Plate
			Annealed	—	38/12	C70400 Smls. Tube
			Annealed	—	40/15	C70600 Smls. Tube
			Annealed	—	45/16	C71000 Smls. Tube
			Annealed	—	52/18	C71500 Smls. Tube
			As Cast	—	45/25	C96200 Casting
			Annealed	—	40/15	C70600 Smls. Tube
			Annealed	—	45/16	C71000 Smls. Tube
			Annealed	—	52/18	C71500 Smls. Tube
			Drawn, Stress, Rlvd.	—	72/50	C71500 Smls. Tube
	PS	B402	Annealed	To 2.5 in.	50/20	C71500 Cu-Ni Plate
			Annealed	Over 2.5 in. to 5 in. incl.	45/18	C71500 Cu-Ni Plate
			Annealed	—	40/15	C70600 Cu-Ni Plate
			Annealed	—	38/13	C70600 (10 Ni) Cu-Ni Pipe
			Annealed	—	45/16	C71000 (20 Ni) Cu-Ni Pipe
			Annealed	—	50/18	C71500 (30 Ni) Cu-Ni Pipe
			Annealed	To 4-1/2 in.	40/15	C70600 (10 Ni) Cu-Ni Pipe
			Annealed	Over 4-1/2 in.	38/13	C70600 (10 Ni) Cu-Ni Pipe
			Annealed	To 4-1/2 in.	50/20	C71500 (30 Ni) Cu-Ni Pipe
			Annealed	Over 4-1/2 in.	45/15	C71500 (30 Ni) Cu-Ni Pipe
			Annealed	—	38/12	C70400 Welded Tube Cu-Ni
			Annealed	—	40/15	C70600 Welded Tube Cu-Ni
			Welded from Annealed Strip	—	45/30	C70600 Welded Tube Cu-Ni
			Annealed	—	52/18	C71500 Welded Tube Cu-Ni
			Drawn, Stress Rlvd.	—	72/50	C71500 Welded Tube Cu-Ni
			Annealed	—	50/19	C60800 Smls. Tube
			As Cast	—	65/25	C95200 A1-Bronze Casting
			As Cast	—	75/30	C95400 A1-Bronze Casting

(continued)

Table 1 (Continued)

Mat'l No.	Std.	Base Metal Specification	Condition	Size(s) or Thickness	Minimum Tensile/ Yield ksi	Type of Base Metal
35	PS	B150	Annealed	1/2 in. and under	80/40	C61400 Rod, Bar & Shapes
				1/2 in. to 1 in.	75/35	C61400 Rod, Bar & Shapes
				Over 1 in. to 3 in.	70/32	C61400 Rod, Bar & Shapes
			Annealed	All	75/30	C62300 Rod, Bar & Shapes
			Annealed	1/2 in. to 1 in.	100/50	C63000 Rod, Bar
				Over 1 in. to 2 in.	90/45	C63000 Rod, Bar
				2 in. to 4 in.	85/42.5	C63000 Rod, Bar
			Annealed	All	80/42.5	C63000 Shapes
				1/2 in. and under	90/45	C64200 Rod, Bar
				1/2 in. to 1 in.	85/45	C64200 Rod, Bar
				Over 1 in. to 2 in.	80/42	C63000 Rod, Bar
				Over 2 in. to 3 in.	75/35	C64200 Rod, Bar
	PS	B169	Annealed	—	50/20	C61000 Aluminum Bronze Plate, Sheet
			Annealed	1/2 in. under	72/32	C61400 Aluminum Bronze Plate, Sheet
			Annealed	Over 1/2 in. to 2 in.	70/30	C61400 Aluminum Bronze Plate, Sheet
	PS	B171	Annealed	2 in. to 5 in.	65/28	C61400 Aluminum Bronze Plate, Sheet
			Annealed	2 in. and under	70/30	C61400 Aluminum Bronze, Plate
				2 in. to 5 in.	65/28	C61400 Aluminum Bronze, Plate
			Annealed	2 in. and under	90/36	C63000 Aluminum Bronze, Plate
				Over 2 in. to 3.5 in. incl.	85/33	C63000 Aluminum Bronze, Plate
				Over 3.5 in. to 5 in. incl.	80/30	C63000 Aluminum Bronze, Plate
	PS	B271	As Cast	—	65/25	C95200 Aluminum Bronze, Casting
			As Cast	—	75/30	C95400 Aluminum Bronze, Casting
	PS	B359	Annealed	—	50/19	C60800 Finned Tube
	PS	B395	Annealed	—	50/19	C60800 Smls. Tube
	PS	B505	As Cast	—	68/26	C95200 Con. Cast.

(continued)

Table 1 (Continued)

Mat'l No.	Std.	Base Metal Specification	Alloy Designations	Minimum Tensile/ Yield ksi	Type of Base Metal
Nickel and Nickel-Base Alloys					
41	PS	B160 Annealed	N02200	55/15	Rod, Bar (99.0 Ni)
		B160 Hot Rolled	N02200	60/15	Rod, Bar (99.0 Ni)
		B160 Annealed	N02201	50/10	Rod, Bar Low C, Ni
		B160 Hot Rolled	N02201	50/10	Rod, Bar Low C, Ni
	PS	B161 Annealed	N02200	55/15	Pipe, Tube (99.0 Ni)
		B161 Stress Relieved	N02200	65/40	Pipe, Tube (99.0 Ni)
		B161 Annealed	N02201	50/12	Pipe, Tube Low C, Ni
		B161 Stress Relieved	N02201	60/30	Pipe, Tube Low C, Ni
	PS	B162 Annealed	N02200	55/15	Plate, Sheet, Strip (99.0 Ni)
		B162 Hot Rolled	N02200	55/15	Plate, Sheet, Strip (99.0 Ni)
		B162 Annealed	N02201	50/12	Plate, Sheet, Strip Low C, Ni
		B162 Hot Rolled	N02201	50/12	Plate, Sheet, Strip Low C, Ni
	PS	B163 Annealed	N02200	55/15	Condenser Tube (99.0 Ni)
		B163 Stress Relieved	N02200	65/40	Condenser Tube (99.0 Ni)
		B163 Annealed	N02201	50/12	Condenser Tube Low C, Ni
		B163 Stress Relieved	N02201	60/30	Condenser Tube Low C, Ni
42	PS	B127 Annealed	N04400	70/28	Plate, Sheet, Strip Ni-Cu
		B127 Hot Rolled	N04400	75/40	Plate, Sheet, Strip Ni-Cu
	PS	B163 Annealed	N04400	70/28	Condenser Tube Ni-Cu
		B163 Stress Relieved	N04400	85/55	Condenser Tube Ni-Cu
	PS	B164 Annealed	N04400	70/25	Rod, Bar Ni-Cu
		B164 Hot Finished	N04400	75/30	Rod, Bar Ni-Cu
		B164 Hot Finished	N04400	80/40	Rod, Bar Ni-Cu
		Except Hex over 2-1/8 in. B164 Hot Finished	N04400	75/40	Rod, Bar Ni-Cu
	PS	Hex over 2-1/8 in. B164 Stress Relieved	N04400	87/60	Round Bar Ni-Cu
		4 in.-12 in. B164 Stress Relieved	N4400	84/55	Round Bar Ni-Cu
		1/2-3-1/2 in. B165 Annealed	N04400	70/28	Pipe, Tube Ni-Cu
		B165 Stress Relieved	N04400	85/55	Pipe, Tube Ni-Cu
43	PS	B564 Annealed	N04400	70/28	Forging Ni-Cu
	PS	B163 Annealed	N06600	80/35	Condenser Tube Ni-Cr-Fe
	PS	B166 Annealed	N06600	80/35	Rod, Bar Ni-Cr-Fe
		B166 Hot Finished	N06600	90/40	Rod, Bar Ni-Cr-Fe
		1/4 in.-3 in. incl. B166 Hot Finished	N06600	85/35	Rod, Bar Ni-Cr-Fe
		Over 3 in. and Hex. B167 Cold Drawn/Ann.	N06600	80/35	Pipe, Tube Ni-Cr-Fe
	PS	5 in. and under B167 Cold Drawn/Ann.	N06600	80/30	Pipe, Tube Ni-Cr-Fe
		Over 5 in. O.D. B167 Hot Finished/	N06600	80/30	Pipe, Tube Ni-Cr-Fe
		Annealed 5 in. O.D. & under B167 Hot Finished/	N06600	75/25	Pipe, Tube Ni-Cr-Fe
		Annealed over 5 in. O.D. B168 Annealed	N06600	80/35	Plate, Sheet, Strip Ni-Cr-Fe
	PS	B168 Hot Rolled	N06600	85/35	Plate, Sheet, Strip Ni-Cr-Fe
		B435 under 3/16 in.	N06002	100/40	Sheet Ni-Cr-Fe-Mo
		B435 3/16 in. and over	N06002	95/35	Plate, Ni-Cr-Fe-Mo

(continued)

Table 1 (Continued)

Mat'l No.	Std.	Base Metal Specification	Alloy Designations	Minimum Tensile/ Yield ksi	Type of Base Metal
43	PS	B443 Annealed	N06625	120/60	Plate, Sheet, Strip Ni-Cr-Mo-Cb
	PS	B444 Annealed	N06625	120/60	Pipe, Tube Ni-Cr-Mo-Cb
	PS	B446 Annealed	N06625	120/60	Rod, Bar Ni-Cr-Mo-Cb
	PS	B516 Annealed	N06600	80/35	Welded Tube Ni-Cr-Fe
	PS	B517 Annealed	N06600	80/35	Welded Pipe Ni-Cr-Fe
	PS	B564 Annealed	N06600	80/35	Forging Ni-Cu-Fe
		B564 Annealed up to 4 in.	N06625	120/60	Forging Ni-Cr-Mo-Cb
		B564 Annealed over 4 in.-10 in.	N06625	110/50	Forging Ni-Cr-Mo-Cb
	PS	B572 Annealed	N06002	95/35	Rod, Ni-Cr-Fe-Mo
	PS	B619 Annealed	N06002	100/40	Welded Pipe Ni-Cr-Fe-Mo
	PS	B622 Annealed	N06002	100/40	Smls. Pipe & Tube Ni-Cr-Fe-Mo
	PS	B626 Annealed	N06002	100/40	Tube Ni-Cr-Fe-Mo
	S	B704 Annealed	N06625	120/60	Welded Tubing Ni-Cr-Mo-Cb
	S	B705 Annealed	N06625	120/60	Welded Pipe Ni-Cr-Mo-Cb
44	PS	B33 Annealed under 3/16 in.	N10001	115/50	Sheet Ni-Mo
		B333 Annealed	N10001	100/45	Plate Ni-Mo
		3/16 in.-2-1/2 in. incl.			
		B333 Annealed	N10665	110/51	Plate, Sheet, Strip Ni-Mo
	PS	B335 Annealed 5/16-1-1/2	N10001	115/46	Rod Ni-Mo
		B335 Annealed over 1-1/2	N10001	100/46	Rod Ni-Mo
		B335 Annealed	N10665	110/51	Rod Ni-Mo
	PS	B434 Annealed	N10003	100/40	Plate, Sheet Ni-Mo-Cr-Fe
	PS	B573 Annealed	N10003	100/40	Rod Ni-Mo-Cr-Fe
	PS	B574 Annealed	N10276	100/41	Rod Low C-Ni-Mo-Cr
		B574 Annealed	N06455	100/40	Rod Low C-Ni-Mo-Cr
		B574 Annealed	N06022	100/45	Rod Low C-Ni-Mo-Cr
	PS	B575 Annealed	N10276	100/41	Plate, Sheet, Strip Low C-Ni-Mo-Cr
		B575 Annealed	N06455	100/40	Plate, Sheet, Strip Low C-Ni-Mo-Cr
		B575 Annealed	N06022	100/45	Plate, Sheet, Strip Low C-Ni-Mo-Cr
	PS	B619 Annealed	N10001	100/45	Welded Pipe Ni-Mo
		B619 Annealed	N10665	110/51	Welded Pipe Ni-Mo
		B619 Annealed	N10276	100/41	Welded Pipe Low C-Ni-Mo-Cr
		B619 Annealed	N06455	100/40	Welded Pipe Low C-Ni-Mo-Cr
		B619 Annealed	N06022	100/45	Welded Pipe Low C-Ni-Mo-Cr
	PS	B622 Annealed	N10001	100/45	Smls. Pipe and Tube Ni-Mo
		B622 Annealed	N10065	110/51	Smls. Pipe & Tube Ni-Mo
		B622 Annealed	N10276	100/41	Smls. Pipe & Tube Low C-Ni-Mo-Cr
		B622 Annealed	N06455	100/40	Smls. Pipe & Tube Low C-Ni-Mo-Cr
		B622 Annealed	N06022	100/45	Smls. Pipe Low C-Ni-Mo-Cr
	PS	B626 Annealed	N10001	100/45	Tube Ni-Mo
		B626 Annealed	N10665	110/51	Tube Ni-Mo
		B626 Annealed	N06455	100/40	Tube Low C-Ni-Mo-Cr
		B626 Annealed	N10276	100/41	Tube Low C-Ni-Mo-Cr
		B626 Annealed	N06022	100/45	Tube Low C-Ni-Mo-Cr
45	PS	B163 Annealed Gr. 1	N08800	75/30	Condenser Tube Ni-Fe-Cr
		B163 Annealed Gr. 2	N08810	65/25	Condenser Tube Ni-Fe-Cr
		B163 Annealed	N08825	85/35	Condenser Tube Ni-Fe-Cr
	PS	B407 Annealed	N08800	75/30	Pipe, Tube Ni-Fe-Cr
		B407 Annealed	N08810	65/25	Pipe, Tube Ni-Fe-Cr
	PS	B408 Annealed	N08800	75/30	Rod, Bar Ni-Fe-Cr
		B408 Annealed	N08810	65/25	Rod, Bar Ni-Fe-Cr
	PS	B409 Annealed	N08800	75/30	Plate, Sheet, Strip Ni-Fe-Cr

(continued)

Table 1 (Continued)

Mat'l No.	Std.	Base Metal Specification	Alloy Designations	Minimum Tensile/ Yield ksi	Type of Base Metal
45	PS	B409 Annealed	N08810	65/25	Plate, Sheet, Strip Ni-Fe-Cr
		B409 Annealed	N08811	65/25	Plate, Sheet, Strip Ni-Fe-Cr
	PS	B423 Annealed	N08825	85/35	Pipe, Tube Ni-Fe-Cr
	PS	B424 Annealed	N08825	85/35	Plate, Sheet, Strip Ni-Fe-Cr
	PS	B425 Annealed	N08825	85/35	Rod, Bar Ni-Fe-Cr
	PS	B462 Annealed	N08020	80/35	Forging Cr-Ni-Fe-Mo-Cu-Cb
	PS	B463 Annealed	N08020	80/35	Plate, Sheet, Strip Cr-Ni-Fe-Mo-Cu-Cb
		B463 Annealed	N08026	80/35	Plate, Sheet, Strip Ni-Fe-Cr-Mo-Cu
	PS	B464 Annealed	N08020	80/35	Pipe/Tube Cr-Ni-Fr-Mo-Cu-Cb
		B464 Annealed	N08026	80/35	Pipe/Tube Ni-Fe-Cr-Mo-Cu
	PS	B468 Annealed	N08020	80/35	Tube Cr-Ni-Fe-Mo-Cu-Cb
		B468 Annealed	N08026	80/35	Tube Ni-Fe-Cr-Mo-Cu
	PS	B473 Annealed	N08020	80/35	Bar/Wire Cr-Ni-Fe-Mo-Cu-Cb
	PS	B514 Annealed	N08800	75/30	Pipe Ni-Fe-Cr
		B514 Annealed	N08810	65/25	Pipe Ni-Fe-Cr
	S	B515 Annealed	N08800	75/30	Tube Ni-Fe-Cr
		B515 Annealed	N08810	65/25	Tube Ni-Fe-Cr
	PS	B564 Annealed	N08800	75/30	Forging Ni-Fe-Cr
		B564 Annealed	N08810	65/25	Forging Ni-Fe-Cr
	PS	B581 Thru 3/4 in.	N06007	90/35	Rod Ni-Cr-Fe-Mo-Cu
		B581 Above 3/4 in.	N06007	85/30	Rod Ni-Cr-Fe-Mo-Cu
		B581 Annealed	N06975	85/32	Rod Ni-Cr-Fe-Mo-Cu
		B581 Annealed	N06985	85/30	Rod Ni-Cr-Fe-Mo-Cu
	PS	B582 thru 3/4 in.	N06007	90/35	Plate, Sheet, Strip Ni-Cr-Fe-Mo-Cu
		B582 Above 3/4 in.	N06007	85/30	Plate, Sheet, Strip Ni-Cr-Fe-Mo-Cu
		B582 Annealed	N06975	85/32	Plate Ni-Cr-Fe-Mo-Cu
		B582 Annealed	N06985	90/35	Plate, Sheet, Strip Ni-Cr-Fe-Mo-Cu
	S	B599 Annealed	N08700	80/35	Plate Ni-Fe-Cr-Mo-Cb
	PS	B619 Annealed	N08320	75/28	Welded Pipe Ni-Fe-Cr-Mo
		B619 Annealed	N06007	90/35	Welded Pipe Ni-Fe-Cr-Mo-Cu
		B619 Annealed	N06975	85/32	Welded Pipe Ni-Cr-Fe-Mo-Cu
		B619 Annealed	N06985	90/35	Welded Pipe Ni-Cr-Fe-Mo-Cu
	PS	B620 Annealed	N08320	75/28	Sheet, Plate, Strip Ni-Fe-Cr-Mo
	PS	B621 Annealed	N08320	75/28	Bar Ni-Fe-Cr-Mo
	PS	B622 Annealed	N08320	75/28	Smls. Pipe & Tube Ni-Fe-Cr-Mo
		B622 Annealed	N06007	90/35	Smls. Pipe & Tube Ni-Cr-Fe-Mo-Cu
		B622 Annealed	N06975	85/32	Smls. Pipe & Tube Ni-Cr-Fe-Mo-Cu
		B622 Annealed	N06985	90/35	Smls. Pipe & Tube Ni-Cr-Fe-Mo-Cu
	PS	B625 Annealed	N08904	71/31	Plate, Sheet, Strip Ni-Fe-Cr-Mo-Cu
	PS	B626 Annealed	N06007	90/35	Welded Tube Ni-Cr-Fe-Mo-Cu
		B626 Annealed	N06985	90/35	Tube Ni-Cr-Fe-Mo-Cu
	PS	B626 Annealed	N08320	75/28	Welded Tube Ni-Fe-Cr-Mo
		B626 Annealed	N06975	85/32	Welded Tube Ni-Cr-Fe-Mo-Cu
	PS	B668 Annealed	N08028	73/31	Tube Ni-Fe-Cr-Mo
	S	B670 Annealed	N07718	180/150	Plate, Sheet, Strip Ni-Fe-Cr-Cb
	PS	B672 Annealed	N08700	80/35	Bar, Wire Ni-Fe-Cr-Mo-Cb
	PS	B673 Solution Treated	N08904	71/31	Welded Pipe Ni-Fe-Cr-Mo-Cu
	PS	B674 Solution Treated	N08904	71/31	Welded Tube Ni-Fe-Cr-Mo-Cu
	PS	B675 Solution Treated	N08366	75/30	Welded Pipe Ni-Fe-Cr-Mo
	PS	B676 Solution Treated	N08366	75/30	Welded Tube Ni-Fe-Cr-Mo
	PS	B677 Solution Treated	N08904	71/31	Smls. Pipe Ni-Fe-Cr-Mo-Cu
	S	B704	N08825	85/35	Welded Tubing Ni-Fe-Cr

(continued)

Table 1 (Continued)

Mat'l No.	Std.	Base Metal Specification	Alloy Designations	Minimum Tensile/ Yield ksi	Type of Base Metal
45	S	B705	N08825	85/35	Welded Pipe Ni-Fe-Cr
46	PS	B511 Annealed	N08330	70/30	Bar Ni-Fe-Cr-Si
	PS	B535 Annealed	N08330	70/30	Smls. & Welded Pipe Ni-Fe-Cr-Si
	PS	B536 Annealed	N08330	70/30	Plate, Sheet, Strip Ni-Fe-Cr-Si
		B536 Annealed	N08332	67/27	Plate, Sheet, Strip Ni-Fe-Cr-Si
	S	B718	N06333	80/35	Plate, Sheet, Strip Ni-Cr-Mo-Co-W-Fe-Si
	S	B719	N06333	80/35	Bar Ni-Cr-Mo-Co-W-Fe-Si
	S	B722	N06333	80/35	Seamless Pipe & Tube Ni-Cr-Mo-Co-W-Fe-Si
	S	B723	N06333	80/35	Welded Pipe Ni-Cr-Mo-Co-W-Fe-Si
	S	B726	N06333	80/35	Welded Tube Ni-Cr-Mo-Co-W-Fe-Si

(continued)

Table 1 (Continued)

Mat'l No.	Std.		Base Metal Specification	Minimum Tensile/ Yield ksi	Type of Base Metal
Titanium and Titanium-Base Alloys					
51	PS	B265	Grade 1	35/25	Strip, Sheet & Plate
			Grade 2	50/40	Strip, Sheet & Plate
			Grade 7	50/40	Alloy, Strip, Sheet, Plate
	PS	B337	Grade 1	35/25	Smls. & Welded Pipe
			Grade 2	50/40	Smls. & Welded Pipe
			Grade 7	50/40	Smls. & Welded Pipe
	PS	B338	Grade 1	35/25	Smls. & Welded Pipe
			Grade 2	50/40	Smls. & Welded Pipe
			Grade 7	50/40	Smls. & Welded Pipe
	PS	B348	Grade 1	35/25	Bars & Billets
			Grade 2	50/40	Bars & Billets
			Grade 7	50/40	Alloy Bars & Billets
	PS	B381	Grade F-1	35/25	Forging
			Grade F-2	50/40	Forging
			Grade F-7	50/40	Forging
52	PS	B265	Grade 3	65/55	Strip, Sheet & Plate
			Grade 12	70/50	Strip, Sheet & Plate
	PS	B337	Grade 3	65/55	Seamless & Welded Pipe
			Grade 12	70/50	Seamless & Welded Pipe
	PS	B338	Grade 3	65/55	Seamless & Welded Pipe
			Grade 12	70/50	Seamless & Welded Pipe
	PS	B348	Grade 3	65/55	Bar & Billets
			Grade 12	70/50	Bar & Billets
	PS	B381	Grade F-3	65/55	Forging
			Grade F-12	70/50	Forging
Zirconium and Zirconium-Base Alloys					
61	PS	B493	Grade R60702	55/32	Forging and Extrusions
	PS	B523	Grade R60702	55/30	Seamless and Welded Tubing
	PS	B550	Grade R60702	55/30	Bar
	PS	B551	Grade R60702	55/30	Strip, Sheet & Plate
	PS	B658	Grade R60702	55/30	Smls. & Welded Pipe
62	PS	B493	Grade R60705	70/55	Forging
	PS	B523	Grade R60705	80/55	Seamless & Welded Tubing
	PS	B550	Grade R60705	80/55	Bar
	PS	B551	Grade R60705	80/55	Plate, Sheet & Strip
	PS	B658	Grade R60705	80/55	Smls. & Welded Pipe

3. Welding Processes

All of the welding processes listed in Table 6 may be used in the fabrication of rotating elements.

4. Filler Metals

Filler metals and fluxes shall conform to AWS filler metal specifications. Filler metals and fluxes not covered by an AWS filler metal specification shall require a separate welding procedure qualification as specified in section 5.

5. Welding Procedure and Performance Qualification

5.1 Scope. The requirements of this section apply to the qualification of welding procedures, welders, and welding operators for the welding processes listed in Table 6. These requirements shall apply to other welding processes, and to filler metals and fluxes not covered by an AWS filler metal specification. Procedures, welders, and welding operators qualified to other codes and specifications (such as, ASME IX, AWS D1.1 etc.) shall be acceptable to this specification if the previous qualifications meet the requirements specified herein.

Qualification records, previously complying with 5.1 shall continue to be acceptable. New qualifications shall be in conformance to the current revision of this specification.

5.2 Responsibility for Welding. Each manufacturer or contractor is responsible for the welding done by their organization and shall conduct the tests required in this section. It is not permissible for the manufacturer or contractor to have the welding of the test weldments performed by another organization. It is permissible, however, to subcontract any or all of the work of preparation of test materials for welding, and subsequent work on preparation of test specimens from the completed weldment, performance of nondestructive examination, and mechanical tests, provided the manufacturer, contractor, assembler, or installer accepts the responsibility for any such work.

5.2.1 A manufacturer or contractor may approve a subcontractor's welding procedure and performance qualification records for work to be performed by the subcontractor, provided that the records meet this specification.

5.2.2 Each manufacturer or contractor shall maintain welding procedure specifications and records of the results obtained in welding procedure qualification records

(PQR) and welder and welding operator performance qualifications. These records shall be certified by the manufacturer or contractor and shall be accessible to the purchaser's inspector. Refer to recommended forms in Annex A.

5.3 Weld Orientation. Weld positions are illustrated in Figures 1 through 5.

5.4 Test Positions for Groove Welds. Groove welds may be made in test material oriented in any of the positions in Figures 2 and 3, and as described in the following paragraphs, except that angular deviations, in accordance with Figure 1, are permitted during welding.

5.4.1 Test Positions (Plate)—Groove Welds

5.4.1.1 Flat Test Position 1G. The 1G test position designation for plate is for a linear groove weld applied to a joint in which the weld is made in the flat welding position. Refer to Figure 2(A).

5.4.1.2 Horizontal Test Position 2G. The 2G test position designation for plate is for a linear groove weld applied to a joint in which the weld is made in the horizontal welding position. Refer to Figure 2(B).

5.4.1.3 Vertical Test Position 3G. The 3G test position designation for plate is for a linear groove weld applied to a joint in which the weld is made in the vertical position. Refer to Figure 2(C).

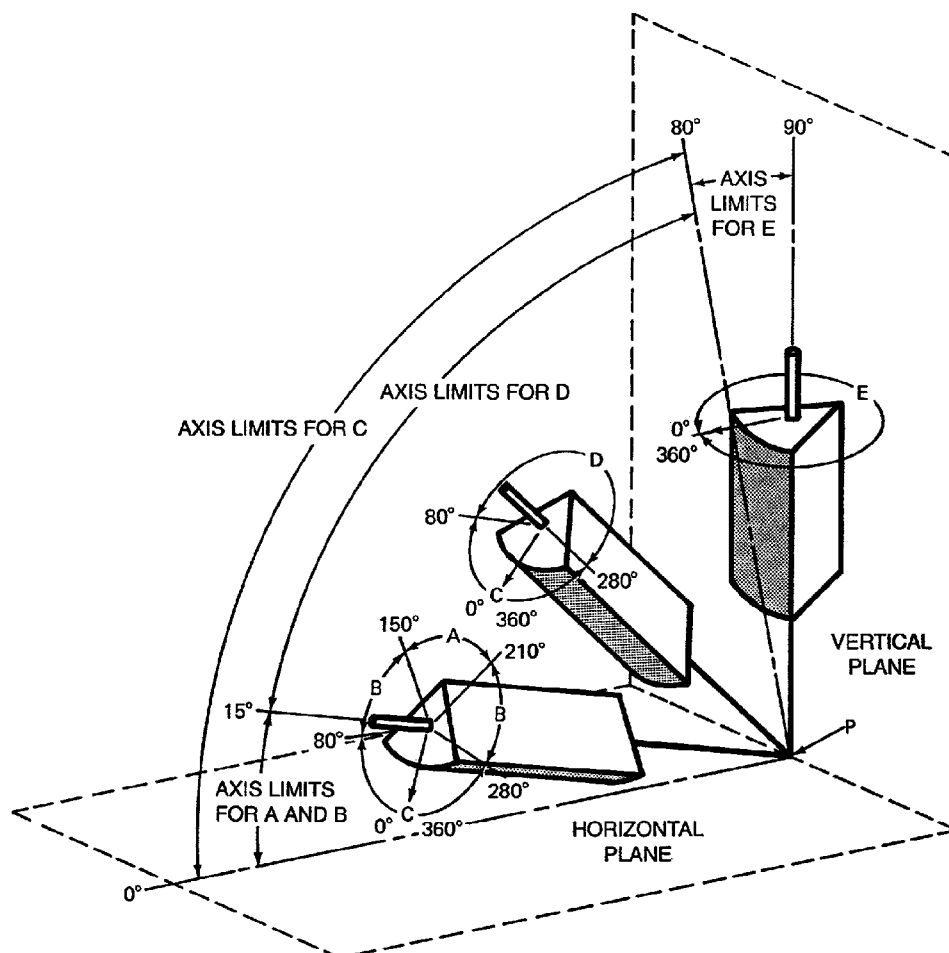
5.4.1.4 Overhead Test Position 4G. The 4G test position designation for plate is for a linear groove weld been applied to a joint in which the weld is made in the overhead position. Refer to Figure 2(D).

5.4.2 Test Positions (Pipe and Tube)—Groove Welds

5.4.2.1 Flat Test Position 1G. The 1G test position designation for piping and tubing is for a circumferential groove applied to a joint in pipe in which the weld is made in the flat welding position by rotating the pipe about its axis. Refer to Figure 3(A).

5.4.2.2 Horizontal Test Position 2G. The 2G test position designation for piping and tubing is for a circumferential groove weld applied to a joint in pipe with its axis approximately vertical, in which the weld is made in the horizontal welding position. Pipe or tubes shall not be rotated during welding. Refer to Figure 3(B).

5.4.2.3 Multiple Test Positions 5G. The 5G test position designation for piping and tubing is for a circumferential groove weld applied to a joint in a pipe with its axis horizontal, in which the weld is made in the flat, vertical, and overhead welding positions. The pipe remains fixed until the welding of the joint is complete. Refer to Figure 3(C).



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 construction.
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 1—Positions of Groove Welds

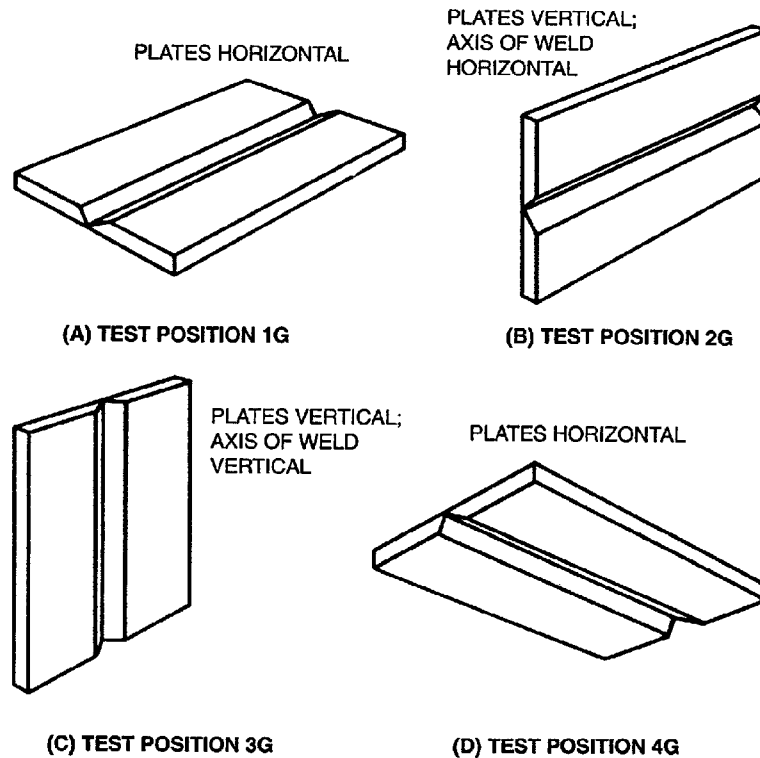


Figure 2—Positions of Test Plates for Groove Welds

5.4.2.4 Multiple Test Positions 6G. The 6G test position designation for piping and tubing is for a circumferential groove weld that has been applied to a joint in pipe with its axis approximately 45 degrees from horizontal, in which the weld is made in the flat, vertical, and overhead welding positions. The pipe remains fixed until welding is complete. Refer to Figure 3(D).

5.5 Test Plate Positions for Fillet Welds. Fillet welds may be made in test material oriented in any of the positions of Figure 5 and as described in the following paragraphs except angular deviations in accordance with Figure 4 are permitted during welding.

5.5.1 Flat Test Position 1F. This welding test position designation is for a linear fillet weld applied to a joint in which the weld is made in the flat welding position. Refer to Figure 5(A).

5.5.2 Horizontal Test Position 2F. This welding test position designation is for a linear fillet weld applied to a joint in which the weld is made in the horizontal welding position. Refer to Figure 5(B).

5.5.3 Vertical Test Position 3F. This welding test position designation is for a linear fillet weld applied to a

joint in which the weld is made in the vertical welding position. Refer to Figure 5(C).

5.5.4 Overhead Test Position 4F. This welding test position designation is for a linear fillet weld applied to a joint in which the weld is made in the overhead welding position. Refer to Figure 5(D).

5.6 Types and Purposes of Mechanical Tests and Examinations. Mechanical tests used in procedure or performance qualification are as follows:

5.6.1 Tension Tests. Tension tests as described in 5.7 are used to determine the ultimate tensile strength of groove welded joints.

5.6.2 Guided-Bend Tests. Guided-bend tests, as described in 5.8, are used to determine the degree of soundness and ductility of groove welded joints.

5.6.3 Notch-Toughness Tests. Tests, as described in 5.9, are used to determine the notch toughness of the weldment.

5.6.4 Fillet Weld Tests. Tests, as described in 5.10.4.3, are used to determine the size, contour, and degree of soundness of fillet welds.

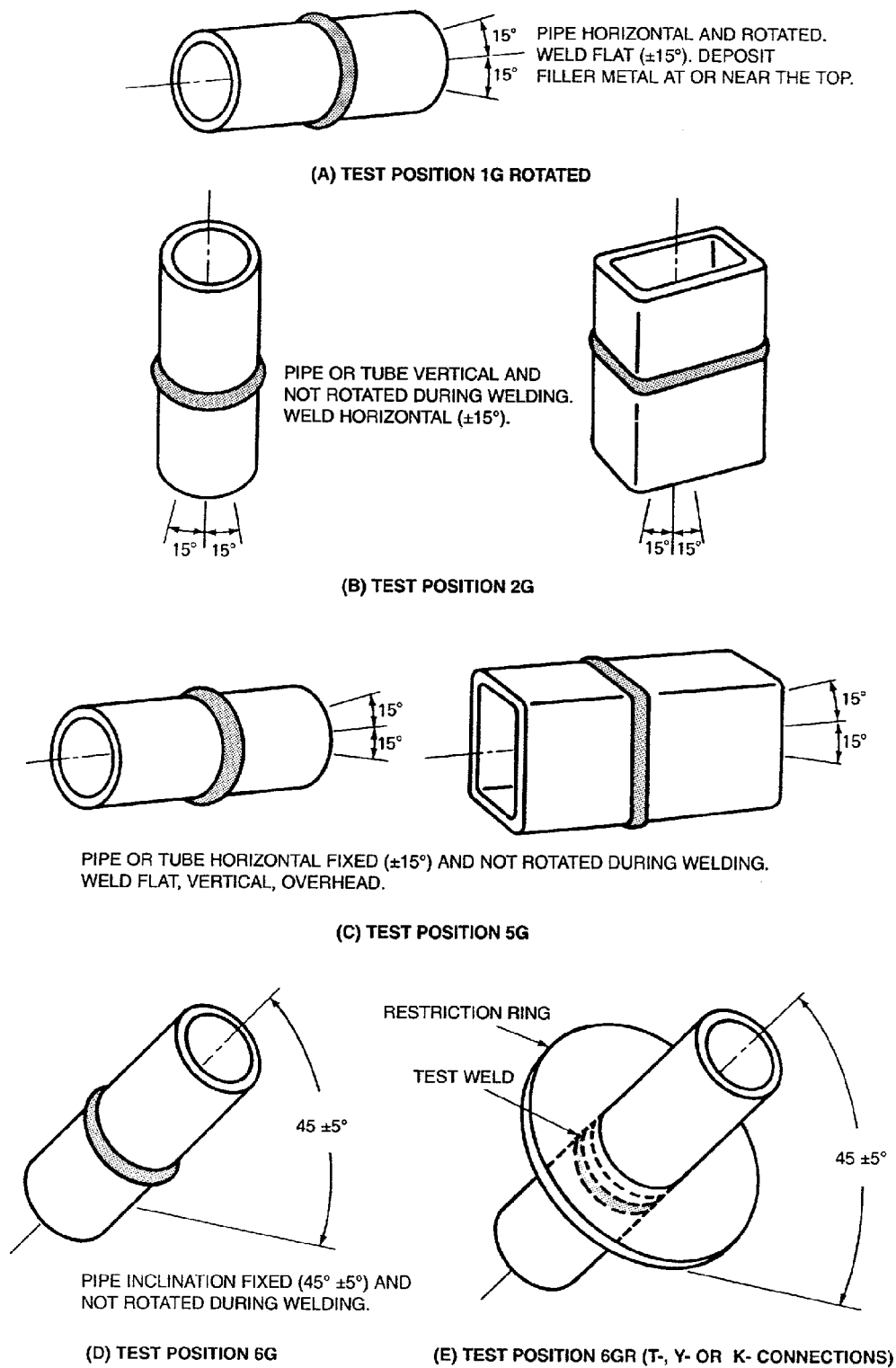
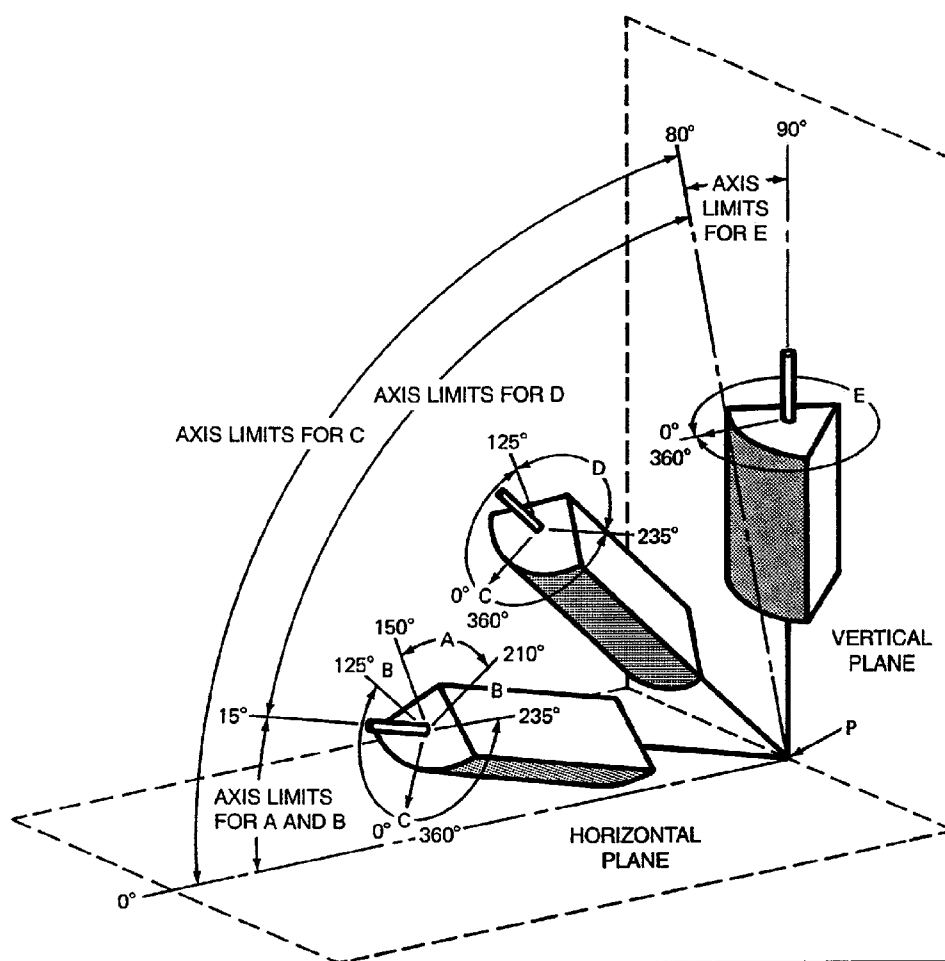


Figure 3—Positions of Test Pipe or Tubing for Groove Welds



Tabulation of positions of fillet welds			
Position	Diagram reference	Inclination of axis	Rotation of face
Flat	A	0° to 15°	150° to 210°
Horizontal	B	0° to 15°	125° to 150° 210° to 235°
Overhead	C	0° to 80°	0° to 125° 235° to 360°
Vertical	D	15° to 80°	125° to 235°
	E	80° to 90°	0° to 360°

Figure 4—Positions of Fillet Welds

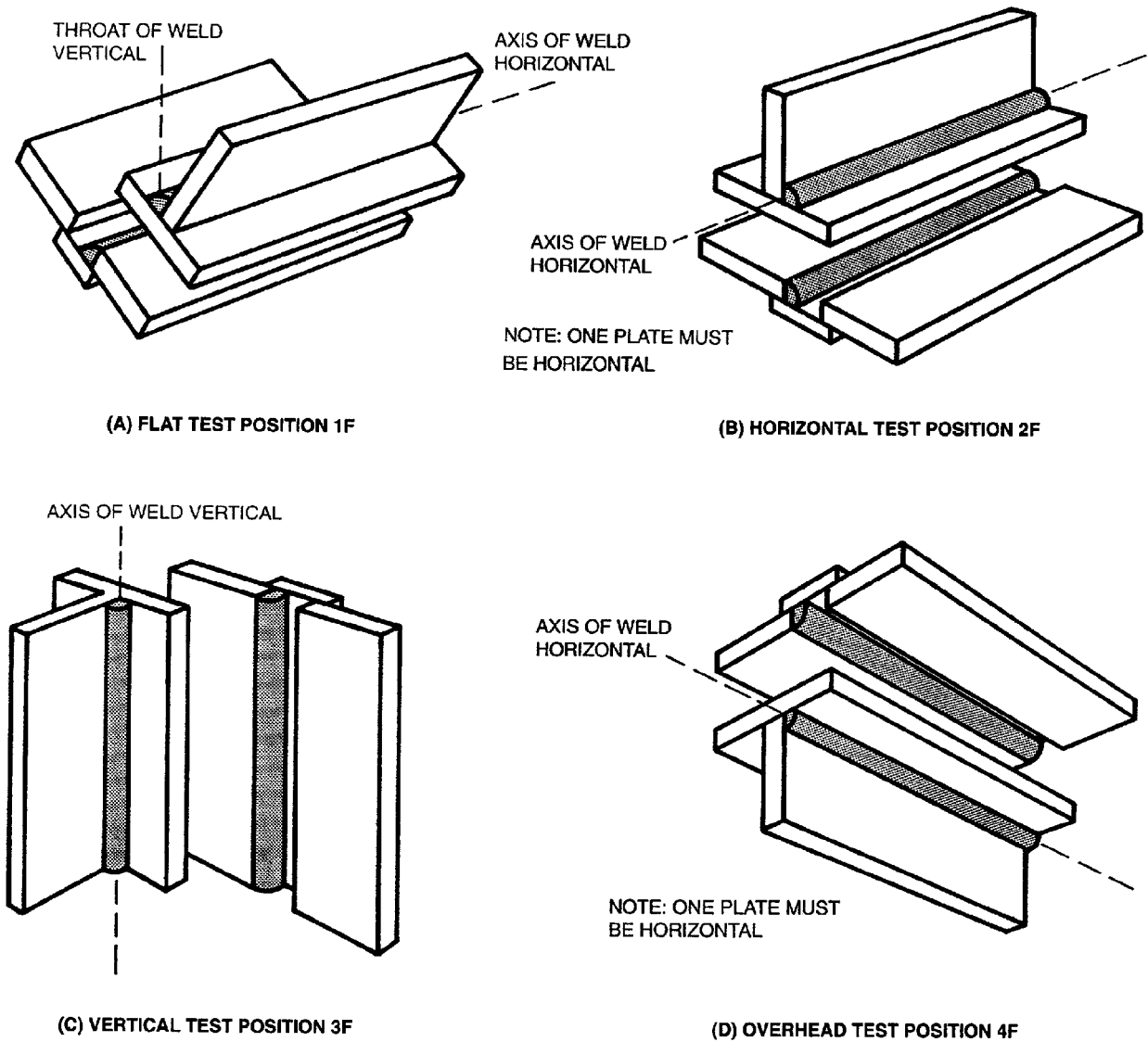


Figure 5—Positions of Test Plates for Fillet Welds

5.7 Tension Tests. (Reference ANSI/AWS B4.0, *Standard Methods for Mechanical Testing of Welds*).

5.7.1 Specimens. Tension test specimens shall conform to one of the types illustrated in Figure 6 and shall meet the requirements of 5.7.3.

5.7.1.1 Reduced-Section: Plate. Reduced-section specimens conforming to the requirements given in Figure 6(A) may be used for tension tests on all thicknesses of plate.

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

(2) For plate thicknesses greater than 1 in. (25 mm), single or multiple specimens may be used, provided they are in compliance with 5.7.1.1(3) and 5.7.1.1(4).

(3) When multiple specimens are used, each set shall represent a single required tension test [see Figure 6(E)]. Collectively, all of the specimens required to represent the full thickness of the weld at one location shall comprise a set. The results of each test specimen of the set shall be documented on the PQR.

(4) When multiple specimens are necessary, the entire thickness shall be mechanically cut into a minimum number of approximately equal strips of a size that can be tested in the available equipment. Each specimen shall be tested and meet the requirements of 5.7.3.

5.7.1.2 Reduced-Section: Pipe. For pipe having an outside diameter of 3 in. (76 mm), or less, reduced-section specimens conforming to the requirements given in Figure 6(B) may be used for tension tests. Reduced-section specimens conforming to the requirements given in Figure 6(C) may be used for tension tests on all thicknesses of pipe having an outside diameter greater than 3 in. (76 mm).

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

(2) For pipe thicknesses greater than 1 in. (25 mm), single or multiple specimens may be used, provided they are in compliance with 5.7.1.2(3) and 5.7.1.2(4).

(3) When multiple specimens are used, each set shall represent a single required tension test. Collectively, the specimens required to represent the full thickness of the weld at one location shall comprise a set [see Figure 6(E)]. The results of each test specimen of the set shall be documented on the PQR.

(4) When multiple specimens are necessary, the entire thickness shall be mechanically cut into a minimum number of approximately equal strips of a size that can be tested in the available equipment. Each specimen shall be tested and meet the requirements of 5.7.3.

5.7.1.3 Turned Specimens. Turned specimens conforming to the requirements given in Figure 6(D) may be used for tension tests.

(1) For thicknesses up to and including 1 in. (25 mm), a single turned specimen shall be used.

(2) For thicknesses over 1 in. (25 mm), multiple specimens shall be cut through the full thickness of the weld with their centerlines parallel to the metal surface and not over 1 in. (25 mm) apart. The centerlines of the specimens adjacent to the metal surfaces shall not exceed 5/8 in. (16 mm) from the surface.

(3) When multiple specimens are used, each set shall represent a single required tension test. Collectively, all the specimens required to represent the full thickness of the weld at one location shall comprise a set [see Figure 6(E)]. The results of each test specimen of the set shall be documented on the PQR.

(4) Each specimen shall be tested and meet the requirements of 5.7.3.

5.7.2 Procedure. The tension test specimen shall be ruptured under tensile load. The tensile strength shall be computed by dividing the maximum load by the least cross-sectional area of the specimen as measured before the load is applied.

5.7.3 Acceptance Criteria—Tension Test. The specimen shall have a tensile strength that is not less than:

(1) The specified minimum tensile strength of the base metal.

(2) The specified minimum tensile strength of the lesser of the two, if base metals of different minimum tensile strengths are used.

(3) The specified minimum tensile strength of the weld metal having lower minimum tensile strength than the base metal at room temperature.

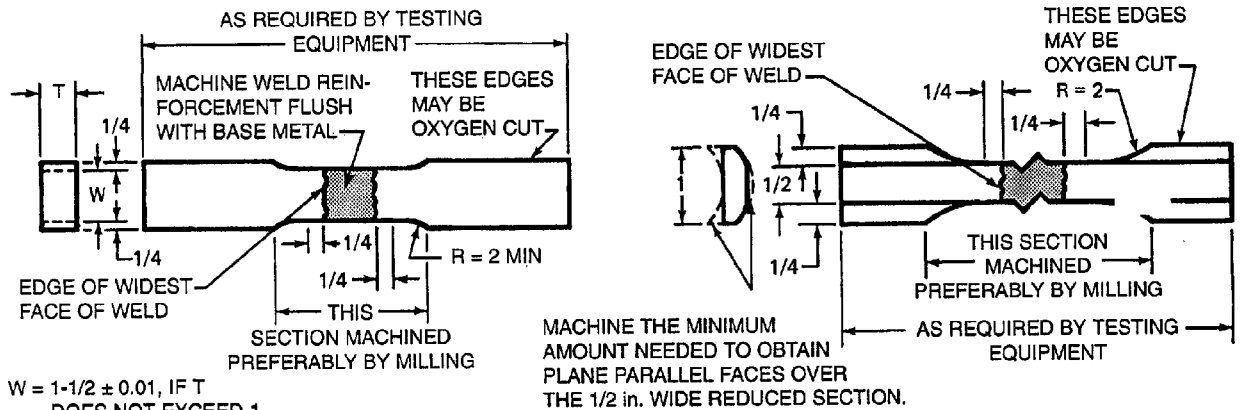
(4) If the specimen breaks in the base metal outside of the weld or fusion line, the test shall be accepted as meeting the requirements, provided the strength is not more than five percent below the specified minimum tensile strength of the base metal.

(5) If the base metal does not have a specified minimum tensile strength, the base metal shall be tensile tested, and the strength established. The welding procedure tensile test specimens shall meet or exceed applicable requirements of 5.7.3(1) through 5.7.3(4).

5.8 Guided-Bend Test (Reference ANSI/AWS B4.0, *Standard Methods for Mechanical Testing of Welds*.)¹

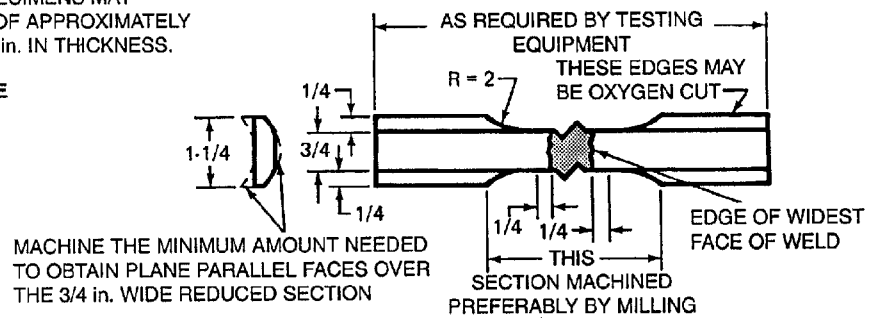
5.8.1 Specimens. Guided-bend test specimens shall be prepared by cutting the test plate or pipe to form specimens of approximately rectangular cross section. The

1. For metals of M-23 and M-35 in Table 1, test specimens of Figures 7, 8 and 9 shall be reduced from 3/8 in. (10 mm) thickness to 1/8 in. (3.2 mm) in thickness and the corner radius "R" reduced to 1/16 in. (1.6 mm) maximum.

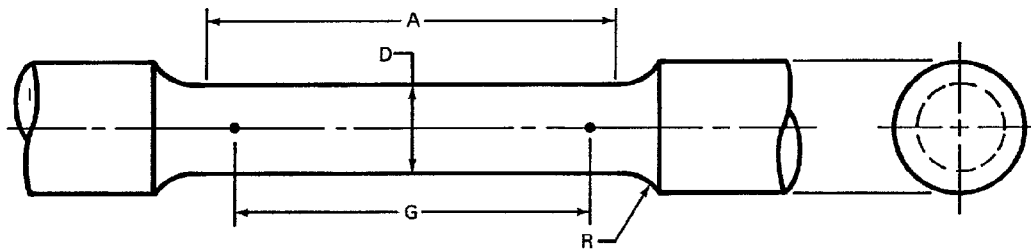


(A) TEST PLATE

(B) TEST PIPE 2 in. AND 3 in. DIAMETER



(C) TEST PIPE 6 in. AND 8 in. DIAMETER



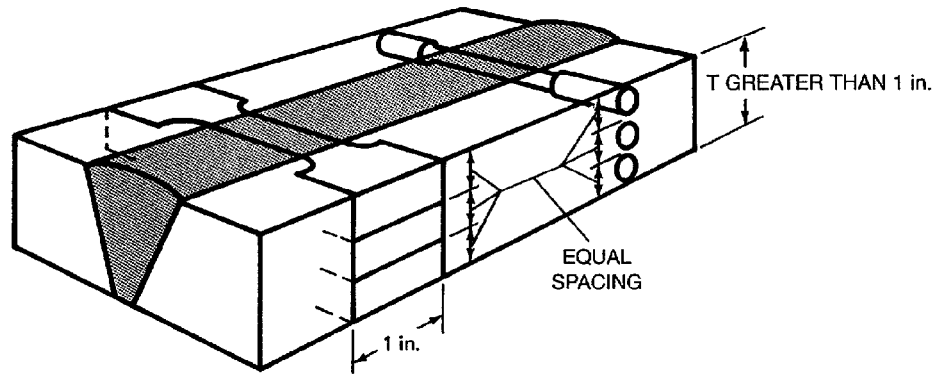
	DIMENSIONS		
	Standard specimen	Small size specimens proportional to standard	
	0.500 in. round	0.350 in. round	0.250 in. round
G—Gage length, in.	2.000 ± 0.005	1.400 ± 0.005	1.000 ± 0.005
D—Diameter (Note 1), in.	0.500 ± 0.010	0.350 ± 0.007	0.250 ± 0.005
R—Radius of fillet, min, in.	3/8	3/8	1/4
A—Length of reduced section (Note 2), min, in.	2-1/4	1-3/4	1-1/4

Notes:

1. The reduced section may have a gradual taper from the center toward the ends with the ends not more than 0.005 in. larger in diameter than the center (controlling dimension) on the standard specimen and not more than 0.003 in. larger than the center on the small size specimens.
2. If desired, on the small size specimens the length of the reduced section may be increased to accommodate an extensometer. However, reference marks for the measurement of elongation should nevertheless be spaced at the indicated gage length.
3. The gage length and fillets shall be as shown, but the ends may be of any form to fit the holders of the testing machine in such a way that the load shall be axial.
4. All dimensions in inches.

(D) TURNED SPECIMENS

Figure 6—Tension Test Specimens



(E) TYPICAL FOR MULTIPLE SPECIMENS AT ONE LOCATION

Figure 6 (Continued)—Tension Test Specimens

cut surfaces shall be designated the sides of the specimen. The other two surfaces shall be called the face and root surfaces, the face surface having the greater width of weld. Guided-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 bend specimen. The five types are defined as follows:

5.8.1.1 Transverse Side-Bend. The weld is transverse to the longitudinal axis of the specimen, which is bent so that one of the side surfaces becomes the convex surface of the bent specimen. Transverse side-bend test specimens shall conform to the dimensions shown in Figure 7.

Specimens of base-metal thickness over 1-1/2 in. (38 mm) may be cut into approximately equal strips between 3/4 in. (19 mm) and 1-1/2 in. (38 mm) wide for testing, or the specimens may be bent at full width. (See requirements on jig width in Figure 10.)

If multiple specimens are used, one complete set shall be made for each required test. Each specimen shall be tested and meet the requirements in 5.8.3.

5.8.1.2 Transverse Face-Bend. 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. Transverse face-bend test specimens shall conform to the dimensions shown in Figure 8.

5.8.1.3 Transverse Root-Bend. 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. Transverse root-bend test specimens shall conform to the dimensions shown in Figure 8.

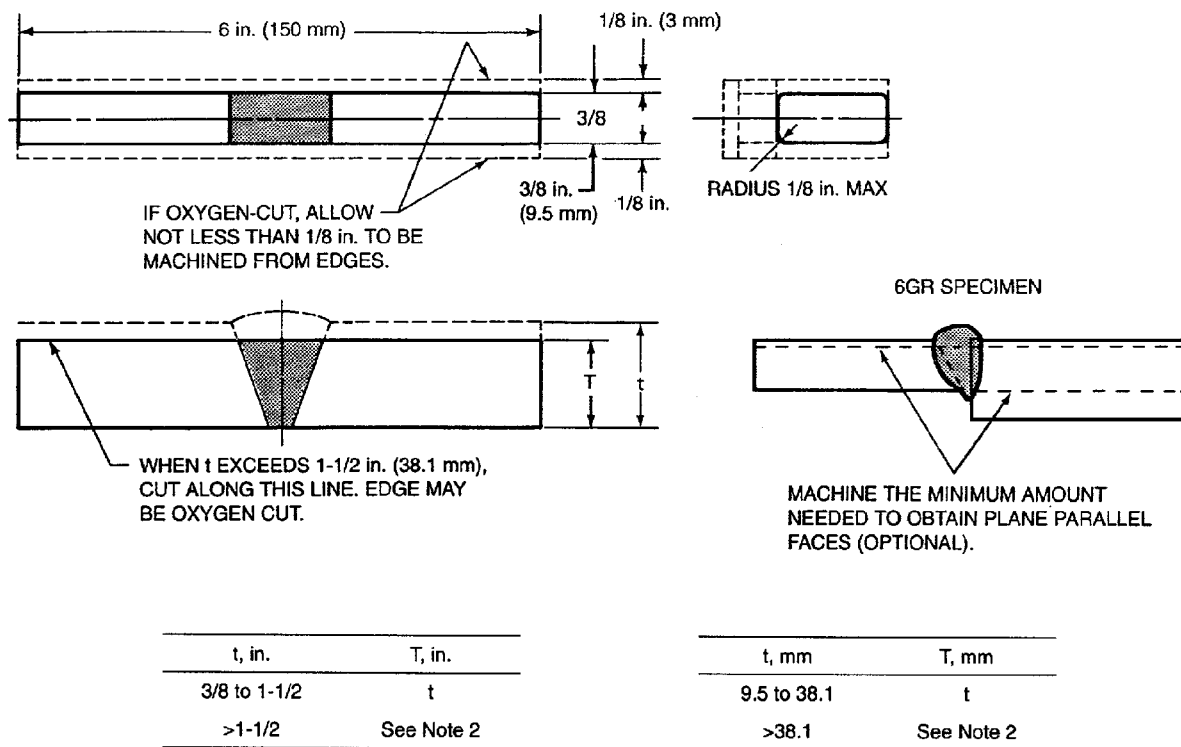
5.8.1.4 Subsize Transverse Face- and Root-Bends. For pipe of 3 in. (76 mm) outside diameter or less, the width of the bend specimen of Figure 8 may be 3/4 in. (19 mm) measured around the outside surface. Alternatively, for pipe of less than 2-3/8 in. (60 mm) outside diameter, the width of the bend specimens may be obtained by cutting the pipe into quarter sections, less the allowance for cutting.

5.8.1.5 Longitudinal Bend Tests. Longitudinal bend tests may be used in lieu of the transverse side-, face- and root-bend tests for testing weld metal or base-metal combinations that differ markedly in bending properties between (a) the two base metals or (b) the weld metal and the base metal.

5.8.1.6 Longitudinal Face-Bend. 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 9.

5.8.1.7 Longitudinal Root-Bend. 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 9.

5.8.2 Guided-Bend Test Procedure. Guided-bend specimens shall be bent in test jigs that are in substantial accordance with Figure 10. When using the jigs illustrated in Figure 10(A), the side of the specimen turned toward the gap of the jig shall be the face for face-bend

**Notes:**

1. A longer specimen length may be necessary when using a wraparound type bending fixture or when testing steel with a yield strength of 90 ksi (620 MPa) or more.
2. For plates over 1-1/2 in. (38.1 mm) thick, cut the specimen into approximately equal strips with T between 3/4 in. (19.0 mm) and 1-1/2 in. and test each strip.
3. t = plate or pipe thickness.

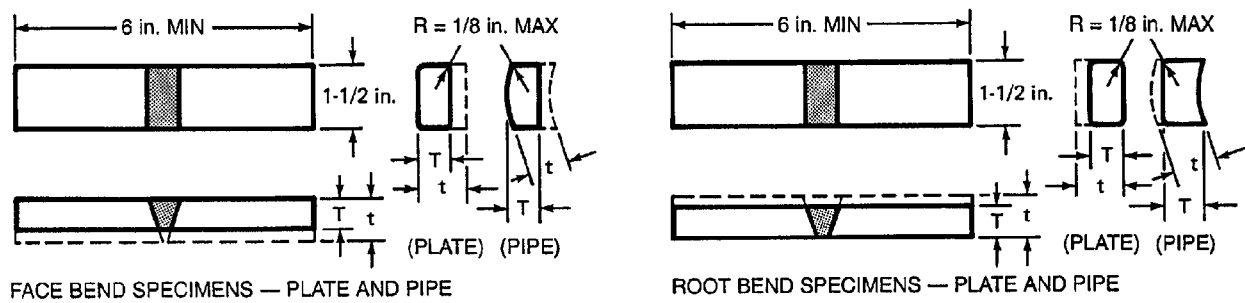
Figure 7—Side Bend Specimens

specimens, the root for root-bend specimens, and the side with the greater defects, if any, for side-bend specimens.

The specimen shall be loaded with the weld at mid-span and forced into the die by applying a load on the plunger until the curvature of the specimen is such that a 1/8 in. (3.2 mm) diameter wire cannot be inserted between the specimen and the die of Figure 10(A); or the specimen is bottom ejected, if the roller-type jig, Figure 10(C), is used. When using the wraparound jig, Figure 10(B), the side of the specimen turned toward the roller shall be the face for the face-bend specimens, the root for the root-bend specimens, and the side with the greater defects, if any, for the side-bend specimens. Test specimens shall be removed from the jig when the outer roll has been moved 180 degrees from the starting point.

5.8.3 Acceptance Criteria. The weld and heat-affected zone of a transverse weld bend specimen shall be completely within the bent portion of the specimen after testing.

The guided-bend specimens shall have no open defects exceeding 1/8 in. (3.2 mm) measured in any direction on the convex surface of the specimen after bending, except that cracks occurring on the corners of the specimen during testing shall not be considered, unless there is definite evidence that they result from slag inclusions or other internal defects. For corrosion resistance weld overlay cladding, no open defect exceeding 1/16 in. (1.6 mm) measured in any direction shall be permitted in the cladding, and no open defects exceeding 1/8 in. (3.2 mm) shall be permitted in the bond line.

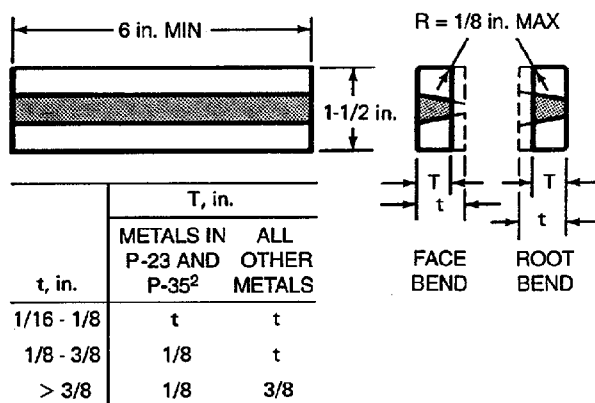


t, in.	T, in.	
	Metals in P-23 and P-35 ³	All other metals
1/16 - 1/8	t	t
1/8 - 3/8	1/8	t
> 3/8	1/8	3/8

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 3 in. O.D. or less, the width of the bend specimen may be 3/4 in., measured around the outside surface. Alternatively, if the pipe being tested is less than 2 in. pipe size (2.375 in. 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. Except B-148 alloys CDA 952 and 954 and B-271 alloys CDA 952 and 954.

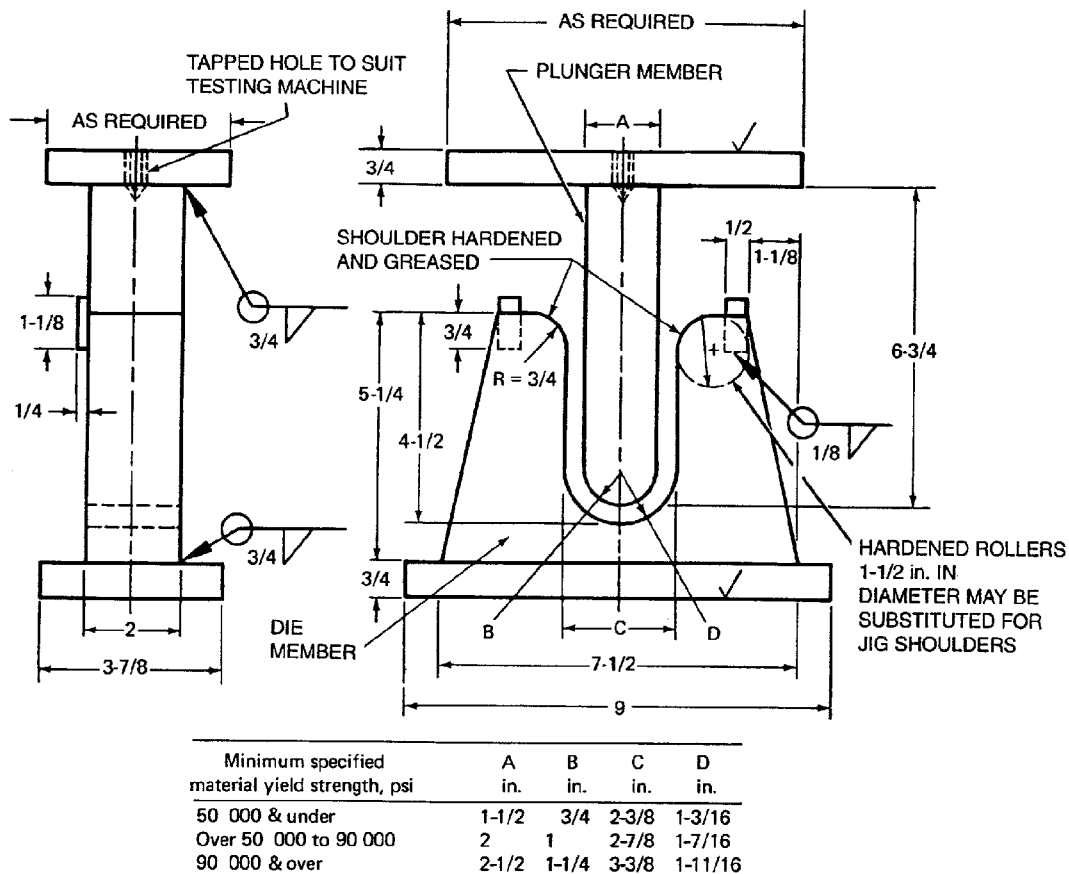
Figure 8—Face and Root Bends—Transverse Specimens



Notes:

1. 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.
2. Except B-148 alloys CDA 952 and 954 and B-271 alloys CDA 952 and 954.

Figure 9—Face and Root Bends—Longitudinal Specimens



Note: Plunger and interior die surfaces shall be machine-finished.

Figure 10—Jigs for Guided Bend Test

5.9 Notch-Toughness Tests

5.9.1 Drop-weight and Charpy V-notch tests shall be performed when agreed on by the buyer and manufacturer. The acceptance criteria, location, and orientation of the test specimens shall be by agreement between the purchaser and manufacturer.

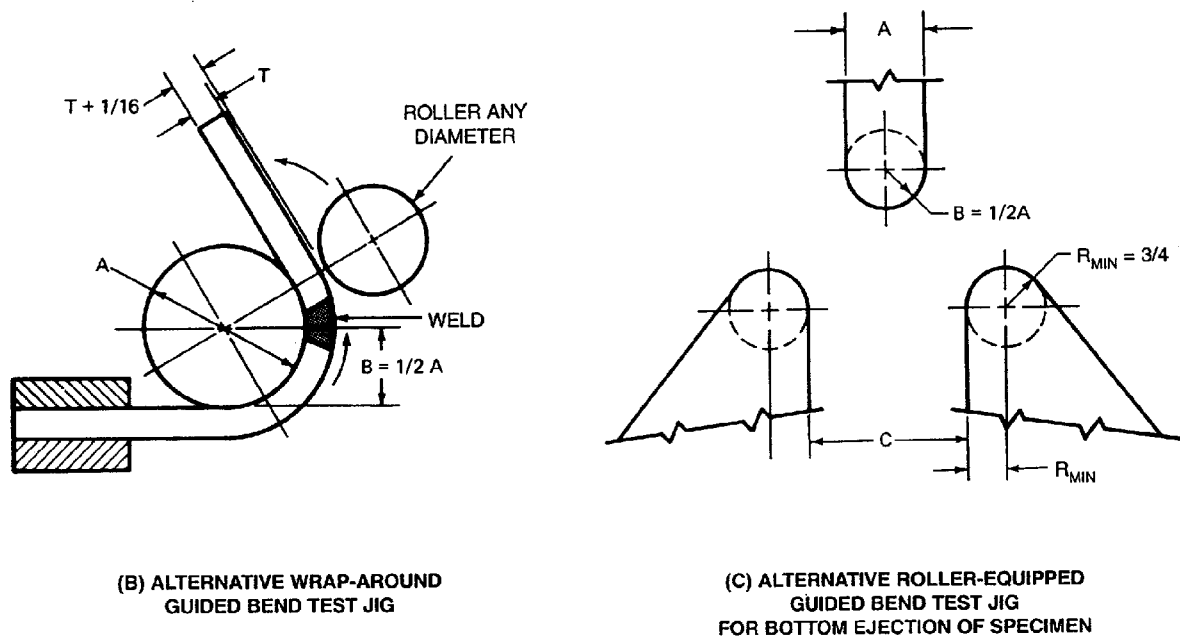
5.9.2 Test procedures and apparatus for Charpy V-notch testing shall conform to the requirements of ANSI/AWS B4.0, *Standard Methods for Mechanical Testing of Welds*.

5.9.3 Test procedures and apparatus for drop-weight testing shall conform to the requirements of ANSI/AWS B4.0, *Standard Methods for Mechanical Testing of Welds*.

Part I Procedure Qualification

5.10 Manufacturer's or Contractor's Responsibility. Each manufacturer or contractor shall list the variables applicable to the welding that each performs in construction of weldments built in conformance to this specification. These variables shall be listed in a document known as a welding procedure specification (WPS).

Each manufacturer or contractor shall qualify the WPS by the welding of test assemblies, the testing of specimens as required in this specification, and the recording of the welding data and test results in a document known as a procedure qualification record (PQR). The welders or welding operators, working to produce



Thickness of Specimens, in.	A, in.	B, in.	C, in.	D, in.	Material
$\frac{3}{8}$ T	$1\frac{1}{2}$ 4T	$\frac{3}{4}$ 2T	$2\frac{3}{8}$ $6T + \frac{1}{8}$	$1\frac{3}{16}$ $3T + \frac{1}{16}$	All others
$\frac{1}{8}$	$2\frac{1}{16}$	$1\frac{1}{32}$	$2\frac{3}{8}$	$1\frac{3}{16}$	
$\frac{3}{8}$ T	$2\frac{1}{2}$ $6\frac{2}{3}T$	$1\frac{1}{4}$ $3\frac{1}{3}T$	$3\frac{3}{8}$ $8\frac{2}{3}T + \frac{1}{8}$	$1\frac{11}{16}$ $4\frac{1}{2}T + \frac{1}{16}$	P-11, P-25, P-35 subgroups, B-148 and B-271, Alloys CDA-952 and 954 B-171, Alloy 62B
$\frac{1}{16} - \frac{3}{8}$ in. incl.	8T	4T	$10T + \frac{1}{8}$	$5T + \frac{1}{16}$	
$\frac{1}{16} - \frac{3}{8}$ in. incl.	10T	5T	$12T + \frac{1}{8}$	$6T + \frac{1}{16}$	P-52

Figure 10 (Continued)—Jigs for Guided Bend Test

weldments to be tested for qualification of procedures, shall be under the full supervision and control of the manufacturer or contractor during the production of these test weldments. A WPS may require the support of more than one PQR while, alternatively, one PQR may support more than one WPS.

5.10.1 Welding Procedure Specification (WPS).

The WPS shall list in detail the various base-metal M-numbers to be joined by welding, their thicknesses, the filler metals to be used, the range of preheat and postweld heat treatment, and other variables described for each welding process as either essential or nonessential variables (see Table 6.) Copies of the WPS shall be available for reference by the welders or welding opera-

tors and the purchaser's inspector. A recommended form for this WPS is given in Annex A.

Changes may be made in the nonessential variables to suit production requirements without requalification of the procedure, provided such changes are documented in either an amendment to the original WPS or a new WPS. A change in any essential variable shall require requalification to be recorded in another PQR.

The manufacturer or contractor shall certify that he or she has qualified for each welding procedure specification; has performed the procedure qualification test(s); and has documented it with the necessary PQR.

5.10.2 Procedure Qualification Record (PQR). The specific facts involved in qualifying a WPS shall be

recorded in a form called the PQR, which shall document the essential variables of the specific welding process or processes, as listed in Table 6, and the test results. These documents shall be certified by the manufacturer or contractor and shall be available for examination by the inspector. Recommended forms are given in Annex A.

5.10.3 Combination of Welding Processes or Procedures. More than one process or procedure may be used in a single production joint. Each welding process or procedure shall be qualified either separately or in combination with other processes or procedures (within the thickness limits specified in Table 2) for the base metal thickness and for the deposited weld metal thickness range for each process or procedure to be used in the production joint. For multiprocess or multiprocedure applications, the qualified thickness of each process or procedure shall be cumulative in determining the maximum thickness of the production joint to be welded. One or more processes of a multiple process procedure qualification may be deleted if the remaining processes are qualified for the entire production deposit of weld thickness as defined in Table 2.

5.10.4 Type of Tests Required

5.10.4.1 Mechanical Tests. The type and number of test specimens that must be tested to qualify a welding

procedure are given in Table 2 and the order of removal is shown in Figure 11.

5.10.4.2 Base Metals—Groove and Fillet Welds. WPS qualification tests for groove and fillet welds may be made on groove welds using reduced-section tension specimens and guided-bend specimens. The groove weld tests shall qualify the WPS for use with groove welds within the range of essential variables listed. Groove weld tests shall also qualify the WPS for use with fillet welds in all thicknesses, sizes of fillet welds, and diameters of pipe or tube, within the applicable essential variables. Where a WPS qualification of fillet welds only is required, tests shall be made in conformance to 5.10.4.3. The tests shall qualify the fillet WPS for use only with fillet welds in all thicknesses of metal, sizes of fillet welds, and diameters of pipe or tube, for use with the applicable essential variables.

5.10.4.3 Procedure Specimens—Fillet Weld Test. The dimensions and preparation of the fillet weld test specimen for procedure qualification shall conform to Figure 12.

The test specimen shall not contain visible cracks. It shall be cut transversely to provide two sections, each approximately 4 in. (100 mm) long, and shall conform to the requirements of 5.10.4.4.

Table 2
Procedure Qualification Specimens

1. Tension Tests and Transverse Bend Tests

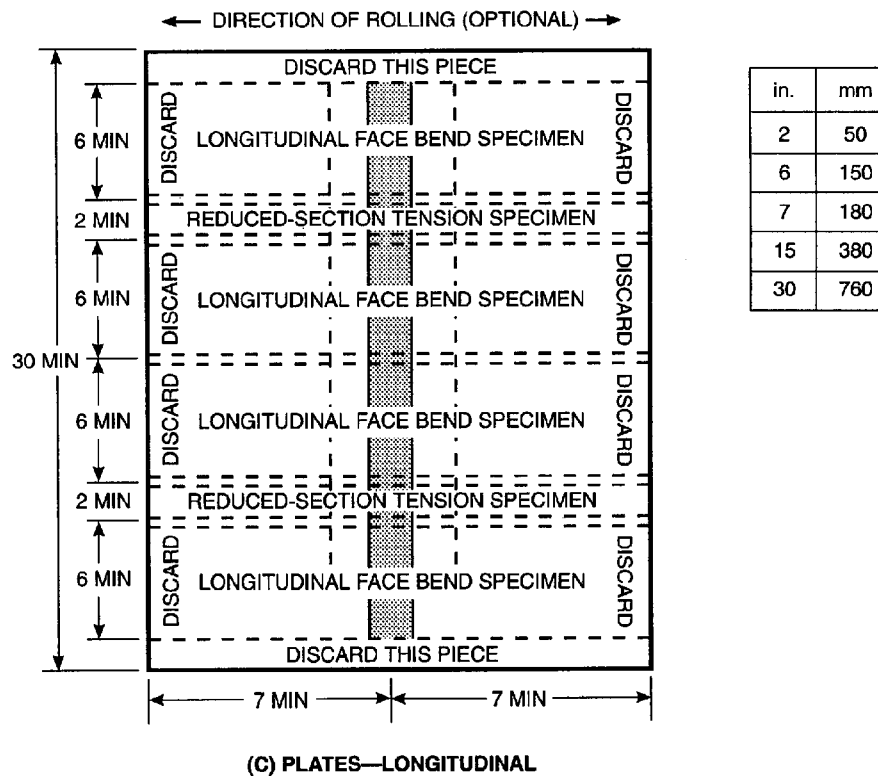
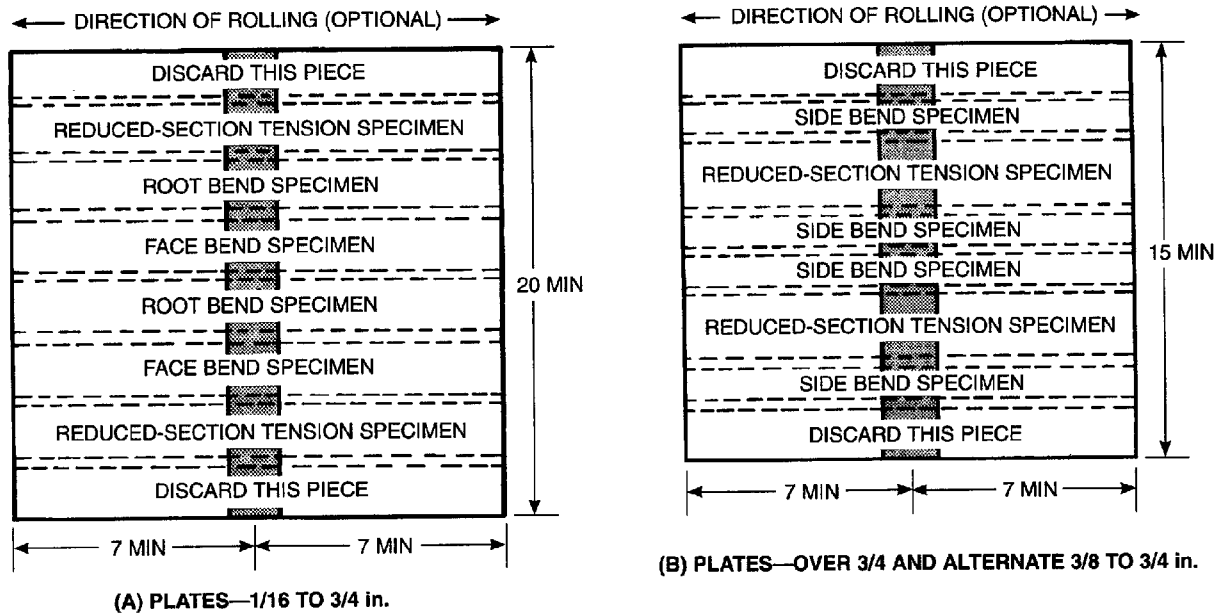
Thickness, <i>t</i> , of Test Plate or Pipe as Welded, in.	Range of Thickness of Materials Qualified by Test Plate, in. (Note 2)		Type and Number of Tests Required (Guided Bend Tests)			
	Min.	Max.	Tension	Side Bend	Face Bend	Root Bend
Less than 1/16	<i>t</i>	2 <i>t</i>	2		2	2
1/16 to 3/8, incl.	1/16 in.	2 <i>t</i>	2		2	2
Over 3/8, but less than 3/4	3/16 in.	2 <i>t</i>	2	Note 1	2	2
3/4 and over	3/16 in.	2 <i>t</i>	2	4		

2. Tension Tests and Longitudinal Bend Tests

Thickness, <i>t</i> , of Test Plate or Pipe as Welded, in.	Range of Thickness of Materials Qualified by Test Plate, in.		Type and Number of Tests Required (Guided Bend Tests)			
	Min.	Max.	Tension	Side Bend	Face Bend	Root Bend
Less than 1/16	<i>t</i>	2 <i>t</i>	2	2	2	
1/16 to 3/8, incl.	1/16 in.	2 <i>t</i>	2	2	2	
Over 3/8	3/16 in.	2 <i>t</i>	2	2	2	

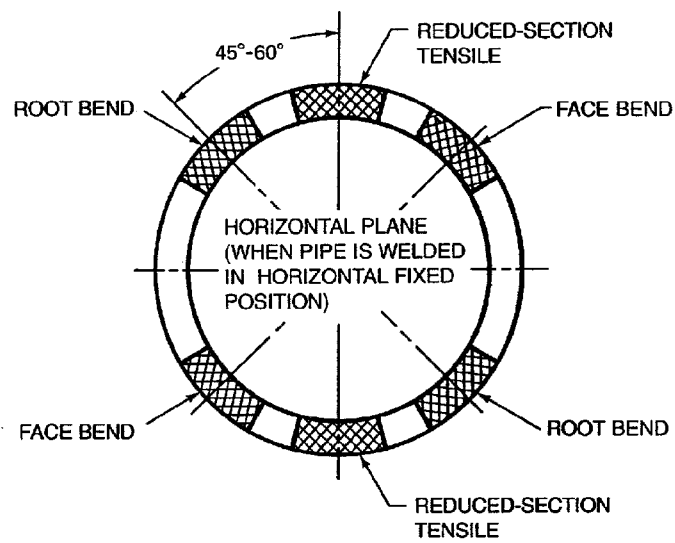
Notes:

- Four side bend tests may be substituted for the required face and root bend tests.
- See 5.18.2 for further limits on range of thickness qualified.

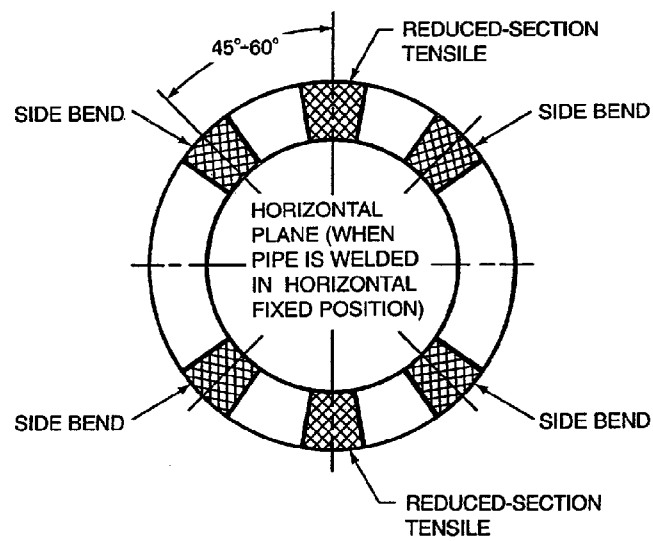


THE GROOVE CONFIGURATION SHOWN IS FOR ILLUSTRATION ONLY. THE GROOVE SHAPE USED SHALL CONFORM TO THAT BEING QUALIFIED.

Figure 11—Procedure Qualification

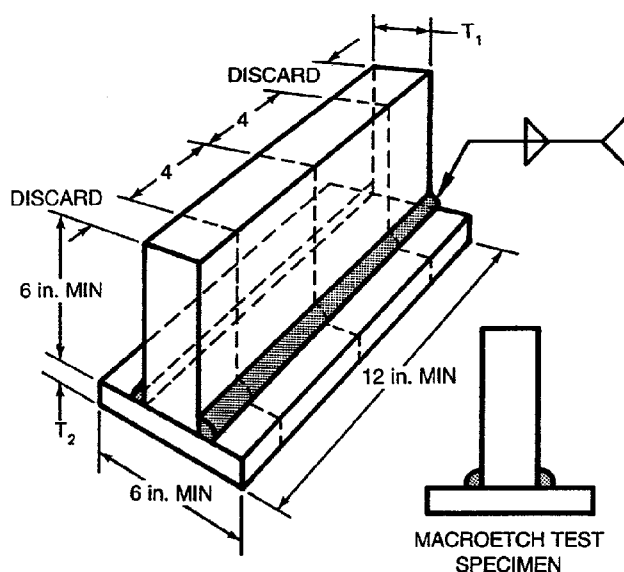


(D) PIPES—1/16 TO 3/4 in.



(E) PIPES—OVER 3/4 in. THICKNESS AND ALTERNATE FROM 3/8 in., BUT LESS THAN 3/4 in. THICKNESS

Figure 11 (Continued)—Procedure Qualification



Weld size		T ₁		T ₂	
in.	mm	in.	mm	in.	mm
3/16	4.8	1/2	12.7	3/16	4.8
1/4	6.4	3/4	19.0	1/4	6.4
5/16	8.0	1 min	25.4	5/16	8.0
3/8	9.5	1 min	25.4	3/8	9.5
1/2	12.7	1 min	25.4	1/2	12.7
5/8	16.0	1 min	25.4	5/8	16.0
3/4	19.0	1 min	25.4	3/4	19.0
<3/4	19.0	1 min	25.4	1	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 12—Fillet Weld Soundness Test for Procedure Qualification

5.10.4.4 Macroetch Examination—Procedure Specimens. One face of each cross section shall be smoothed and etched with a suitable etchant to give a clear definition of the weld metal and heat-affected zone (HAZ). Visual examination of the cross sections of the weld metal shall show complete fusion. The weld metal and HAZ shall be free of cracks. Minimum leg size shall meet the specified fillet weld size, in compliance with Figure 15.

5.11 Preparation of Test Joint

5.11.1 Base Metal and Filler Metal. The base metals and filler metals shall be one or more of those listed in the WPS. The dimensions of the test assembly shall be

sufficient to provide the required test specimens. The base metals may consist of either plate, pipe, or other product forms. Qualification in plate also qualifies for pipe welding and vice versa.

5.11.2 Type and Dimension of Groove Welds. The test joint shall be welded using a type of welding groove proposed in the WPS for use in construction. Except as otherwise provided in Table 6, the type and dimensions of the welding groove are not essential variables.

5.11.3 Corrosion-Resistant Overlay Cladding

5.11.3.1 Test Base Metal. The test base metal for production base metals greater than 1 in. (25 mm) thickness may be thinner than the base metal thickness used in production but shall not be less than 1 in. (25 mm). Qualification for production base metal less than 1 in. (25 mm) thickness shall be done on test base metal that is equal to or less than the thickness of the production base metal.

5.11.3.2 Examination. The weld overlay surface shall be examined by the liquid penetrant method (see Annex C).

Following the liquid penetrant examination, the weld overlay clad test plate shall be sectioned to make four guided side-bend test specimens, either two parallel and two perpendicular to the direction of welding, or four parallel to the direction of welding, or four perpendicular to the direction of welding.

5.11.3.3 Chemical Analysis. A chemical analysis shall be obtained from the test coupon at the minimum overlay thickness specified in the WPS. The chemical analysis of the sample, taken from the corrosion-resistant weld metal overlay clad specimen, shall be within the range of analysis given in the WPS.

5.11.4 Electron Beam Welding. For electron beam welding, the WPS qualification test joint shall be prepared with the joint geometry duplicating that to be used in production. If the production weld is to include a lapover (completing the weld by rewelding over the starting area of the weld, as for a girth weld) such lapover shall be included in the WPS qualification test joint.

Part II Performance Qualification

5.12 Tests

5.12.1 Purpose of Tests. The performance qualification tests are intended to determine the ability of welders and welding operators to make sound welds.

5.12.2 Qualification Tests. Each manufacturer or contractor shall qualify each welder or welding operator for each welding process to be used by that individual in production welding. The performance qualification test shall be welded in conformance to one of the qualified welding procedure specifications, except for departures that are allowed as given below. When performance qualification is done in conformance to a WPS that requires postweld heat treatments, the postweld heat treatment may be omitted. Changes beyond which requalification is required are given in 5.13.6 for welding positions, in 5.14.2 for welder testing, and in 5.14.3 for welding operator testing. Retest and renewal requirements for qualification are given in 5.16 and 5.17.

The welder or welding operator who prepares the WPS qualification test coupons meeting the requirements of section 5—Part I is also qualified within the limits of the performance qualifications, listed in 5.14.2 for welders and in 5.14.3 for welding operators. The

welder is qualified for the welding positions tested in the procedure qualification in conformance to 5.13.6.

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 or welding operator does not have the required skill to produce satisfactory results.

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

5.12.4 Performance Qualification Test Record. The performance qualification test records shall list, in detail, the base metal M-numbers used, the filler metals used, and any other variables described in Table 3. Copies of the test record shall be available for reference by the welding inspector or other designated representatives of

Table 3
Essential Variables, Welder Performance Qualification

Variables	Para.	Subject	Processes					
			SMAW	SAW	GMAW	FCAW	GTAW	PAW
Joints								
5.18.1	(3)	– Backing in CP Joints	X	X	X	X	X	X
Filler Metals								
5.18.3	(24)	Δ F-number	X	X	X	X	X	
	(25)	Qual. F-2X Al.			X		X	X
	(26)	± Preplaced Inserts					X	X
Position								
5.18.4	(1)	+ Position	X	X	X	X	X	X
Gas								
5.18.7	(7)	– Gas Backing					X	X
Electrical Characteristics								
5.18.8	(2)	Δ Mode of Transfer			X			
Technique								
5.18.9	(11)	Δ to, or ↓ Vice Versa	X		X	X		

Note: If an "X" is displayed under the process, it establishes a controlling restriction on the welder's qualification. The variables are shown in Section 5.18.

Legend

Δ Change
+ Addition
– Deletion
> Increase
< Decrease
t Thickness
↑ Uphill
↓ Downhill

the buyer or seller. Recommended forms are shown in Annex A.

5.13 Type of Test Required

5.13.1 Mechanical Test. The type and number of test specimens required for mechanical testing shall be in conformance to Table 4.

All mechanical tests shall meet the requirements prescribed in 5.7.3, 5.8.3, 5.10.4.4, or 5.13.5.1, as applicable.

5.13.2 Radiographic Examination. When the welder or welding operator is qualified by radiographic examination, as permitted in 5.14.2 for welders and 5.14.3 for welding operators, the minimum length for welds to be examined shall be 6 in. (152 mm) and shall include the entire weld circumference for pipes; for small diameter pipe, multiple specimens may be required, but the number need not exceed four, consecutively made, test welds. The radiographic technique and acceptance criteria shall be in conformance to Annex C.

5.13.3 Test Welds in Pipe. For welds made in pipe positions, the test specimens shall be removed as shown in Figures 13(A) and 13(B).

5.13.4 Test Welds in Plate. For test welds made in any plate position, 1 in. (25 mm) from each end, shall be discarded from each of the test plates [see Figures 13(C) and 13(D)].

5.13.5 Test Welds—Fillets. For test welds made for fillet weld qualifications, the specimens shall be removed as shown in Figure 14.

5.13.5.1 Bend-Break Test—Fillet Welds. The fillet weld bend-break specimen, shall be bent with the root in tension until the specimen either fractures, or until it is bent flat upon itself. The specimen shall pass if it does not fracture, or if the fillet fractures, the fractured surface shall show complete fusion to the joint root and shall exhibit no inclusion or porosity larger than 3/32 in. (2.4 mm) in its greatest dimension.

5.13.6 Limits of Qualified Welding Positions. The limits of welder and welding operator qualification with regard to welding positions tested shall be in conformance to Table 5.

5.14 Essential Variables for Qualifying Welders and Welding Operators

5.14.1 General. A welder shall be requalified whenever a change is made in one or more of the essential variables listed for each welding process shown in Table 3.

Where a welding procedure consists of more than one process, the welder may be qualified by making tests with each individual welding process or with a combination of welding processes in a single test plate or pipe.

The limits of thickness for which a welder will be qualified are dependent upon the thickness of the weld made by the welder with each process. This thickness shall be considered the test plate or pipe thickness as given in Table 4.

5.14.2 Welder Testing. Each welder who welds under the requirements of this specification shall have passed the mechanical tests prescribed in Table 4 for performance qualifications. Alternatively, welders making a groove weld in M-1 through M-11, M-3X, and M-4X base metals with the shielded metal arc welding (SMAW) process, flux cored arc welding (FCAW) process, submerged arc welding (SAW) process, or the gas tungsten arc welding (GTAW) process (or a combination of these processes) may be qualified by radiographic examination. The welder who makes groove welds in M-2X and M-5X metals with the GTAW process may, alternatively, be qualified by radiographic examination. The radiographic examination shall be in conformance to Annex C of this specification. A welder qualified to weld in conformance to one qualified WPS is also qualified to weld in conformance to other qualified WPS, using the same welding process, within the limits of the essential variables of Table 3.

5.14.3 Welding Operator Testing. Each welding operator who welds under the requirements of this specification shall be qualified for each welding process used. A welding operator qualified to weld in conformance to one qualified WPS is also qualified to weld in conformance to other qualified WPS, using the same welding process, within the limits of the essential variables of Table 3.

The welding operator shall be requalified when a change is made from one welding process to any other welding process. Welding operators who weld acceptable WPS qualification test assemblies are also qualified for the welding process used.

5.14.3.1 Examination. Welds made in test assemblies may be examined by radiography or by bend tests. Alternatively, a 3 ft (0.9 m) length of the first production weld made by the welding operator in conformance to a qualified WPS may be examined by radiography.

(1) Reference Annex C for radiographic technique and acceptance criteria.

(2) When bend tests are employed for performance qualifications of a welding operator, they shall meet the requirements of 5.8.3 as required by Table 4.

5.14.3.2 Failure to Meet Radiographic Standards. If a portion of a production weld, for which this specification does not require radiography, is selected for testing welding operator performance and does not meet the radiographic standards, the welding operator has

Table 4
Performance Qualification Specimens

Plate Transverse Bend Tests							
Type of Joint	Thickness, t, of Test Plate as Welded, in.	Range of Thickness of Materials Qualified by Test Plate, in.		Type and Number of Tests Required (Guided Bend Tests)			T-Joint Macro
		Min.	Max.	Side Bend	Face Bend	Root Bend	
Groove	1/16 to 3/8 incl.	1/16 in.	2t		1	1	
Groove	Over 3/8 but less than 3/4	3/16 in.	2t		1	1	
Groove	Over 3/8 but less than 3/4	3/16 in.	2t	Note 1			
Groove	3/4 and over	3/16 in.	Max. to be welded	2			
Fillet	All thicknesses, sizes, and diameters						1 1

Note:

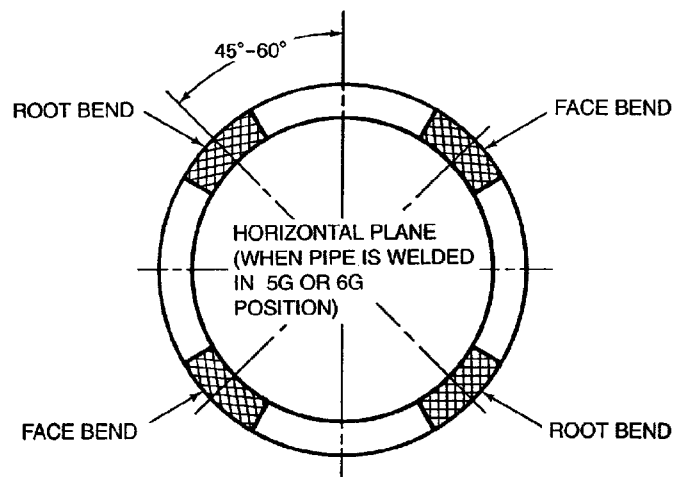
1. Side bend tests may be substituted for the required face and root bend tests for thicknesses from 3/8 in., but less than 3/4 in.

Plate Longitudinal Bend Tests					
Type of Joint	Thickness, t, of Test Plate as Welded, in.	Range of Thickness of Materials Qualified by Test Plate, in.		Type and Number of Tests Required (Guided Bend Tests)	
		Min.	Max.	Face Bend	Root Bend
Groove	1/16 to 3/8 incl.	1/16 in.	2t	1	1
Groove	Over 3/8	3/16 in.	2t	1	1

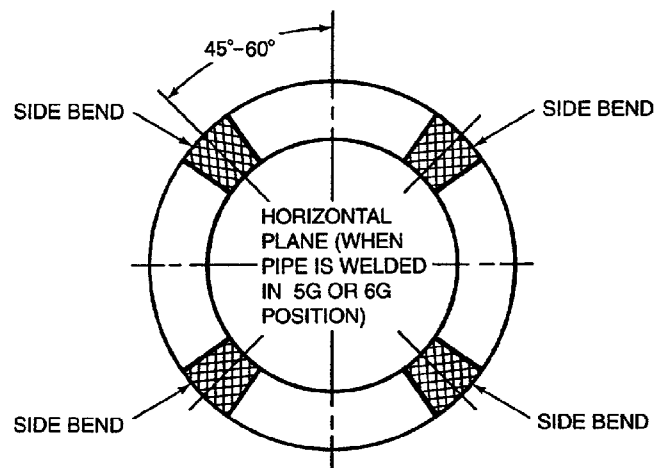
Pipe Groove Weld Bend Tests						
Nominal Pipe Size of Sample Weld, in.	Outside Diam. Qualified, in. (No Maximum)	Pipe or Tube Wall Thickness Range Qualified, in.		Type and Number of Tests Required (Guided Bend Tests)		
		Min.	Max.	Side Bend	Face Bend	Root Bend
Less than 3/4	Min. of lot less than size welded	1/16 in.	2t		2	2
3/4 through 2	Over 1	1/16 in.	2t	Note 1	2	2
Over 2 t = 1/16 to less than 3/4	2-7/8 and over	1/16 in.	2t	Note 1	2	2
Over 2 t = 3/4 and over	2-7/8 and over Note 2	3/16 in.	Max. to be welded	4		

Notes:

- Side bend tests may be substituted for the required face and root bend tests for thickness from 3/8 in., but less than 3/4 in.
- 2-7/8 in. O.D. is considered the equivalent of 2-1/2 in. nominal pipe size.

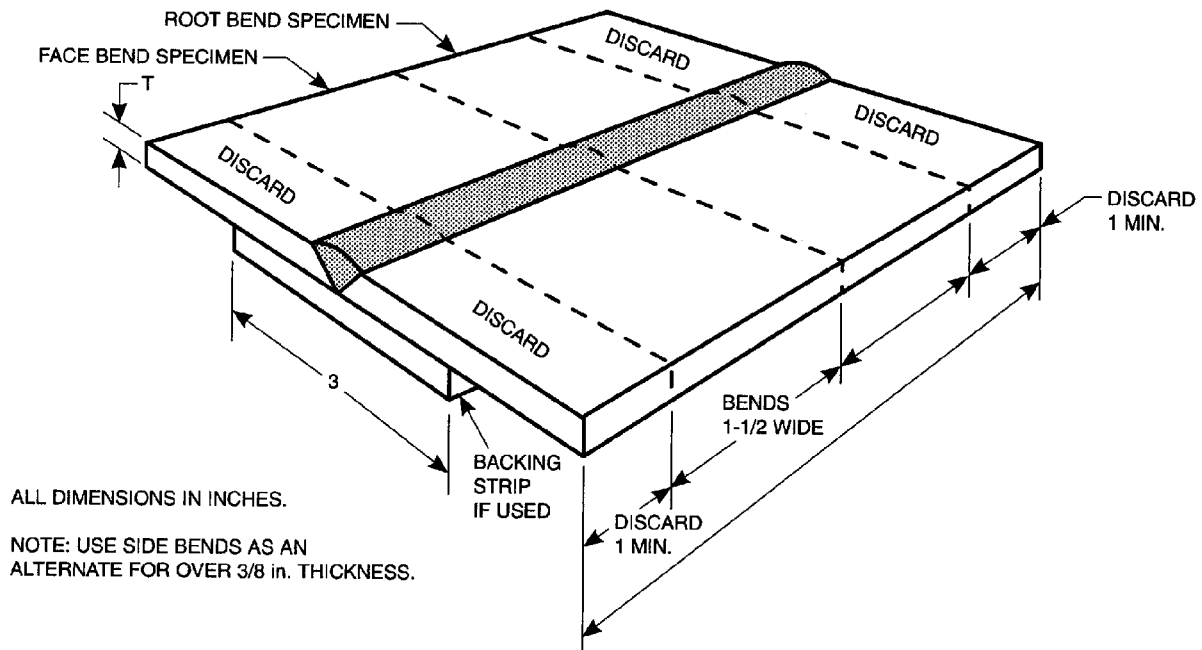


(A) PIPES—1/16 in., UP TO 3/4 in. THICKNESS

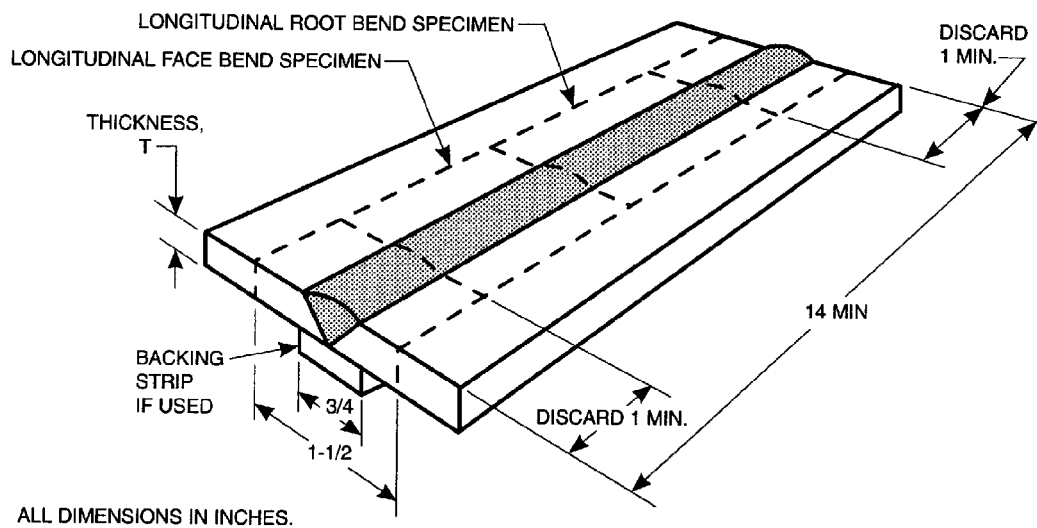


(B) PIPES—3/4 in. AND OVER THICKNESS, AND ALTERNATE FROM 3/8 in., BUT LESS THAN 3/4 in. THICKNESS

Figure 13—Performance Qualification



(C) PLATES—TRANSVERSE



(D) PLATES—LONGITUDINAL

Figure 13 (Continued)—Performance Qualification

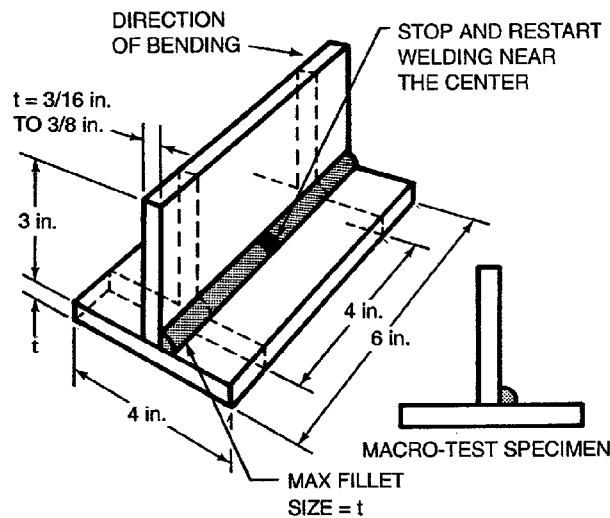


Figure 14—Fillet Welds for Performance Qualification

failed the test. In this event, the entire production weld made by this welding operator shall be radiographed completely and repaired by a qualified welder or welding operator.

5.15 Qualification Test Joints

5.15.1 Test Assemblies. The test assemblies may be plate, pipe, or other product forms (see Table 5).

5.15.2 Pipe Joint Size. Welders and welding operators qualifying using pipe shall use a pipe of the diameter and thickness that meets the requirements of the production work they are to be welding, as identified by the requirements of Table 4.

5.15.3 Plate Joint Size. Welders and welding operators qualifying using plate shall use a plate 6 in. (152 mm) long. The thickness of the plate used shall meet the production requirements for the work they are to be welding, as identified by the requirements of Table 4.

5.15.4 Carbon and Alloy Steel. When a welder is to be qualified to weld on carbon or alloy steels, except austenitic stainless steels of M-8 (see 5.15.5), the test plates or pipes shall be base metal of the M-number or M-numbers to be joined in production welding, except that carbon steel M-1 base metals may be used for the qualification tests with the following limitations:

(1) The total alloy content of the base metal, for which carbon-steel base metal is substituted, shall not exceed a nominal six percent (the 5 Cr-1/2 Mo alloy

steels are included within this nominal six percent). The total alloy content of the weld metal used shall not exceed this nominal six percent.

(2) When alloy steel filler metals, as permitted in (1), are used on carbon-steel plate or pipe, the test specimens are to be preheated and postheated in conformance to the WPS, using the type of filler metal involved, except as permitted in 5.12.2.

(3) Welders who qualify on carbon-steel test plates or pipe using any F-number electrodes (within the nominal six percent total alloy content limitation), up to and including F-4, are also qualified to weld using electrodes of the same or lower F-number.

(4) When a welder is to be qualified to weld on alloy-steel base metal using the F-41 through F-45 filler metals of Table 7, carbon-steel plates or pipes may be used in the performance qualification tests.

5.15.5 Austenitic Stainless Steel. When a welder is to be qualified to weld on austenitic stainless steel M-8 base metal, carbon-steel plates or pipes of M-1 may be used for the performance test and welded with austenitic filler metal of weld metal analysis A-8 or A-9 of Table 8.

When a welder is to be qualified for the use of austenitic filler metal of weld metal analysis A-8 or A-9 to join M-1, M-3, M-4, and M-5 or M-8 base metals to themselves or to each other, carbon-steel plate or pipe may be used for the performance qualification test. A performance qualification test made using A-8 or A-9 austenitic filler metal with one or a combination of M-1, M-3,

Table 5
Welder Qualification—Type and Position Limitations

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

Notes:

1. Not applicable for welding operator qualification.
2. Welding operators qualified to weld pipe or tubing over 24 in. (600 mm) in diameter or the test positions indicated.
3. Not applicable for fillet welds between parts having a dihedral angle of 75 degrees or less.
4. Qualifies for all butt groove welds for T-, Y-, and K- connections.

*Positions for welding: F=flat, H=horizontal, V=vertical, OH=overhead.

**See Figs. 2, 3, and 5.

M-4, M-5, or M-8 base metals will qualify for all combinations of these base metals using A-8 or A-9 filler metals.

5.15.6 Aluminum Alloy. When a welder is to be qualified to weld on aluminum alloy base metals, the test specimens for the welder performance test may be of the M-21 through M-25 aluminum base alloys.

5.15.7 Nickel Alloy. When a welder is to be qualified to weld on M-41 through M-45 base metals, the test specimens may be of the alloy base metal, or carbon-steel plates or pipes may be used in the performance qualification test, using the filler metal of the qualified WPS.

5.15.8 Titanium. When a welder is to be qualified to weld titanium base metals of M-51 and M-52, the test plates or pipes shall be of the base metal in the qualified WPS, except that qualification with M-52 shall qualify for M-51, but not vice versa.

5.15.9 Copper. When a welder is to be qualified to weld copper or copper-base alloys of M-31 through

M-35, the test plates or pipes shall be of the M-Number or M-Numbers to be employed in production welding in conformance to the qualified WPS.

5.15.10 Corrosion-Resistant Weld Overlay Cladding. Welders and welding operators who have been qualified for plate or pipe groove welds using the applicable F-number filler metal and applicable welding process to be used for the production cladding shall be qualified to perform the production work.

5.16 Retests. A welder or welding operator who fails to meet the requirements of the test may be retested under the following conditions.

5.16.1 Where immediate retesting is made, the welder or welding operator must make two consecutive test welds for each position failed, and each shall pass the test that originally failed.

5.16.2 When the welder or welding operator has had further training and practice, a complete retest shall be made for each position failed. Each retest must be tested and meet the original test requirement.

5.17 Renewal of Qualification. Renewal of performance qualification is required when a welder or welding operator has not used the specific process (i.e., SMAW, GMAW, SAW, etc.) for a period of 6 months or more, except when employed on some other welding process, or when there is a specific reason to question the ability to make welds that meet the specification. Renewal of qualification for a specific welding process may be made with that process by making only one test joint (plate or pipe) with all of the essential variables used on any one of the welder's or welding operator's qualifications for all conditions previously qualified with the specific welding process.

Part III **Welding Process Variables**

5.18 General. The welding process variables described in the following paragraphs are either essential to the PQR, supplementary to the PQR, or nonessential to the PQR, but are required to be stated in the WPS. The essential and nonessential variables for each welding process are tabulated in Table 6 (see 5.10.2).

5.18.1 Joints. When listed in Table 6 as an essential variable for the welding process used, the following changes require requalification:

(1) A change in the dimension of the welding groove exceeding the following:

(a) Root opening, with backing, +1/4 in., -1/16 in. (+6 mm, -1.6 mm).

(b) Root face, +20 percent when back gouging is not used.

(c) Groove angle, +20 degrees, -5 degrees.

(d) Groove radius, +1/8 in., -0 (+3.2 mm, -0).

(2) The addition or deletion of backing.

(3) The deletion of backing in complete joint penetration welds, welded from one side.

(4) The addition of backing and its nominal composition.

(5) An increase in the fit-up gap beyond that initially qualified.

5.18.2 Base Metals When listed in Table 6 as an essential variable for the welding process used, the following changes require requalification:

(1) Where the measurement of penetration can be made by visual or mechanical means, requalification is required where the base-metal thickness differs by 20 percent from that of the test-plate thickness when the test plate thickness is 1 in. (25 mm) and under, and 10 percent when the test-plate thickness is over 1 in. (25 mm). Where the measurement of penetration cannot be made, requalification is required where the base-metal thick-

ness differs by 10 percent from that of the test plate when the test plate thickness is 1 in. (25 mm) and under, and 5 percent when the test plate thickness is over 1 in. (25 mm).

(2) Welding procedure qualification for base metals that have specified impact test requirements shall be made using a base metal of the same type or grade or another base metal listed in the same group (see Table 1) as the base metal to be used in production welding. When joints are to be made between base metals from two different groups, a procedure qualification must be made for the applicable combination of base metals, even though procedure qualification tests have been made for each of the two base metals welded to themselves. If the procedure qualification test for each base metal has used the same electrode or weld metal to qualify the two base metals separately, it will not be necessary to make weld impact tests to qualify the two together.

When a procedure has been previously qualified to satisfy all requirements other than notch toughness, it is then necessary only to prepare an additional test plate for that requirement. The test plates need to be long enough to provide the necessary notch toughness specimens. If a previously qualified weld procedure has satisfactory notch toughness values in the weld metal, then it is necessary only to test notch toughness specimens from the heat-affected zone (HAZ).

(3) For thicknesses less than 5/8 in. (16 mm), the thickness of the test plate or pipe is the maximum thickness qualified.

(4) A change in base-metal thickness beyond the range qualified in Table 2.

(5) For single or multiple-pass welding in which the depth of any pass is greater than 1/2 in. (13 mm), an increase in thickness beyond 1.1 times that of the qualification test plate or pipe.

(6) For the short-circuiting transfer mode of the GMAW process, when the qualification test coupon thickness is less than 1/2 in. (13 mm), an increase in thickness beyond 1.1 times that of the qualification test coupon. For thickness of 1/2 in. (13 mm) and greater, use Table 2.

(7) A change from a base metal listed under one M-number in section 2 to a base metal listed under another M-number. When joints are made between two base metals that have different M-numbers, requalification is required even though the two base metals have been independently qualified using the same procedure. However, for base metals of M-numbers 1, 3, 4, and 5 (of three percent maximum nominal chromium content), a procedure qualification test with one M-number metal shall qualify also for that M-number metal welded to each of the lower M-number metals, but not vice versa.

(8) A change from M-9A to M-9B, but not vice versa.

Table 6
Welding Process Variables

Variables Para.		
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(continued)

Table 6 (Continued)

Variables	Para.	Subject	Filler Metal (Continued)																	
			SMAW		SAW		FCAW		GMAW		GTAW		PAW		ESW		EGW		EBW	
			A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C
Filler Metal (Continued)																				
	(20)	±	Supplemental Filler Metal	X		X		X		X		X		X						X
	(21)	±	Supplemental Powder Filler Metal			X														
	(22)	>	Supplemental Powder Filler Metal			X														
	(23)	Δ	Chemistry by > or < Supp. Powder			X														
Positions																				
5.18.4	(1)	+	Position	X		X		X		X		X		X						
	(2)	Δ	Position to Vertical	X				X				X								
Preheat																				
5.18.5	(1)	<	100°F	X		X		X		X		X		X		X		X		
	(2)	Δ	Temperature			X		X				X								
	(3)	>	Maximum Interpass Temperature			X		X		X		X		X						
Postweld Heat Treatment																				
5.18.6	(1)	Δ	PWHT	X		X		X		X		X		X		X		X		
	(2)	±	Solution PWHT for M-8 Base Metal	X		X		X		X		X		X		X		X		
Gas																				
5.18.7	(1)	±	Trailing or Δ Chemical Composition											X						
	(2)	Δ	Gas or Gas Mixture					X		X		X				X				
	(3)	Δ	Flow Rate					X		X		X				X				
	(4)	Δ	Chemical Composition and Flow Rate									X								
	(5)	+	Backing Gas or Δ Rate or Composition							X		X								
	(6)	Δ	Environmental																	X
Electrical Characteristics																				
5.18.8	(1)	Δ	Current Type (I), Polarity, > Heat input	X		X		X		X		X		X		X				
	(2)	Δ	Mode of Metal Transfer					X		X				X						
	(3)	±	Pulsed Current																	
	(4)	±	15% Current or Voltage																	
	(5)	Δ	Beam Parameters (EBW)												X				X	
	(6)	Δ	Pulsing Frequency																X	
	(7)	Δ	Current Type or Polarity, or ± I or V		X		X		X		X		X		X		X		X	
Technique																				
5.18.9	(1)	Δ	Bead Technique		X		X		X		X		X		X					
	(2)	Δ	Method of Back Gouging		X		X		X		X		X		X					
	(3)	Δ	Oscillation		X		X		X		X		X		X		X		X	
	(4)	Δ	Multiple pass to single pass per side		X		X		X		X		X		X		X			
	(5)	Δ	Single to Multiple electrode, or Vice Versa				X		X		X		X		X		X		X	

(continued)

Table 6 (Continued)

Variables	Para.	Subject	Technique (Continued)																										
			SMAW			SAW			FCAW			GMAW			GTAW			PAW			ESW			EGW			EBW		
			A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C
(6)	-	Chamber																											
(7)	Δ	Melt-in to Keyhole or Vice Versa																											
(8)	±	Retainers																											
(9)	Δ	Gun Angle																											
(10)	Δ	Electrode Spacing																											
(11)	↑	to J or Vice Versa																											
(12)	Δ	Type or Model of Equipment																											
(13)	>	Absolute Pressure (Vacuum)																											
(14)	Δ	Filament Configuration																											
(15)	+	Wash Pass																											
(16)	Δ	1 to 2 Sides or Vice Versa																											
(17)	<	Travel Speed over 10%																											

Notes:

A. The symbol A when marked with an "X" signifies that the given variable is essential and must be documented in both the PQR and WPS. If this variable is changed from that qualified (i.e., documented on the PQR), the welding procedure specification must be requalified.

B. The symbol B when marked with an "X" signifies that the given variable is essential only when fracture toughness is a requirement. When fracture toughness is a requirement, these variables are the same as those in Note A.

C. The symbol C when marked with an "X" signifies that the given variable is nonessential and may be changed on the WPS without requalification, but the WPS must be revised.

LEGEND:

Δ Change
+ Addition
- Deletion
> Increase
< Decrease
↑ Uphill
↓ Downhill

SMAW Shielded Metal Arc Welding
SAW Submerged Arc Welding
FCAW Flux Cored Arc Welding
GMAW Gas Metal Arc Welding
GTAW Gas Tungsten Arc Welding
PAW Plasma Arc Welding
ESW Electroslag Welding
EGW Electrogas Welding
EBW Electron Beam Welding

5.18.3 Filler Metals and Fluxes When listed in Table 6 as an essential variable for the welding process used, the following changes require requalification:

(1) A change in the cross-sectional area of the filler metal added (excluding buttering) or in the wire feed speed greater than $\pm$ ten percent beyond that qualified.

(2) A decrease in the thickness or change in nominal specified chemical analysis of weld-metal buttering beyond that qualified. (Buttering or surfacing is the deposition of weld metal on one or both faces of the joint prior to preparation of the joint for final welding.)

(3) A change in the size of the filler metal.

(4) A change from one F-number in Table 7 to any other F-number or to any other filler metal not listed in Table 7.

(5) A change in the chemical composition of the weld deposit from one A-number to any other A-number in Table 8 or to a deposit analysis not listed in Table 8, except that qualification with A-1 shall qualify for A-2, and vice versa.

(6) An increase of more than one size of the electrode or electrodes specified in the WPS.

(7) Addition, deletion, or a change in nominal amount or composition of supplementary deoxidation material (in addition to filler metal) beyond that qualified. (Such supplementary material may be required for weld metal deoxidation for some metals being welded.)

(8) A change from one flux classification listed in a specification to any other flux classification. In addition, a change in either the electrode or the flux when not classified in a specification. The presence or absence of 0.5 percent molybdenum in the electrode and flux combination shall not require requalification.

(9) Where the alloy content of the weld metal is largely dependent upon the composition of the flux used, any change in any part of the welding procedure that would result in the important alloying elements in the weld metal being outside of the specification range of chemistry given in the welding procedure specification. If there is evidence that the production welds are not being made in conformance to the procedure specification, the purchaser's inspector may require that a check be made on the chemical composition of the weld metal. Such a check shall preferably be made on a production weld.

(10) A change in the size of flux particles.

(11) A change in the AWS filler metal classification or a change in a weld metal or filler metal composition not covered by AWS specifications.

(12) The addition or deletion of consumable inserts. When added, a change in the consumable insert composition beyond that specified in the qualified WPS.

(13) The addition or deletion of filler metal.

(14) A change in the type of flux or composition of the flux.

(15) A change from wire to strip electrodes, and vice versa.

(16) A change from consumable guide to nonconsumable guide, and vice versa.

(17) Any change in the method by which filler metal is added, such as preplaced shim, top strip, wire, wire feed, or prior weld metal buttering of one or both joint faces.

(18) For filler metal additions, any change from the nominal specified analysis of the filler metal qualified.

(19) A change from gas shielded flux cored wire to self-shielded flux cored wire, and vice versa.

(20) The addition or deletion of supplemental filler metal.

(21) The addition or deletion of supplementary powdered filler metal.

(22) An increase in the amount of supplementary powdered filler metal.

(23) Where the alloy content of the weld metal is largely dependent upon the composition of the supplementary powdered filler metal, any change in any part of the welding procedure that would result in the important alloying elements in the weld metal being outside of the specification range of chemistry given in the welding procedure specification.

(24) A change from one F-number in Table 7 to any other F-number, or to any other filler metal not listed, except qualification under any F-number up to and including F-4, with a total nominal alloy content not exceeding 6 percent, shall qualify a welder for all lower F-numbers.

(25) Qualification with an F-2X aluminum filler metal shall qualify to weld with any other F-2X filler metal.

(26) The addition or deletion of preplaced consumable inserts. Qualification in a single-welded groove joint, with or without consumable inserts, qualifies for fillet welds and single-welded groove joints with backing or double-welded groove joints.

5.18.4 Welding Positions When listed in Table 6 as an essential variable for the welding process used, the following changes require requalification:

(1) The addition of welding positions other than those already qualified (see 5.4).

(2) A change from any position to the vertical position with uphill progression (see 5.4). Vertical-up qualifies for all positions.

5.18.5 Preheat When listed in Table 6 as an essential variable for the welding process used, the following changes require requalification:

(1) A decrease of 100°F (55°C) or more in the minimum specified preheating or interpass temperature from that qualified.

Table 7
F-Numbers: Grouping of Electrodes and Welding Rods for Qualification

F-Number	AWS Specification Number	AWS Classification Number
Steel and Steel Alloys		
1	A5.1 and A5.5	EXX20, EXX24, EXX27, EXX28, EXX20-X, EXX27-X
2	A5.1 and A5.5	EXX12, EXX13, EXX14, EXX13-X
3	A5.1 and A5.5	EXX10, EXX11, EXX10-X, EXX11-X
4	A5.1 and A5.5	EXX15, EXX16, EXX18, EXX15-X, EXX16-X, EXX18-X
4	A5.4 Nominal Total Alloy 6% or less	EXXX-15, EXXX-16
4	A5.4 Nominal Total Alloy More Than 6%	EXXX-15, EXXX-16
5	A5.4 Cr-Ni Electrode	EXXX-15, EXXX-16
6	A5.17 and A5.23	FXX-XXXX (FXX-EXXX), FXX-EXXX-X, FXX-ECXXX-X, FXX-EXXX-XN, FXX-ECXXX-XN
6	A5.18 and A5.28	ERXXS-X, ERXXX-X, E-XXX-X
6	A5.9	ERXX
6	A5.20 and A5.29	EXXT-X
6	A5.22	EXXT-X
6	A5.25	FESXX-EXXX-EW, FESXX-EXXX
6	A5.26	EGXXTXX, EGXXSXXX
Aluminum and Aluminum-Base Alloys		
20	A5.3	E1100, E3003
21	A5.10	ER1100, ER1260
22	A5.10	ER5554, ER356, ER5556, ER5183, ER5654
23	A5.3	E4043
23	A5.10	ER4043, ER4047
24	A5.10	R355.0, R356.0
Copper and Copper-Base Alloys		
31	A5.6, A5.7, A5.27	ECu, ERCu
32	A5.6, A5.7, A5.27	ECuSi-A, ERCuSi
33	A5.6 and A5.7	ECuSn-A, ECuSn-C, ERCuSn-A
36	A5.6 and A5.7	ECuAl-A2, ECuAl-B, ERCuAl-A1, ERCuAl-A2, ERCuAl-A3
37	A5.6 and A5.7	ECuNiAl, ECuMnNiAl, ERCuNiAl, ERCuMnNiAl
Nickel and Nickel-Base Alloys		
41	A5.11 and A5.14	E Ni-1, ER Ni-1
42	A5.11 and A5.14	E NiCu-7, ER NiCu-7
43	A5.11	E NiCrFe-1,2,3,4, E NiCrMo-2,3,6
43	A5.14	ER NiCr-3, ER NiCrFe-5,6, ER NiCrMo-2,3
44	A5.11	E NiMo-1,3,7, ER NiCrMo-4,5,7
44	A5.14	ER NiCrMo-1,2,3,7, ER NiCrMo-4,5,7, ER NiCrMo-7 (Alloy C4)
45	A5.11	E NiCrMo-1,9
45	A5.14	ER NiCrMo-1,8,9, ER NiFeCr-1
Titanium and Titanium Alloys		
51	A5.16	ERTi-1, ERTi-2, ERTi-3, ERTi-4, ERTi-0.2Pd
Zirconium and Zirconium Alloys		
61	A5.24	ER Zr1, ER Zr2, ER Zr3, ER Zr4
Magnesium Alloys		
71	A5.24	ER AZ61A, ER AZ101A, ER AZ92A, ER AZ33A
Hardfacing Weld Metal Overlay		
81	A5.13	RXXX-X, EXXX-X
82	A5.21	RXXX-X

Table 8
A-Numbers: Classification of Weld Metal Analysis for Procedure Qualification

A-No.	Types of Weld Deposit	Analysis*					
		C %	Cr %	Mo %	Ni %	Mn %%	Si %%
1	Mild Steel	0.15				1.60	1.00
2	Carbon-molybdenum	0.15	0.50	0.40-0.65		1.60	1.00
3	Cr (0.4 to 2%) - Mo	0.15	0.40-2.00	0.40-0.65		1.60	1.00
4	Cr (2 to 6%) - Mo	0.15	2.00-6.00	0.40-1.50		1.60	2.00
5	Cr (6 to 10.5) Mo	0.15	6.00-10.50	0.40-1.50		1.20	2.00
6	Chromium-martensitic	0.15	11.00-15.00	0.70		2.00	1.00
7	Chromium-ferritic	0.15	11.00-30.00	1.00		1.00	3.00
8	Chromium-nickel	0.15	14.50-30.00	4.00	7.50-15.00	2.50	1.00
9	Chromium-nickel	0.30	25.00-30.00	4.00	15.00-37.00	2.50	1.00
10	Nickel to 4%	0.15		0.55	0.80-4.00	1.70	1.00
11	Manganese-molybdenum	0.17		0.25-0.75	0.85	1.25-2.25	1.00
12	Nickel-chromium-molybdenum	0.15	1.50	0.25-0.80	1.25-2.80	0.75-2.25	1.00

*Single values shown are maximum.

(2) A change in the maintenance of temperature upon completion of welding prior to any required postweld heat treatment.

(3) An increase in the maximum preheat or interpass temperature from that qualified.

5.18.6 Postweld Heat Treatment When listed in Table 6 as an essential variable for the welding process used, the following changes require requalification:

(1) A change in the specified postweld heat treatment temperature range requires WPS qualification for each of the following conditions:

(a) Where no postweld heat treatment is used.

(b) Where postweld heat treatment is used (which is defined as below the lower transformation temperature range).

(c) Where a heat treatment of the weldment is applied above the upper transformation temperature range without additional postweld heat treatment.

(d) Where a heat treatment of the weldment is applied above the upper transformation temperature range with additional postweld heat treatment.

(2) For M-8 base metal, the addition or deletion of a solution or stabilizing heat treatment.

5.18.7 Gas When listed in Table 6 as an essential variable for the welding process used, the following changes require requalification:

(1) The addition or deletion of trailing shielding gas or a change in the composition, or both.

(2) A change from a single gas to any other single gas or a mixture of gases, or a change in specified percentage

composition of a gas mixture, or deletion of shielding gas.

(3) An increase or decrease of ten percent or more in the rate of flow of the shielding gas or mixture. The rate of shielding gas flow specified in the WPS qualification may not be satisfactory in all applications, unless the welding area on the weldment is properly and adequately protected from atmospheric disturbances.

(4) A change in composition and flow rates of orifice gas or shielding gas.

(5) The addition or deletion of gas backing, or a change of the gas backing flow rate or composition.

(6) Any change of environment such as from a vacuum to an inert gas, or vice versa.

5.18.8 Electrical Characteristics When listed in Table 6 as an essential variable for the welding process used, the following changes require requalification:

(1) A change in the type of current or polarity or an increase in heat input.

(2) A change from spray transfer, globular transfer, or pulsed spray welding to short circuiting transfer, or vice versa.

(3) The addition or deletion of pulsed dc current.

(4) A change of $\pm$ fifteen percent from the amperage or voltage ranges qualified.

(5) A change in the beam current of more than $\pm$ five percent, or voltage of more than $\pm$ two percent, or beam focus current of more than $\pm$ five percent, or gun-to-work distance of more than $\pm$ five percent, or a change in oscillation length or width of more than $\pm$ twenty percent from those values previously qualified.

(6) Any change in the beam pulsing frequency duration from that qualified.

(7) A change in the type of current or polarity, or a change in the range of amperage or voltage (increase or decrease).

5.18.9 Technique When listed in Table 6 as an essential variable for the welding process used, the following changes require requalification:

(1) A change from the stringer bead technique to the weave bead technique, or vice versa.

(2) A change in the method of back gouging.

(3) A change in the width, frequency, or dwell time of oscillation.

(4) A change from multiple pass per side to single pass per side.

(5) A change from single electrode to multiple electrodes, or vice versa.

(6) A change from closed chamber to out-of-chamber conventional torch welding in M-5X metals, but not vice versa.

(7) A change from the melt-in technique to the key-hole technique of welding, or vice versa, or the inclusion of both techniques, though each has been individually qualified.

(8) The addition or deletion of nonmetallic retainers or nonfusing metal retainers.

(9) A change in the gun angle (axis of the beam).

(10) A change in the electrode spacing.

(11) A change from upward to downward, or from downward to upward, in the progression specified for any pass of a vertical weld, except that the cover or wash pass may be up or down. The root pass may also be run either up or down when the root pass is removed to sound weld metal in the preparation for welding the second side.

(12) A change in the type or model of the welding equipment.

(13) An increase in the absolute pressure of the vacuum welding environment beyond that qualified.

(14) Any change in filament type, size, or shape.

(15) The addition of a wash pass.

(16) A change of welding from one side to welding from both sides, or vice versa.

(17) For ferritic steels, a decrease of more than ten percent from the travel speed range in the qualified WPS.

5.19 Special Processes

5.19.1 Corrosion-Resistant Weld Metal Overlay. Welding procedure specifications (WPS) qualified for corrosion-resistant overlay welding in conformance to 5.11.3 shall be required to identify the essential variables listed in this section. Any change in the qualified essential variables shall require requalification.

5.19.2 Essential Variables—All Welding Processes.

For all welding processes, the WPS shall be set up as a new WPS and shall be completely requalified for any of the following changes:

(1) A change from one welding process to any other welding process, or combination of welding processes.

(2) A change from the base metal, listed under one M-number in Table 1, to a metal listed under another M-number, or to any other base metal group.

(3) A change in the composition of the deposited weld metal from one A-number in Table 8 to any other A-number, or to an analysis not listed in the Table. Each American Iron Steel Institute (AISI) material of an A-8 or A-9 analysis (e.g., type 308, 309, 316) of Table 8, and each nonferrous alloy in Table 7 shall require separate WPS qualification.

(4) The addition of welding positions other than those already qualified.

(5) An increase or decrease of 100°F (55°C) or more in the minimum specified preheat temperature, or a change in the specified minimum or maximum interpass temperature.

(6) A change in the specified postweld heat treatment temperature, or an increase of twenty-five percent or more in the total time at postweld heat-treating temperature.

(7) A change from multiple layer to single layer cladding, or vice versa.

(8) A change in type of current (AC or DC) or polarity.

5.19.3 Essential Variables—Shielded Metal Arc Welding. For SMAW, the WPS shall be set up as a new WPS and shall be completely requalified when any of the following changes are made in addition to the essential variables given in 5.19.2.

(1) A change in the nominal electrode diameter used for the first layer of deposit.

(2) An increase of more than ten percent in the amperage used in application for the first layer.

5.19.4 Essential Variables—Submerged Arc Welding, Gas Metal Arc Welding, or Gas Tungsten Arc Welding. For SAW, GMAW, or GTAW, the WPS shall be set up as a new WPS and shall be completely requalified when any of the following changes are made in addition to the essential variables given in 5.19.2.

(1) For SAW, a change in the trade designation or type of flux used. Requalification is not required for a change in flux particle size.

(2) A change from single-electrode to multiple-electrode techniques, or vice versa. A multiple-electrode process is defined as one in which two or more welding electrodes are acting on the same molten weld pool.

(3) The addition or deletion of supplementary filler metal to the welding arc.

(4) The addition or deletion of oscillation of the electrode or electrodes.

(5) A change in the cross-sectional area of the electrodes or supplementary filler metal.

(6) An increase of more than 10 percent in the welding current beyond the range specified.

(7) A change in the voltage beyond the range specified.

(8) A variation of more than ten percent in travel speed.

(9) In GMAW and GTAW, a change from a single gas to any other single gas or to a mixture of gases, or vice versa; a change in the specified percentage composition of a gas mixture; a decrease of ten percent or more in the rate of flow of shielding gas or gas mixture.

5.19.5 Nonessential Variables. Changes other than those given in 5.19.2 through 5.19.4 may be made in a procedure without the necessity for requalification, provided the procedure specification is amended to show the changes.

5.20 F-numbers. The F-number grouping of electrodes and welding rods in Table 7 is based essentially on their usability characteristics, which fundamentally determine the ability of welders to make satisfactory welds with a given filler metal. This grouping is made to reduce the number of welding procedure and performance qualifications where this can logically be done. The grouping does not imply that base metals or filler metals within a group may be indiscriminately substituted for a metal that was used in the qualification test without consideration of the compatibility of the base and filler metals from the standpoint of metallurgical properties, postweld heat treatment, design and service requirements, and mechanical properties.

5.21 A-numbers. The classification of weld metal analysis for procedure qualification is given in Table 8.

6. Fabrication Requirements

6.1 General

6.1.1 All applicable paragraphs of this section shall be observed in the production and inspection of welded assemblies and structures produced by any of the processes acceptable under this specification.

6.1.2 All items of equipment for welding, oxygen cutting, and arc gouging shall be so designed and manufactured and be in such condition as to enable qualified welders, welding operators, and tack welders to follow the procedures and attain the results prescribed elsewhere in this specification.

6.1.3 Welding shall not be done when the ambient temperature is lower than 0°F (-18°C), when surfaces are wet or exposed to rain, snow, or high wind, or when welders are exposed to inclement weather conditions. Unless specified otherwise herein, the minimum base-metal temperature for welding shall be 50°F (10°C).

Local protection and heating may be used to correct these conditions.

6.1.4 Welds shall be as specified by design requirements and detailed drawings. The location of welds shall not be changed without design engineering approval and drawing revisions.

6.1.5 Production welding must be accomplished using a welding procedure specification (WPS) qualified in conformance to Section 5, Part I, of this document.

6.1.6 Welders or welding operators performing production welding shall be qualified in conformance to section 5, Part II, of this document.

6.1.7 Welds requiring a combination of processes may be performed by one or more welders or welding operators. They may perform only that portion of the weld for which they have been qualified.

6.2 Preparation of Base Metal

6.2.1 Surfaces and edges to be welded shall be smooth, uniform, and free from fins, tears, cracks, and other defects that would adversely affect the quality or strength of the weld. Surfaces to be welded shall also be free from moisture, loose or thick scale, slag, rust, grease, or other foreign material that will interfere with producing sound welds.

6.2.2 Surfaces within 1/2 in. (13 mm) of any weld location shall be free from any paint or other material that would prevent proper welding.

6.2.3 Machining, air carbon arc or oxygen cutting or gouging, plasma arc cutting, chipping, or grinding may be used for the preparation of base metal, back gouging, or the removal of defective welds or metal. Oxygen gouging shall not be used on quenched and tempered steel. When oxygen, air carbon arc, or plasma arc cutting is employed, all scale, slag, gouges, or other irregularities on the surface shall be removed by mechanical means. Thermally cut or gouged surfaces of M-8 base metal shall be ground to bright metal. All reentrant corners shall be free from sharp notches.

6.2.4 The type of material used for backing straps, rings, and spacer blocks shall be as specified in the design drawings or approved welding procedure.

6.3 Assembly

6.3.1 The parts to be joined by fillet welds shall be brought into as close contact as practicable, and in no event shall they be separated by more than 1/8 in. (3.2 mm). 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. The separation between facing surfaces of lap joints shall not exceed 1/16 in.

(1.6 mm). The separation between the underside of butt joints and the face of the backing bar shall not exceed 1/16 in. (1.6 mm).

6.3.2 Dimensions of the cross section of groove welded joints shall not vary from those shown on the detail drawings by more than the following workmanship tolerances:

- (1) Root face of joint, +0, -1/16 in. (+0, -1.6 mm)
- (2) Root opening of joints without steel backing, $\pm 1/16$ in. (± 1.6 mm)
- (3) Root opening of joints with steel backing, +1/8, -1/16 in. (+3.2, -1.6 mm)
- (4) Groove angle of joint, +10 degrees, -5 degrees

6.3.3 Root openings wider than those permitted by the above tolerances, but not greater than twice the thickness of the thinner part or 1/2 in. (13 mm), whichever is less, may be built up by welding to acceptable dimensions prior to the joining of the parts.

6.3.4 Complete joint penetration welding procedures, in which the joint is welded from both sides, shall require either back gouging of the underside of the root pass before welding the second side, or demonstration by actual welding tests that back gouging may be omitted without detriment to the joint. Back gouging shall require removal of the backside of the joint to sound metal.

6.3.5 Each weld pass shall be thoroughly cleaned using slag hammers, grinding wheels, rotary burrs, or wire brushes, as required. Pneumatic chippers may be used, provided they do not peen or distort the weld.

6.3.6 Preheating and interpass temperature control shall be such as to ensure that the full thickness of the weld joint and the adjacent weld metal are at the temperature specified by the welding procedure.

6.3.7 Tack Welds

6.3.7.1 Tack welds and temporary welds shall be made with filler materials meeting the same requirements as the final welds. Multiple-pass tack welds shall have cascaded ends.

6.3.7.2 Tack welds to be incorporated in the final weld shall be deposited by qualified welders using a qualified welding procedure. Tack welds and temporary welds shall be deposited by qualified welders.

6.3.7.3 Tack welds not incorporated in a final weld and temporary welds shall be removed when required by the contract specification. When they are removed, the surface shall be made flush with the original surface.

6.4 Weld Surface Conditions

6.4.1 The faces of fillet welds may be slightly convex, flat, or slightly concave as shown in Figures 15(A),

15(B), and 15(C), but shall have no defects such as shown in Figure 15(D). Except at outside corner joints, the convexity shall not exceed the value of $0.1S + 0.03$ in. (1 mm) where S is the actual size of the fillet weld in inches (millimeters) [see Figures 15(B) and 15(C)].

6.4.2 Groove welds shall preferably be made with slight or minimum reinforcement, except as may be otherwise specified. In the case of the butt and corner joints, the reinforcement shall not exceed 1/8 in. (3.2 mm) in height and shall have gradual transition to the plane of the base-metal surface [see Figure 15(E)]. Groove welds shall be free of defects as shown for butt joints in Figure 15(F).

6.4.3 Surfaces of butt joints required to be flush shall be finished so as not to reduce the thickness of the thinner base metal or weld metal by more than 1/32 in. (1 mm), or leave reinforcement that exceeds 1/32 in. (1 mm). However, all reinforcement must be removed where the weld forms part of faying or contact surfaces. Any reinforcement must blend smoothly into the plate surfaces.

6.4.4 Undercut, regardless of depth, shall not occur within 3 in. (76 mm) of the end of any joint and shall be no more than 1/32 in. (1 mm) in depth elsewhere in the joint. Continuous length of undercut shall be no more than 6 in. (152 mm).

6.4.5 Welds shall be free from overlap, cracks, or incomplete fusion.

6.4.6 Where surface finishing of a weld is required, its value should not exceed 500 μ in. (12.5 μ m) (reference ANSI/ASME B46.1, *Surface Texture*).

6.4.7 The frequency of visible porosity in fillet welds shall not exceed one pore of 3/32 in. (2.4 mm.) maximum diameter in each 4 in. (102 mm) of length. Groove welds shall have no visible porosity.

6.4.8 Visual inspection of welds may begin immediately after the completed welds have cooled to near ambient temperature. Acceptance criteria for quenched and tempered steels (e.g., ASTM A514 and A517) shall be based on inspection performed not less than 48 hours after completion of the welds.

6.5 Corrections. All corrections shall be done in conformance to section 8, Modification and Repair.

6.6 Peening. Peening may be used on intermediate weld layers for control of shrinkage stresses in thick welds to prevent cracking. No peening shall be done on the root or surface layer of the weld, or in the base metal at the edge of the weld, except when it is done in conformance to the

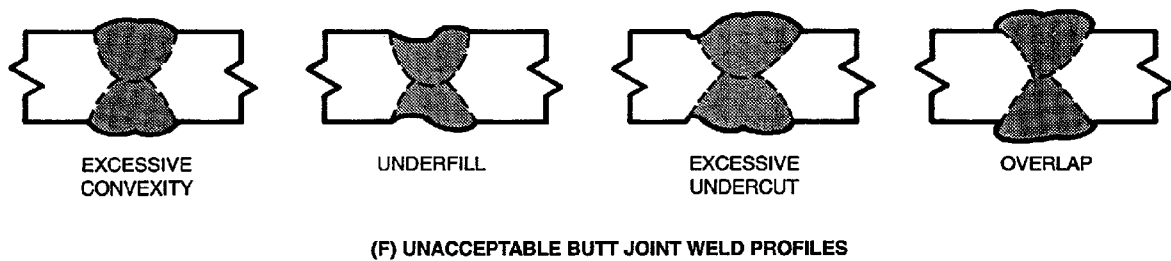
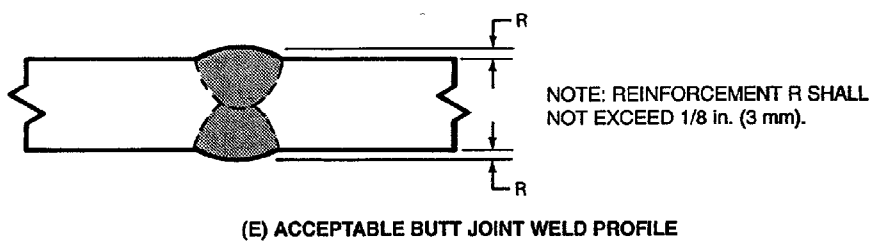
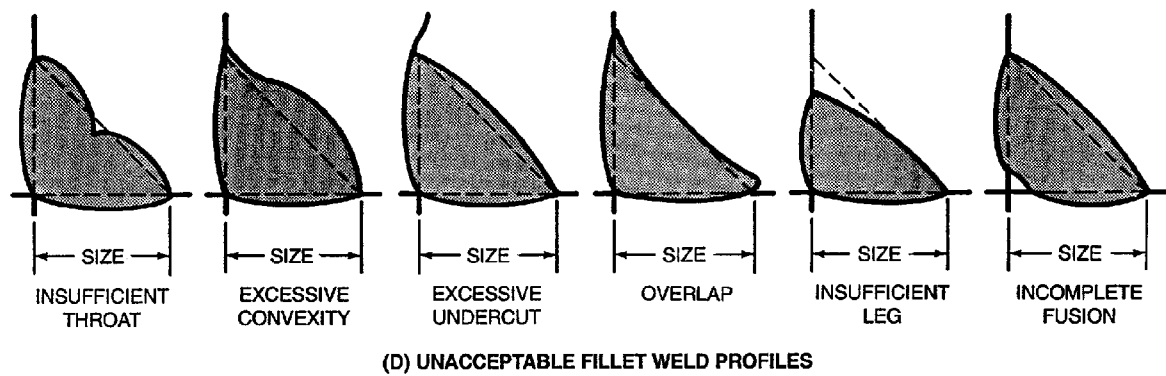
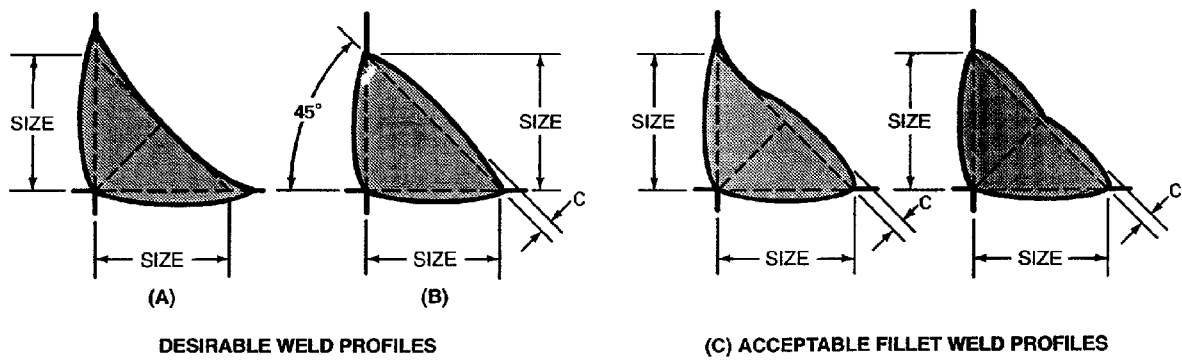


Figure 15—Acceptable and Unacceptable Weld Profiles

Military Specification MIL-S-13165, *Shot Peening of Metal Parts*.²

Care shall be exercised to prevent over-peening which may cause overlapping, sealing, cracking, flaking, or excessive cold working of the weld and base metal.

6.7 Preheat and Postweld Heat Treatment

6.7.1 For the heat treatment of all materials listed in this section, the furnace air temperature shall not exceed 600°F (316°C) at the time of loading of the parts.

6.7.2 Above 600°F (316°C), the rate of increase in temperature of the furnace shall not exceed 400°F/hr (220°C/hr) divided by the maximum metal thickness of the part in inches, but in no case more than 400°F/hr (220°C/hr). During the heating period, there shall not be a greater variation in temperature than 250°F (140°C) throughout the part being heat treated.

6.7.3 Above 600°F (316°C), cooling shall be done in a closed furnace or cooling chamber at a rate not greater than 500°F/hr (280°C/hr) divided by the maximum metal thickness of the part in inches, but in no case more than 500°F/hr (280°C/hr). Below 600°F (330°C), the part may be cooled in still air. During the cooling period, there shall not be a greater variation in temperature than 200°F (110°C) throughout the part being heat treated.

6.7.4 The temperature of the part during heat treating shall be measured with thermocouples attached to the part.

6.7.5 M-1 Materials. For M-1 material,³ the following minimum preheat and interpass temperatures are mandatory:

Up to, and including, 1-1/2 in. (38 mm)	50°F (10°C)
Over 1-1/2 in. (38 mm), and including,	
2-1/2 in. (64 mm)	150°F (65°C)
Over 2-1/2 in. (64 mm)	200°F (95°C)

The postweld heat treatment (PWHT) of M-1 materials is neither mandatory nor prohibited under this specification. If PWHT is specified, it shall be accomplished at a temperature from 1100°F (595°C) to 1200°F (650°C) and shall be at temperature for 1 hour per 1 in. (25 mm) of thickness, plus 15 minutes for each 1 in. (25 mm) over 2 in. (50 mm).

2. Standardization Document Order Desk, 700 Robbins Ave., Bldg. #4, Section D, Philadelphia, PA 19111.

3. The temperatures herein are consistent with the use of low hydrogen filler materials only. For filler materials not falling into this category, it is suggested that higher minimum preheat and interpass temperatures may be required.

6.7.6 M-3, M-4, and M-5 Materials

6.7.6.1 For M-3, M-4, and M-5 materials, preheat is mandatory for thickness over 1/2 in. (13 mm). The following minimum preheat and interpass temperatures are to be used.

Preheat for M-3 material	200°F (95°C)
Preheat for M-4 and M-5	
Group 1 materials	300°F (150°C)
Preheat for M-5 Group 2 materials	400°F (190°C)

6.7.6.2 For M-3, M-4, and M-5 Group 1 materials over 1/2 in. (13 mm) thick and all M-5 Group 2 materials, PWHT is mandatory. The following PWHT temperatures shall be required for these materials.

M-3, 1100°F–1250°F (595°C–675°C)

M-4 and all M-5, 1250°F–1350°F (675°C–730°C)

6.7.6.3 The time at temperature shall be based on the HAZ hardness as determined on the procedure qualification test plate. The maximum acceptable hardness shall be 22 Rockwell “C” scale.

6.7.7 M-6 and M-7 Materials

6.7.7.1 For M-6 and M-7 Group 1 materials, a minimum preheat and interpass temperature of 400°F (205°C) shall be mandatory.

6.7.7.2 A PWHT of these materials at 1400°F (760°C) shall be mandatory when austenitic stainless steel filler metal is not used.

6.7.7.3 The time at temperature shall be based on the HAZ hardness as determined on the procedure qualification test plate. The maximum acceptable hardness shall be 22 Rockwell “C” scale.

6.7.7.4 The PWHT of M-7 Group 2 materials is neither mandatory nor prohibited.

6.7.8 M-8 Materials. Preheat and PWHT of M-8 materials is neither mandatory nor prohibited. The maximum interpass temperature of M-8 materials shall be 350°F (175°C), except during hard surfacing.

6.7.9 M-9 Material

6.7.9.1 Minimum preheat and interpass temperatures shall be as follows:

Preheat for M-9A materials	250°F (120°C)
Preheat for M-9B materials	300°F (150°C)

6.7.9.2 The PWHT of M-9 materials is neither mandatory nor prohibited.

6.7.10 M-10 Materials

6.7.10.1 M-10A materials shall be preheated and interpass temperatures maintained in conformance to the following:

Up to, and including, 3/4 in. (19 mm)	50°F (10°C)
Over 3/4 in. (19 mm), and including, 1-1/2 in. (38 mm)	150°F (65°C)
Over 1-1/2 in. (38 mm), and including, 2-1/2 in. (64 mm)	250°F (120°C)
Over 2-1/2 in. (64 mm)	300°F (150°C)

6.7.10.2 M-10A material over 1 in. (25 mm) thick shall be PWHT at 1050°F (565°C) $\pm$ 50°F (30°C) for one hour per 1 in. (25 mm) of thickness.

6.7.10.3 M-10B materials shall be preheated and PWHT same as M-4 materials.

6.7.10.4 M-10C materials shall be preheated and PWHT same as M-10A materials.

6.7.10.5 M-10E materials shall be preheated at 300°F (150°C) and shall maintain interpass 350°F–450°F (175°C–235°C). PWHT is neither mandatory nor prohibited. However, if these materials are PWHT, the cooling from 1200°F (650°C) $\pm$ 50°F (30°C) shall be sufficiently rapid to prevent embrittlement.

6.7.10.6 M-10F materials shall be preheated and PWHT same as M-3 materials.

6.7.10.7 For M-10G materials, preheat and PWHT are neither mandatory nor prohibited.

6.7.10.8 For M-10H materials, preheat and PWHT are neither mandatory nor prohibited. If PWHT is done, check manufacturer's literature for proper holding temperatures and cooling rates.

6.7.10.9 For M-10I materials, preheat is not mandatory. PWHT at 1300°F to 1400°F (705°C to 760°C) for 1 hour per 1 in. (25 mm) of thickness is mandatory for thicknesses in excess of 1/2 in. (13 mm). This material shall be rapidly cooled from the PWHT temperature.

6.7.11 M-11 Materials

6.7.11.1 The preheat and interpass temperatures that are used during the welding of these materials should be compatible with the heat input of the welding process. The heat input and preheat should be selected so that the as-welded mechanical properties in the HAZ are optimized and do not indicate the possibility of underbead cracking as determined by restrained weld tests.

6.7.11.2 For M-11A Groups 1 and 2 materials, preheat and PWHT are neither mandatory nor prohibited. PWHT procedures require rapid cooling rates. Check

Literature for proper holding temperatures and cooling rates if PWHT is done.

6.7.11.3 For M-11A Groups 3, 4, 5, and 6 materials, preheat in conformance to 6.7.10.1. PWHT shall be mandatory and shall be accomplished at a temperature 50°F (30°C) below the tempering temperature. The time at temperature shall be a minimum of 1/2 hour per 1 in. (25 mm) of thickness but not less than 1/2 hour.

6.7.11.4 For M-11B materials, preheat and PWHT are neither mandatory nor prohibited.

7. Inspection and Quality Control

7.1 General Requirements

7.1.1 The inspector designated by the purchaser shall determine that fabrication by welding is performed in conformance to requirements of this specification.

7.1.2 Detail drawings showing the size, length, type, and location of all welds shall be made available to the inspector for use at the manufacturer's or contractor's facility.

7.1.3 The inspector shall be qualified in conformance to AWS QC 1-9X, *Standard for AWS Certification of Welding Inspectors*, or an equivalent program. (CSA-W178.2 Certification of Welding Inspectors.) The inspector shall be familiar with the requirements of this specification.

7.1.4 The manufacturer shall have and maintain a quality control system that will establish that all requirements of this specification will be met. A recommended quality system is outlined in Annex B.

7.2 Examination and Inspection

7.2.1 The inspector may review the procedure qualification test records that are required by other sections of this specification. The inspector may witness the welding and testing of procedure qualification tests required by this specification and occurring within the time frame of the contract.

7.2.2 The inspector shall permit welding to be performed only by welders, welding operators, and tack welders who are qualified in conformance to the requirements of this specification. The inspector may witness the welding and testing of performance qualification tests during the time frame of the contract. The records of previously qualified welders, welding operators, or tack welders may be reviewed for accuracy, completeness, and conformance to the current contract in force.

7.2.3 When the quality of a welder's, welding operator's, or tack welder's work appears to be below the requirements of this specification, the inspector may require testing of a welder's, welding operator's, or tack welder's capability by means of simple tests, such as the fillet weld break test, or by complete requalification in conformance to this specification.

7.2.4 The inspector shall ascertain that the size, length, and location of welds conform to the requirements of the specifications and to the detail drawings, that no specified welds are omitted, and that no unspecified welds have been added.

7.2.5 The inspector shall ascertain that only welding procedures that meet the provisions of this specification are employed.

7.2.6 The inspector shall ascertain that electrodes are used only in the position and with the type of welding current and polarity for which they are classified.

7.2.7 The inspector may observe the technique and performance of each welder, welding operator, and tack welder during production to make certain that the applicable requirements of this specification are met.

7.2.8 The inspector shall examine the work to determine that it meets the requirements of this specification. Size and contour of welds shall be measured with suitable gauges. Visual inspection for cracks in welds and base metal, and other defects, should be aided by a strong light sufficient to properly illuminate the area.

7.2.9 The inspector may identify with a distinguishing mark all parts or joints that have been inspected and accepted, and shall maintain a written record of such parts and joints not accepted and the corrective actions taken.

7.3 Obligations of the Manufacturer

7.3.1 When the manufacturer and purchaser's inspector agree upon a nonconformance to this specification, the manufacturer shall correct such nonconformities.

7.3.2 There shall be a system agreed upon with the purchaser's inspector for correction of nonconformities.

7.3.3 In the event that repair of rejected welds shall so damage the base metal that it is not in accordance with the intent of the design drawings and specifications, the manufacturer shall resolve the deficiency in a manner approved by the designer.

7.3.4 The manufacturer shall be responsible for the necessary corrections of all welds in conformance to the requirements of this specification.

7.3.5 Corrections and repairs shall be accomplished by methods permitted in section 8.

7.4 Nondestructive Testing

7.4.1 When nondestructive testing is required by contract, it shall be so stated in the information furnished to the manufacturer. This information shall designate the welds to be examined, the extent of examination of each weld, and the method of testing.

7.4.2 Recommended nondestructive testing methods and acceptance criteria suggested for use with this specification are in Annex C. Alternate methods of inspection may be agreed upon between purchaser and manufacturer.

7.4.3 Personnel performing nondestructive testing shall be qualified in accordance with the American Society for Nondestructive Testing (SNT-TC-1A) and the supplement applicable to the method to be used, or equivalent.

7.4.4 When nondestructive testing is specified, it shall be the manufacturer's responsibility to ensure that all welds meet the quality requirements of applicable sections of this specification.

7.4.5 If nondestructive testing other than visual inspection is not specified in the original contract agreement, but is subsequently requested by the purchaser, the manufacturer shall perform any requested testing or shall permit any testing to be performed. The purchaser shall be responsible for all associated costs, including handling, surface preparation, nondestructive testing, and repair of defects, other than those listed in 6.4 of this specification, at rates mutually agreeable between purchaser and manufacturer.

7.5 Preparation and Disposition of Reports

7.5.1 A report form shall be kept by the manufacturer that clearly identifies the work and the area of inspection. This report shall contain sufficient information to identify the weld, the person doing the inspecting, and the acceptability status of the welds inspected.

7.5.2 The manufacturer's obligation to retain test reports shall cease upon delivery of those reports to the designated recipient, or at the end of one full year after completion of work.

8. Modification and Repair

8.1 Scope

8.1.1 This section pertains to the modification and repair of welds and base metal defects on the manufacturer's premises or otherwise under the manufacturer's control.

8.1.2 Repair or modification work performed by those other than the manufacturer should have approval from the manufacturer and be performed to the manufacturer's specifications.

8.2 Qualification

8.2.1 All repairs by welding on the manufacturer's premises, before acceptance of the product by the purchaser, shall be made utilizing a qualified procedure as per section 5 of this specification.

8.2.2 All field repairs shall be done by a process and procedure mutually acceptable to the purchaser and the manufacturer.

8.3 Removal of Metal

8.3.1 The removal of weld metal or portions of the base metal that require repair may be done by machining, grinding, chipping, oxygen gouging, or air carbon arc gouging. This shall be done in such a manner that the remaining weld metal or base metal does not contain stress risers. Oxygen gouging shall not be used on quenched and tempered steels. Unacceptable portions of the weld shall be removed without substantial removal of the base metal.

8.4 Repair of Type of Defect

8.4.1 **Overlap or Excessive Convexity.** Excess weld metal shall be removed as per 8.3.1 of this specification.

8.4.2 **Excessive Concavity of Weld or Crater, Undersize Welds, Undercutting.** Surfaces shall be prepared and additional weld metal deposited.

8.4.3 **Excessive Weld Porosity, Excessive Slag Inclusions, Incomplete Fusion.** Unacceptable portions shall be removed, as per 8.3.1, and rewelded using a qualified welding procedure specification.

8.4.4 **Cracks in Weld or Base Metal.** The extent of the crack shall be determined by use of magnetic-particle inspection, liquid penetrant inspection, or other suitable methods. The crack shall be removed and rewelded using a qualified welding procedure specification (see 8.3.1).

8.4.5 **Distortion.** Members distorted by welding, or otherwise, shall be straightened by mechanical means or by carefully supervised application of a limited amount of localized heat. The temperature of heated areas, as measured by a temperature-indicating device, shall be no higher than 50°F (30°C) below the original tempering temperature for quenched and tempered steel, or 1200°F (650°C) for other carbon steels. Unstabilized austenitic stainless steel with more than 0.03 percent carbon shall not be heat-straightened with temperatures in excess of 800°F (425°C). For all other materials to be straightened

by heating, the temperature shall be no higher than the temperature recommended by the materials producer.

8.4.6 **Inaccessible Defects.** If work has been performed that has rendered an unacceptable defect inaccessible, or has created new conditions that make correction of the unacceptable defect dangerous or ineffectual, then the original conditions shall be restored by removing weld members 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.

8.5 **Peening.** Peening may be used during a repair procedure on intermediate weld layers for control of shrinkage stress in thick welds to prevent cracking. No peening shall be done on the root or surface layer of the weld or in the base metal at the edges of the weld, except when it is done in conformance to Military Specification MIL-S-13165. Care shall be taken to prevent overlapping or cracking of the weld or base metal.

8.6 **Postweld Heat Treatment.** Repairs to parts or assemblies where postweld heat treatment is required by this Specification shall be stress relieved or otherwise heat treated after the repairs have been completed, examined, and accepted.

8.7 **Tempering.** On quenched and tempered steels and normalized castings, the repair weld shall be covered by an extra layer of weld to temper the weld deposit and heat-affected zone. The tempering layer shall touch only previously deposited weld metal and shall not touch the base metal. This tempering layer shall be removed to leave a tempered weld layer that meets the specified weld size.

8.8 Cleaning

8.8.1 All repair welds shall be cleaned in conformance to the applicable cleaning specification.

8.8.2 Repair welding shall not be painted or coated until after the work has been inspected and accepted.

8.9 Testing and Inspection

8.9.1 Any repair or replaced weld shall be retested by the method originally used when the defect was found, and the same technique and quality acceptance criteria shall be applied.

8.9.2 The purchaser's inspector or the manufacturer shall make a permanent record of the repair as to the type of repair, location, repair procedure, and the final acceptance of the repair; such information shall be filed with the document file pertaining to the job.

Annex A

Sample Forms

(This Annex is not a part of ANSI/AWS D14.6-96, *Specification for Welding of Rotating Elements of Equipment*, but is included for informational purposes only.)

Weld procedure no. _____

WELDING PROCEDURE SPECIFICATIONRevision _____
Page _____ of _____Applicable code(s) _____

_____Supporting PQR(s) _____

Base metal

M-no. _____ Group _____ M-no. _____ Group _____

Thickness range _____

Diameter range _____

Joint preparation _____

_____Process(es) _____

_____Cleaning (initial and interpass) _____

_____Position _____

Gas

Shielding _____ Flow rate _____

Progression _____

Purge _____ Flow rate _____

Trailing _____ Flow rate _____

Filler Metal

Process _____ Spec no. _____ F-no. _____ A-no. _____

Classification _____

Process _____ Spec no. _____ F-no. _____ A-no. _____

Other _____

Flux

Classification _____

Particle size _____

Trade name _____

Preheat

Preheat temp., °F (°C) _____

Interpass range, °F (°C) _____

Postweld heat treatment

Type _____

Temperature _____

Time _____

Additional or supplementary requirements _____

Preparation approval _____

Date _____

Issue date _____

Welding engineer _____

Project _____

Materials engineering _____

Job no. _____

Quality assurance _____

WELDING TECHNIQUE

Weld procedure no. _____

M-no. _____ Group _____ M-no. _____ Group _____
Thickness range _____ to _____

Revision _____
Page _____ of _____
JOINT DESIGN/WELD SEQUENCE**WELD VARIABLES**

Pass	Process	Filler metal		Gas/flux		Electrical Data			Travel, IPM	Max. bead width
		Size	Class	Type	Flow	Type	Amperage	Volts		

Preheat _____	Backgouging method _____
Interpass temp. _____	Contact tube to work (in.) _____
Single or multiple arc _____	Orifice or cup size _____
Single or multiple pass _____	Weld progression _____

SPECIAL INSTRUCTIONS

PROCEDURE QUALIFICATION RECORD

PQR. No. _____

Page _____

Material spec. _____ to _____
 M-no. _____ Gr. no. _____ to M-no. _____ Gr. no. _____ Thickness and O.D. _____
 Welding processes 1. _____ 2. _____
 Manual or automatic 1. _____ 2. _____
 Thickness range 1. _____ 2. _____
 Total qualified thickness range _____

FILLER METAL

F-no. 1. _____ 2. _____
 A-no. 1. _____ 2. _____
 AWS spec. 1. _____ 2. _____
 AWS class 1. _____ 2. _____
 Filler size 1. _____ 2. _____
 Trade name 1. _____ 2. _____

Describe filler metal if not included AWS
 specifications _____

FLUX OR ATMOSPHERE

Trade name 1. _____ 2. _____
 Shielding gas 1. _____ 2. _____
 Flow rate 1. _____ 2. _____
 Purge 1. _____ 2. _____

WELDING VARIABLES

Joint type _____
 Position _____
 Backing _____
 Preheat _____
 Interpass temp. range _____
 PWHT _____
 Passes/side 1. _____ 2. _____
 No. of arcs 1. _____ 2. _____
 Current 1. _____ 2. _____
 Amps 1. _____ 2. _____
 Volts 1. _____ 2. _____
 Travel speed 1. _____ 2. _____
 Oscillation 1. _____ 2. _____
 Bead type 1. _____ 2. _____

TENSILE TESTS

Specimen no.	Dimensions		Area	Ultimate Total Load, lb.	Ultimate Unit Stress psi	Character of Failure and Location
	Width	Thickness				

GUIDED-BEND TESTS

Type and Figure No.	Result	Type and Figure No.	Result

Welder's Name _____ Clock No. _____ Stamp No. _____
 (who by virtue of these tests meets welder performance requirements.) Laboratory Test No. _____

Test Conducted by _____ Address _____
 per _____ Date _____

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 AWS D14.6.

Signed _____
 (Manufacturer)
 Date _____ By _____

SUPPLEMENTAL TESTS										PQR No. _____		
										Page _____ of _____		
Toughness test		Type _____		Per _____								
		Size _____		Per _____								
Specimen identification	Test temp	Notch location	Energy, ft • lbs		Mils lat. exp.		Percent shear	Dropweight				
								Break	No break			
Hardness test		Type _____		Per _____								
No.	Weld metal		Heat-affected zone		Base metal							
Fillet weld test		Fig. _____										
Macro test results						Fracture test results						
Chemical analysis %		Method _____		Per _____								
Elem.	C	Mn	P	S	Si	Cr	Ni	Mo	Cu	Ti		Fe
Weld												
Base												
Additional tests												

We certify that the statements in this record are correct and that the tests were conducted in accordance with _____ and the requirements of _____.

Signed _____

Date _____ By _____

WELDER AND WELDING OPERATOR QUALIFICATION TEST RECORD

Welder or welding operator name _____ Identification _____
 Welding process _____ Manual _____ Semiautomatic _____ Machine _____
 Position _____
 (Flat, horizontal, overhead or vertical — if vertical, state whether upward or downward)
 in accordance with procedure specification no. _____
 Material specification _____
 Diameter and wall thickness (if pipe) — otherwise joint thickness _____
 Thickness range this qualifies _____

FILLER METAL

Specification no. _____ Classification no. _____ F-no. _____
 Describe filler metal (if not covered by AWS specification) _____
 Filler metal diameter and trade name _____ Flux for submerged arc or gas for gas
 metal arc or flux cored arc welding _____

GUIDED-BEND TEST RESULTS

Type	Result	Type	Result

Test conducted by _____ Laboratory test no. _____
 per _____

FILLET TEST RESULTS

Appearance _____ Fillet size _____
 Fracture test root penetration _____ Macroetch _____
 (Describe the location, nature, and size of any crack or tearing of the specimen.)
 Test conducted by _____ Laboratory test no. _____
 per _____

RADIOGRAPHIC TEST RESULTS

Film Identification	Results	Remarks	Film Identification	Results	Remarks

Test witnessed by _____ Test no. _____
 per _____

We, the undersigned, certify that the statements in this record are correct and that the welds were prepared and tested in accordance with the requirements of AWS D14.6, *Specification for Welding of Rotating Elements and Equipment*.

Manufacturer _____
 Authorized by _____
 Date _____

Annex B

Quality Control System

(This Annex is not a part of ANSI/AWS D14.6-96, *Specification for Welding of Rotating Elements of Equipment*, but is included for informational purposes only.)

B1. General

The quality control system that the manufacturer uses should meet the requirements of this specification. A written description of the system shall be available to the purchaser's inspector for review. Depending upon the circumstances, the description may contain information of a proprietary nature relating to the manufacturer's processes. Therefore, information about the system shall be treated as confidential.

B2. Outline of Written Description of the Quality Control System

The following is a guide to some of the features that should be covered in the written description of the quality control system and that are equally applicable to both shop and field work.

B3. Authority and Responsibility

The authority and responsibility of those in charge of the quality control system shall be clearly established. Persons performing quality control functions shall have sufficient and well-defined authority to identify quality control problems and to require action throughout the organization to provide solutions.

An organizational chart showing the relationships between management and engineering, purchasing, manufacturing, field construction, and inspection and quality control, is required to identify and associate the organiza-

tional groups with the particular functions for which each has authority.

B4. Drawings and Specification Control

The manufacturer's quality control system will provide procedures that will ensure that the latest applicable drawings, specifications, and instructions (as well as authorized changes) are used for the manufacture, inspection, and testing.

B5. Material Control

B5.1 The manufacturer shall include a system of purchasing and receiving control that will assure that the material received is properly identified. Documentation (including material certifications or material test reports) shall satisfy the requirements of the contract. The material control system shall assure that only the intended material is used in construction.

B5.2 The purchaser's inspector shall make certain that only materials conforming to the requirements of the specification are used.

B6. Examination and Inspection Program

The manufacturer's quality control system shall sufficiently describe the fabrication operations, including exam-

inations, to permit the purchaser's inspector to determine at what stages specific inspections are to be performed.

B7. Correction of Nonconformities

The manufacturer's quality control system shall describe the method by which nonconformities are corrected.

B8. Nondestructive Examination

The quality control system shall include provision for identifying the nondestructive examination procedures the manufacturer will apply to conform with the requirements of this specification.

B9. Heat Treatment

The quality control system shall provide controls to ensure that heat treatments, as required, are applied.

B10. Calibration of Measurement and Test Equipment

The manufacturer shall have a system for calibration of examination, measurement, and test equipment.

B11. Records Retention

The manufacturer shall have a system for the maintenance and retrieval of quality control records.

B12. Forms

The forms used in the quality control system and any detailed procedures for their use shall be available for review by the purchaser or the purchaser's authorized representative. The quality control system shall make necessary reference to these forms.

Annex C

Inspection Methods

(This Annex is not a part of ANSI/AWS D14.6-96, *Specification for Welding of Rotating Elements of Equipment*, but is included for informational purposes only.)

C1. Method: Liquid Penetrant Inspection of Welds

C1.1 General. The procedures and standards set forth herein are to govern liquid penetrant inspection of welds when such inspection is required by the purchase specification.

C1.2 Extent of Inspection

C1.2.1 Information furnished to the manufacturer shall clearly identify the extent of the liquid penetrant inspection to be performed.

C1.2.2 Drawings with symbols in accordance with ANSI/AWS A2.4, *Standard Symbols for Welding, Brazing, and Nondestructive Examination*, or equivalent information, shall be used.

C1.3 Equipment

C1.3.1 Penetrant Equipment. Aerosol cans, air or CO₂-powered spray guns, paint brushes, spraying, or dipping may be used to apply the liquids.

C1.3.2 Drying Equipment. Paper towels, lint-free cloths, or vacuum equipment may be used for drying.

C1.3.3 Lighting. The test area shall have a minimum of 100 foot-candles of illumination for proper evaluation of the visual indications revealed on the test surface.

C1.3.4 Lighting for Fluorescent Penetrants. A darkened area for black light use is necessary. The black light intensity shall be measured with a black light meter. A minimum of 800 microwatts per centimeter on the surface of the part being examined shall be required.

C1.4 Procedure

C1.4.1 Material. Liquid penetrant materials used on nickel-base alloys or austenitic stainless steels shall be sulphur- and halogen-free, meeting the requirements of ASTM D129 and ASTM D808 for sulphur content and total halogens. The residual amount of total sulphur and halogens shall not exceed 1/2 percent by weight. The penetrant materials for each evaluation, shall be compatible, as defined by the penetrant material manufacturer.

C1.4.2 Temperature. The temperature of the penetrant and the part to be inspected shall be as recommended by the penetrant manufacturer.

C1.4.3 Surface Finish of Completed Welds. As-welded surfaces shall be considered suitable for inspection, without any grinding, provided the following conditions are met:

- (1) There shall be no overlap or undercutting, valleys or grooves, along the toes of, or within, the weld.
- (2) The deposited metal must be fused smoothly and uniformly into the plate surfaces.
- (3) The finished weld shall be reasonably smooth and free from irregularities, grooves, or depressions.

C1.4.4 Precleaning. All parts must be clean and dry before the liquid penetrant is applied. "Clean" means that the materials must be free of any rust, scale, welding flux, slag, spatter, grease, paint, oily films, and dirt that might interfere with liquid penetrant inspection. All of these contaminants are of a type that may prevent the liquid penetrant from entering the discontinuities. If precleaning is necessary, the following procedures are recommended.

(1) Rust, scale, slag, weld spatter, or other hard, tenacious materials shall be removed by wire brushing, pickling, grinding, or machining.

(2) All types of grinding wheels are permitted on carbon steel. All other materials shall be ground with rubber resin-bonded aluminum oxide or silicon carbide wheels.

(3) All oil and grease shall be removed with residue-free solvents using paper towels or lint-free cloth.

(4) Residue-free solvents [initial flash point over 200°F (93°C)] may be used as hand-wipe solvents or as dip-tank degreasing solvents. These solvents are suitable for removing grease and oils, but are generally not adequate if solid materials are imbedded in the void areas.

C1.4.5 Application of Penetrant. The surface shall be thoroughly dry before application of the liquid penetrant. The penetrant may be applied by spraying, brushing, or immersion. The area to be inspected shall be completely covered. The dwell time shall be as recommended by the penetrant manufacturer. Precautions should be taken to prevent inspection materials from entering inaccessible areas.

C1.4.6 Removal of Excess Penetrant

C1.4.6.1 Removal (Water Washable). The water pressure, water temperature, and application distance, shall be as recommended by the penetrant manufacturer.

C1.4.6.2 Removal (Solvent). As much penetrant as possible shall be removed by first wiping the surface thoroughly with a clean dry cloth or absorbent paper. The remaining excess penetrant shall be removed by wiping the surface with a clean cloth or absorbent paper dampened with remover. Flushing of the surface with any liquid, following application of the penetrant and prior to developing, is prohibited.

C1.4.6.3 Removal (Post Emulsifier). With post-emulsifying penetrants, an additional step is required. This step is the application of a liquid emulsifier prior to the rinsing operation. The emulsifier may be applied by brushing, spraying, or dipping. Emulsifying times of ten seconds to five minutes can be used, depending upon prevailing conditions, such as surface roughness or the type of defect sought. The emulsifying time is critical, and shall be as recommended by the penetrant manufacturer. Once the emulsifying time has been set for a particular test, it should not vary more than ± 10 percent. After emulsification, the mixture is removed by a water spray, in accordance with the penetrant manufacturers recommendation.

C1.4.7 Application of Developer

C1.4.7.1 Dry. After the surface has been thoroughly dried, the developer shall be applied by dipping, spraying, or brushing. Application of the developer by spraying is preferable. The surface shall be completely covered with developer. It is suggested that the aerosol can or sprayer be held no less than 10 in. from the work and be applied in short, dusting strokes. The application of excess developer should be avoided, since it is possible for a thick coating of developer to mask indications.

C1.4.7.2 Liquid. The liquid developer is a suspension of powder in water or a volatile solvent. It is applied by dipping, spraying, or brushing. In any case, a film of powder is left on the surface when the developer dries. Where a water suspension developer is used, drying time may be decreased by the use of warm air.

C1.4.8 Examination. Visual examination of the surface being inspected shall be made within a maximum of thirty minutes after developer has dried.

C1.4.9 Final Cleaning. When the inspection is concluded, the penetrant materials shall be removed, as soon as possible, by means of brushing or wiping with paper towels or lint-free cloth, in accordance with C1.4.6.

C1.5 Acceptance Standards. All surfaces required to be examined shall be free of linear indications (cracks, laps, fissures, etc.) and of four, or more, rounded imperfections in a line separated by 1/16 in. (1.6 mm) or less (edge-to-edge).

(1) Linear indications are those indications in which the length is more than three times the width.

(2) Rounded imperfections are indications that are circular or elliptical, with the length less than three times the width.

(3) Indications less than 1/64 in. (0.4 mm) are considered nonrelevant.

In addition, the requirements of 6.4, Weld Surface Conditions shall be applied.

C1.6 Defect Removal and Repair. Unacceptable imperfections shall be removed and re-examination made to assure complete removal. Whenever a defect is removed and subsequent repair by welding is not required, the excavated area shall be blended into the surrounding surface so as to avoid sharp notches, crevices, or corners. Where welding is required after removal of a defect, the area shall be cleaned, and welding performed in conformance to a qualified welding procedure. Completed repairs shall be re-examined by the method originally used for detection of the defect (see section 8).

C2. Method: Magnetic-Particle Inspection of Welds (MT)

C2.1 General. The procedures and standards set forth herein are to govern magnetic-particle inspection of welds when such inspection is required by the purchase specification (reference ASTM E709, *Practice for Magnetic Particle Examination*).

C2.2 Extent of Inspection

C2.2.1 Information furnished to the manufacturer shall clearly identify the extent of the magnetic-particle inspection to be performed.

C2.2.2 Drawings with symbols in accordance with ANSI/AWS A2.4, *Standard Symbols for Welding, Brazing, and Nondestructive Examination*, or equivalent information, shall be used.

C2.3 Equipment

C2.3.1 Source of Magnetic Field. The following magnetizing equipment are capable of inducing a magnetic flux of suitable intensity in the desired direction.

C2.3.1.1 Prod Method. Portable prod-type electrical contacts shall be spaced 3 to 8 in. (76 to 203 mm) apart, using direct current at 100 to 124 amperes per 1 in. (25 mm) of spacing.

C2.3.1.2 Coil Method. Multiple coils shall be looped around the part and be capable of producing a magnetic field strength of 3000 to 10 000 ampere turns using direct current.

C2.3.1.3 Yoke Method. Either alternating current or permanent yokes shall be used. Strength of the magnetic field shall be verified by the method specified in ASTM E709.

C2.3.2 Lighting. The weld areas shall have a minimum of 100 foot-candles of illumination for proper evaluation of the indications revealed on the weld surface.

C2.4 Examination Medium. The magnetic particles used for detection of defects shall be as follows:

C2.4.1 Dry Particles. Dry particles used shall be of high permeability and low retentivity and of such size and shape as will produce suitable indications. It is desirable that the color be such as to provide adequate contrast with the background of the surface being examined.

C2.4.2 Wet Particles. Wet particles used shall be red or black, or, alternatively, may be fluorescent when viewed under ultraviolet illumination. The particles shall be suspended in suitable liquid medium in the concentration recommended by the manufacturer of the particles.

More details on the use of wet particles are given in ASTM E709.

C2.5 Surface Preparation

C2.5.1 Surface Finish of Complete Welds. As-welded surfaces shall be as per C1.4.3.

C2.5.2 Precleaning. The parts to be examined shall be dry and free of oil or other foreign matter which might interfere with the formation or interpretation of magnetic particle patterns or indications.

C2.6 Application of Magnetic Field

C2.6.1 Direction. The magnetic field shall be applied in two directions with the second as nearly perpendicular to the first as possible.

C2.6.2 Extent. Examination of welds by the magnetic particle method shall be made over an area including the weld and base metal and extending at least 1/2 in. (12.7 mm) on each side of the weld.

C2.6.3 Precaution. Care shall be taken to prevent local overheating, arcing, or burning of the surface being inspected. The magnetizing current shall not be turned on until after prods have been properly positioned in contact with the surface, and the current shall be turned off before the prods are removed.

C2.6.4 Sequence of Operation. Inspection shall be performed by the continuous method, leaving the magnetizing current on during the period the inspection medium is being applied and the excess removed.

C2.7 Particle Application and Removal

C2.7.1 Dry Particles. Dry particles may be applied by means of mechanical shakers, bulb blowers, or mechanical blowers. Excess particles shall be removed by means of a dry air current of sufficient force to remove the excess particles. Extreme care should be taken so that any particles indicating discontinuities are not disturbed.

C2.7.2 Wet Particles. Wet particles may be applied by means of spraying or dipping (see ASTM E709).

C2.8 Acceptance Standards. All surfaces required to be examined shall be free of cracks, laps, fissures, or other linear indications. Indications less than 1/64 in. (0.4 mm) are considered nonrelevant. Inline porosity, which appears as a linear accumulation of magnetic powder, shall be removed. Also, the requirements of 6.4 are applicable.

C2.9 Defect Removal and Repair. Unacceptable imperfections shall be removed and re-examined to assure the complete removal. Whenever a defect is removed and subsequent repair by welding is not required, the excavated area shall be blended into the surrounding surface so as to avoid sharp notches, crevices, or corners.

Where welding is required after removal of a defect, the area shall be cleaned, and the welding shall be performed in conformance to a qualified welding procedure. Completed repairs shall be re-examined by the method originally used for detection of the defect (see section 8).

C3. Radiographic Testing of Groove Welds in Butt Joints

C3.1 General

C3.1.1 The procedure and standards set forth in Annex C3 are to govern radiographic testing of welds when such inspection is required by the contract documents. The requirements listed herein are specifically for testing groove welds in butt joints. The methodology shall conform to ASTM E94, *Guide for Radiographic Testing*, and ASTM E142, *Method for Controlling Quality of Radiographic Testing*, except as provided herein.

C3.1.2 Variation in testing procedure, equipment, and acceptance standards, not included herein, may be used upon agreement between the purchaser and the manufacturer. Such variations include, but are not limited to, the following: radiographic testing of fillet, T-, and corner welds; changes in source-to-film distances; unusual application of film; unusual penetrameter application (including film side penetrameters); radiographic testing of thicknesses greater than 6 in. (152.4 mm); film types, densities, and variations in exposure, development, and viewing techniques.

C3.1.3 Information furnished to the manufacturer prior to purchase shall clearly identify the extent of radiographic testing.

C3.1.4 When complete testing is specified, the entire length of the weld in each designated joint shall be inspected.

C3.1.5 When spot testing is specified, the number of spots in each designated category of welded joints to be radiographed, in a stated length of weld, shall be included in information furnished prior to purchase. Each spot radiograph shall show at least 4 in. (102 mm) of weld length. If a spot radiograph shows discontinuities that require repair as defined in C3.4, two adjacent spots shall be inspected. If discontinuities requiring repair are shown in either of these spots, the entire length of weld in that welded joint shall be tested radiographically.

C3.2 Radiographic Procedure

C3.2.1 Radiographs shall be made using a single source of either x-ray or gamma radiation. The radiographic sensitivity shall be judged based on penetrameter image or wire image quality indicators (IQI). Radio-

graphic technique and equipment shall provide sufficient sensitivity to clearly delineate the required penetrameters and the essential holes as described in C3.2.6, Tables C1 and C2, and Figures C5 and C6. Identifying letters and numbers shall show clearly in the radiograph.

C3.2.2 Radiography shall be performed in conformance to all applicable safety requirements.

C3.2.3 When the contract documents require the removal of weld reinforcement, the welds shall be prepared for radiography by grinding as per 6.4.3. Other weld surfaces need not be ground or otherwise smoothed for purposes of radiographic testing, unless surface irregularities or the junction between weld and base metal may cause objectionable discontinuities to be obscured in the radiograph.

C3.2.3.1 Extension bars and run-off plates should be removed prior to radiographic inspection.

C3.2.3.2 When weld reinforcement or backing is not removed, or wire IQI alternate placement is not used, shims, which extend at least 1/8 in. (3.2 mm) beyond three sides of the required penetrameter or wire IQI, shall be placed under the penetrameter or wire IQI, so that the total thickness between the penetrameter and the film is approximately equal to the average thickness of the weld measured through its reinforcement and backing.

C3.2.4 Radiographic film shall be Type 1 or Type 2 as described in ASTM E94. Lead foil screens shall be used as described in ASTM E94. Fluorescent screens shall not be permitted.

C3.2.5 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.

C3.2.5.1 Gamma ray sources, regardless of size, shall be capable of meeting the geometric unsharpness limitation of *ASME Boiler and Pressure Vessel Code*, Section V, Article 2.

C3.2.5.2 The source-to-subject distance shall not be less than the total length of film being exposed in a single plane.

C3.2.5.3 The source-to-subject distance shall not be less than seven times the thickness of weld, plus reinforcement and backing, if any, nor such that the inspecting radiation shall penetrate any portion of the weld represented in the radiograph at an angle greater than 26-1/2 degrees from a line normal to the weld surface.

C3.2.6 Penetrameters or wire IQIs shall show clearly on each radiograph. The minimum number and their required locations shall be as follows:

Table C1
Penetrameter Requirements

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

Table C2
Wire Image Quality Indicators (IQI) Requirements

DIN 62 Fe (Wire Type) Penetrameters			
Nominal Material Thickness Range, in.	Nominal Material Thickness Range, mm	Source	
		Max. Wire Size	
		in.	mm
Up to 0.250 incl.	Up to 6.35 incl.	0.005	0.13
over 0.250 to 0.375 incl.	over 6.35 to 9.5 incl.	0.006	0.16
over 0.375 to 0.500 incl.	over 9.5 to 12.7 incl.	0.008	0.20
over 0.500 to 0.625 incl.	over 12.7 to 15.9 incl.	0.010	0.25
over 0.625 to 0.750 incl.	over 15.9 to 19.1 incl.	0.013	0.33
over 0.750 to 1.250 incl.	over 19.1 to 31.8 incl.	0.016	0.40
over 1.250 to 1.500 incl.	over 31.8 to 38.1 incl.	0.020	0.51
over 1.500 to 1.750 incl.	over 38.1 to 44.4 incl.	0.025	0.64
over 1.750 to 2.000 incl.	over 44.4 to 50.8 incl.	0.032	0.81
over 2.000 to 2.500 incl.	over 50.8 to 63.5 incl.	0.040	1.02
over 2.500 to 3.000 incl.	over 63.5 to 76.2 incl.	0.050	1.27
over 3.000 to 3.500 incl.	over 76.2 to 88.9 incl.	0.063	1.60
over 3.500 to 4.000 incl.	over 88.9 to 102.0 incl.	0.080	2.03
over 4.000 to 5.000 incl.	over 102.0 to 127.0 incl.	0.098	2.50
over 5.000 to 6.000 incl.	over 127.0 to 152.4 incl.	0.126	3.20
over 6.000 to 8.000 incl.	over 152.4 to 203.2 incl.	0.160	4.06

(1) For welds joining nominally equal thicknesses, where a radiograph represents 10 inches (254 mm) or greater weld length, two penetrameters or wire IQIs placed as shown in Figure C1.

(2) Where a radiograph represents less than 10 in. (254 mm) of weld, one penetrometer or wire IQI placed as shown in Figure C2.

(3) For welds at a transition in thickness, where a radiograph represents 10 in. (254 mm) or greater of weld length, two penetrameters or wire IQIs on the thinner plate and one penetrometer or wire IQI on the thicker plate, or two wire IQIs at the alternate wire IQI placement locations as shown in Figure C3.

(4) When a radiograph represents less than 10 in. (254 mm) of weld length, one penetrometer or wire IQI on each thickness or one wire IQI at the alternate wire IQI placement location as shown in Figure C4. Penetrameters or wire IQI shall be placed on the source side with penetrameters parallel to the weld joint and holes at the outer edge of the area being radiographed.

C3.2.6.1 The thickness of the penetrometer or wire IQI set and the essential hole, or wire shall be as specified in Tables C1 and C2. A smaller essential hole or wire or a thinner penetrometer or a wire IQI using smaller wires, or both, may be selected by the contractor, provided all other provisions for radiography are met. Thickness shall be measured as T_1 or T_2 , or both, at the locations shown in Figures C1, C2, C3, and C4 and may be increased to provide for the thickness of allowable weld reinforcement, provided shims are used as specified in C3.2.3.2. Backing material shall not be considered part of the weld or reinforcement in penetrometer or wire IQI selection.

C3.2.6.2 Penetrameters shall be manufactured from steel, preferably stainless steel, and shall conform to dimensions shown in Figure C5. For more detailed information see ASTM E142. Other penetrameters, such as those that are ASME-approved, may be used, provided they have identification numbers indicating penetrometer thickness, in thousandths of an inch, and comply with all other conditions of this paragraph and Figure C5. Each penetrometer shall be manufactured with three holes, one of which shall be of diameter equal to twice the penetrometer thickness (2T). The diameter of the two remaining holes shall be selected by the manufacturer. They will ordinarily be equal to one times (1T) and four times (4T) the penetrometer thickness. Penetrometer designations 10 through 25 shall contain a 4T hole.

C3.2.6.3 Wire IQIs shall be manufactured in conformance to Figure C6. For more detailed information, see ASTM E747, *Guide for Controlling Quality of Radiographic Examination Using Wire Penetrameters*.

C3.2.7 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, excessive undercut by scattered radiation, or any other process that obscures portions of the total weld length shall render the radiograph unacceptable.

C3.2.7.1 Films shall have sufficient length and shall be placed to leave at least 1/2 in. (12.7 mm) of film, exposed to direct radiation from the source, beyond each free edge where the weld is terminated.

C3.2.7.2 Welds longer than 14 in. (355.6 mm) may be radiographed by overlapping film cassettes and making a single exposure, or by using single film cassettes and making separate exposures. The provisions of C3.2.5 shall apply.

C3.2.7.3 To check for back-scattered radiation, a lead symbol "B," 1/2 in. (12.7 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 considered unacceptable.

C3.2.8 Film widths shall be sufficient to cover all portions of the weld joint, including the heat-affected zones, and shall provide sufficient additional space for the required penetrameters or wire IQI and film identification without infringing upon the area of interest in the radiograph.

C3.2.9 All radiographs shall be free from mechanical, chemical or other blemishes to the extent that they cannot 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:

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

C3.2.10 The transmitted film density through of the body of the required penetrometer(s) and the area of interest shall be a minimum of 1.8 for single-film viewing for radiographs made with an x-ray source and a minimum of 2.0 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.

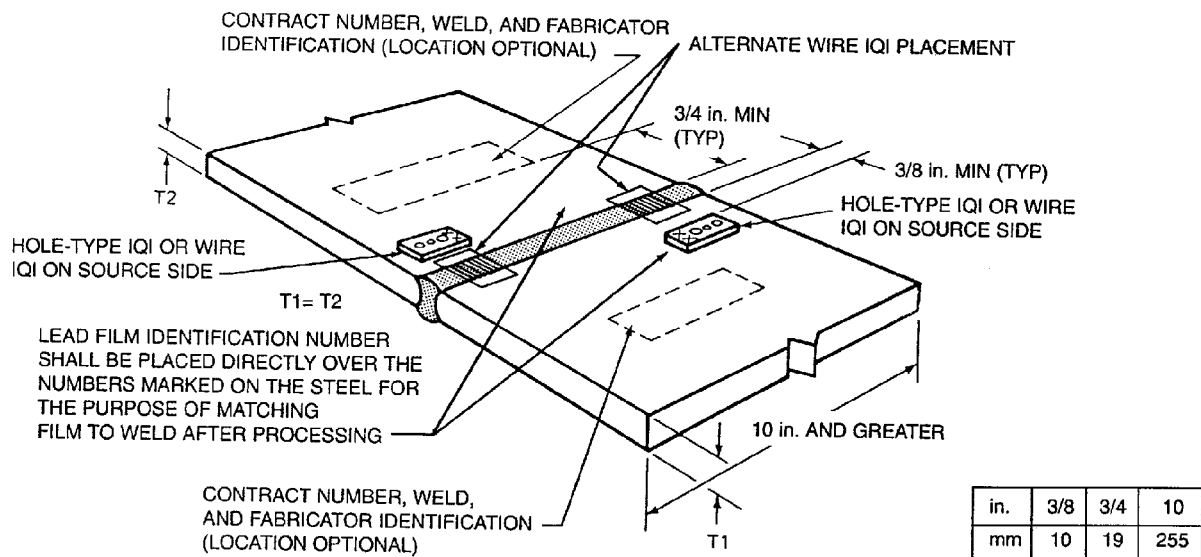


Figure C1—Radiographic Identification and Penetrameter or Wire IQI Locations on Approximately Equal Thickness Joints 10 inches and Greater in Length

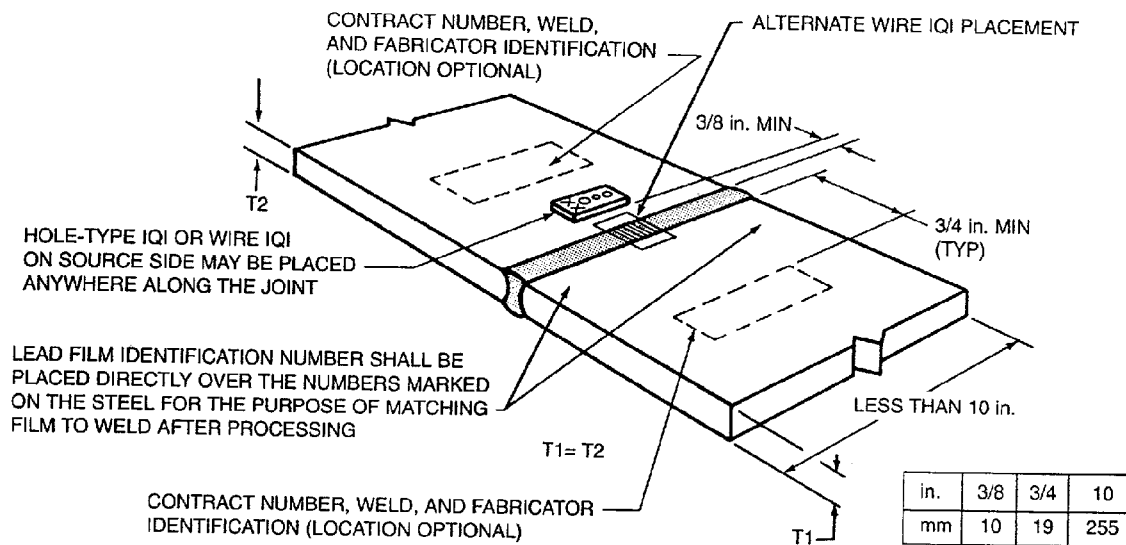


Figure C2—Radiographic Identification and Penetrameter or Wire IQI Locations on Approximately Equal Thickness Joints Less Than 10 inches in Length

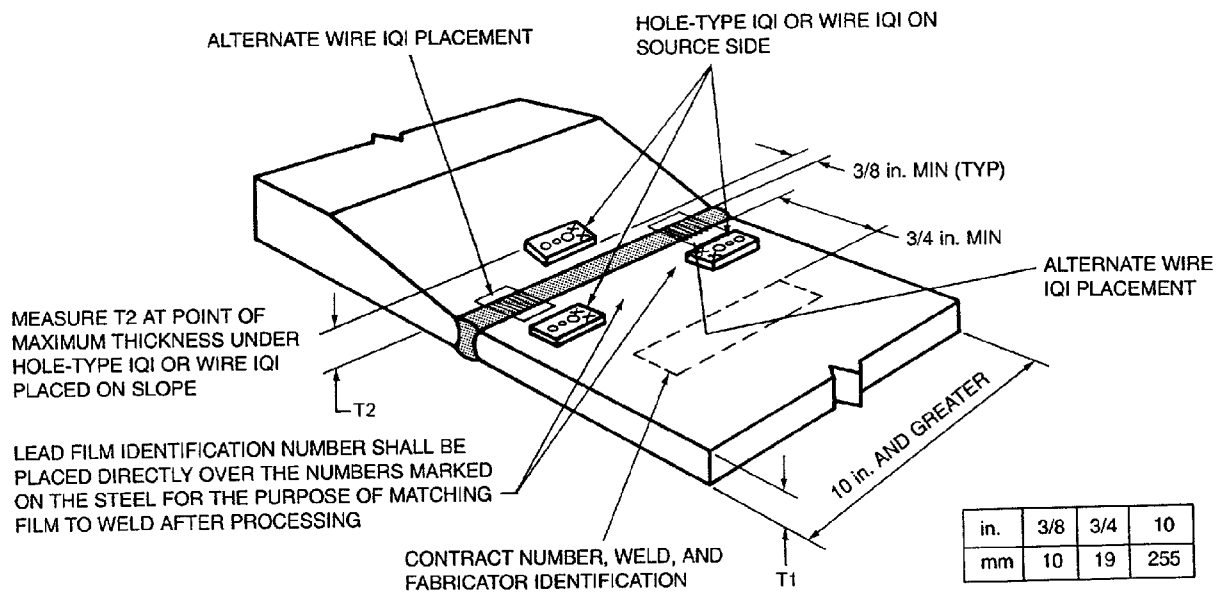


Figure C3—Radiographic Identification and Penetrameter or Wire IQI Locations on Transition Joints 10 inches and Greater in Length

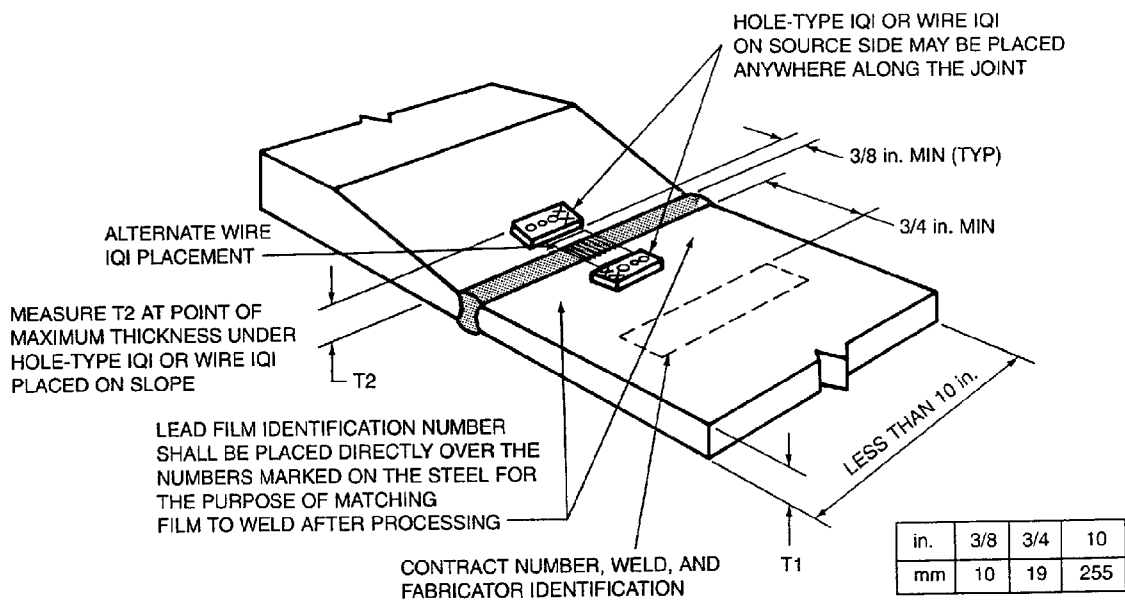
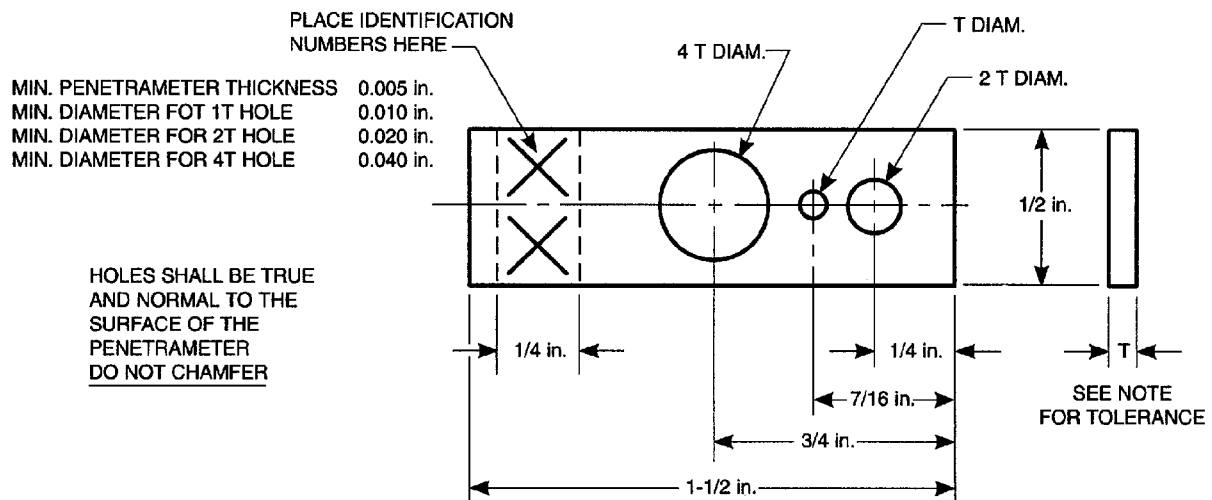
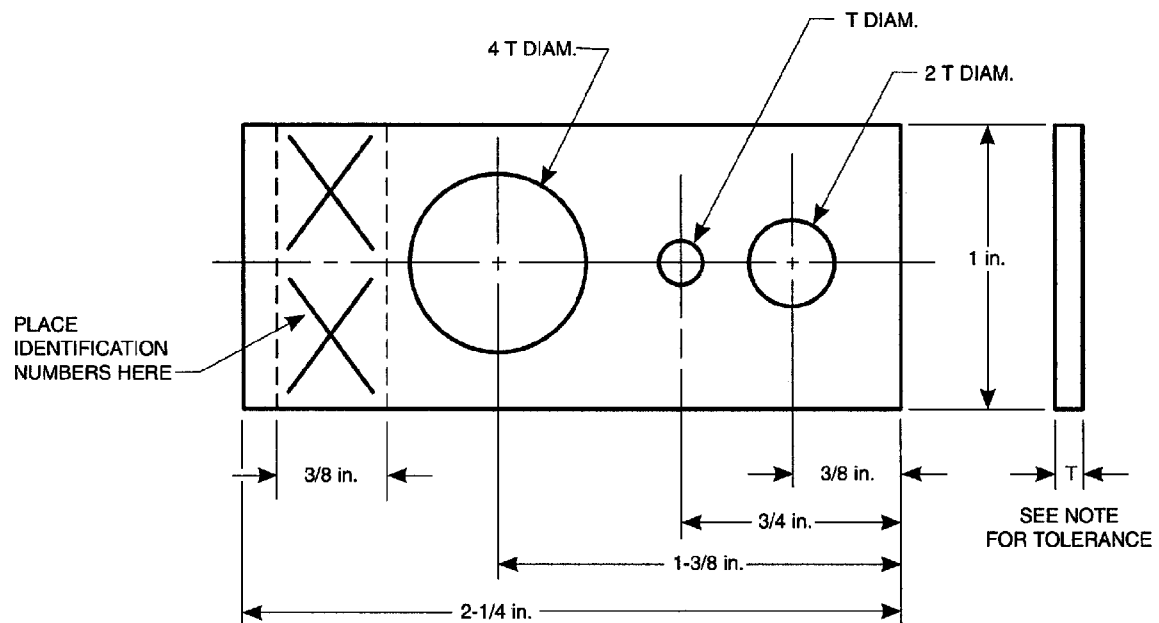


Figure C4—Radiographic Identification and Penetrameter or Wire IQI Locations on Transition Joints Less Than 10 inches in Length



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



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. 1 in. = 25.4 mm.

Figure C5—Penetrator Design

ENCAPSULATED BETWEEN
TWO SHEETS OF .030 in.
(0.76 mm) CLEAR 'VINYL'
PLASTIC

FOR SETS A & B, THE
MINIMUM DISTANCE
BETWEEN THE AXIS
OF WIRES IS NOT LESS
THAN 3 TIMES THE
DIAMETER AND
NOT MORE THAN
5 mm (0.2 in.)

FOR SETS C & D, THE
MINIMUM DISTANCE
BETWEEN THE AXIS
OF WIRES IS NOT LESS
THAN 3 TIMES THE
DIAMETER AND
NOT MORE THAN
19 mm (0.75 in.)

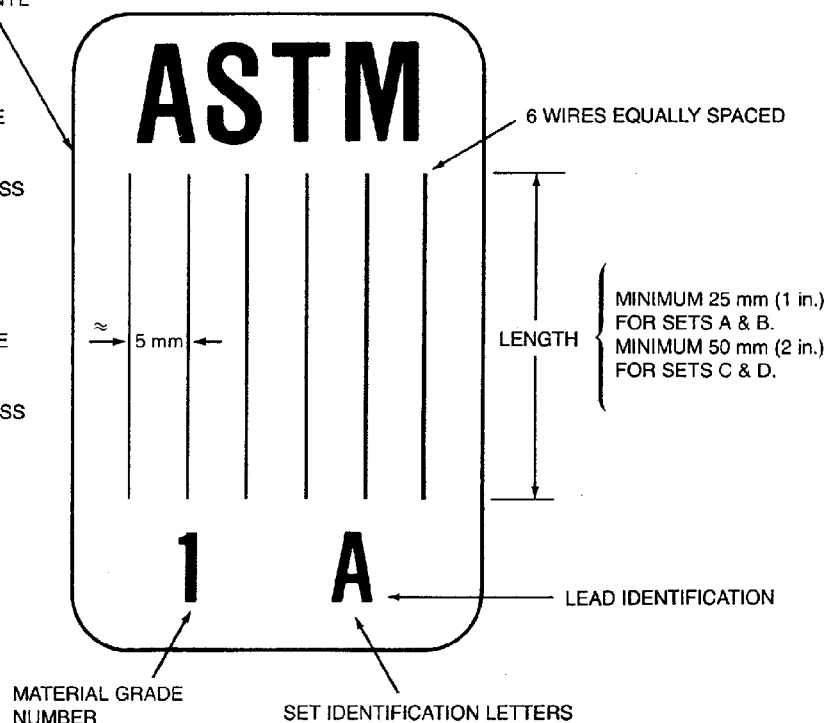


Image quality indicator (wire penetrameter) sizes

Wire diameter, in. (mm)			
Set A	Set B	Set C	Set D
0.0032 (0.08)	0.010 (0.25)	0.032 (0.81)	0.10 (2.5)
0.004 (0.1)	0.013 (0.33)	0.040 (1.02)	0.126 (3.2)
0.005 (0.13)	0.016 (0.4)	0.050 (1.27)	0.160 (4.06)
0.0063 (0.16)	0.020 (0.51)	0.063 (1.6)	0.20 (5.1)
0.008 (0.2)	0.025 (0.64)	0.080 (2.03)	0.25 (6.4)
0.010 (0.25)	0.032 (0.81)	0.100 (2.5)	0.32 (8)

Figure C6—Image Quality Indicator (Wire Penetrameter)

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C3.2.10.1 The density measured shall be H&D density (radiographic density), which is a measure of film blackening, and is expressed as:

$$H\&D = \log I_0/I$$

where

I_0 = light intensity of the film, and

I = light transmitted through the film

C3.2.10.2 When weld transitions in 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 the thinner section. When this is done, the minimum density requirements of C3.2.11 shall be waived unless otherwise provided in the contract documents.

C3.2.11 A radiograph identification mark and two location identification marks shall be placed at each radiograph location. A corresponding radiograph identification mark and two location identification marks, all of which shall show in the radiograph, shall be produced by placing lead numbers or letters, or both, over each of the identical identification and location marks to provide a means for matching the developed radiograph to the weld. Additional identification information may be pre-printed no less than 3/4 in. (19 mm) from the edge of the weld or shall be produced on the radiograph by placing lead figures on the material.

Information required to show on the radiograph shall include the owner's contract identification, initials of the radiographic inspection company, initials of the fabricator, the fabricator shop order number, the radiographic identification mark, and the date and the weld repair number, if applicable.

C3.3 Acceptance Standards

C3.3.1 Terminology

C3.3.1.1 Rounded Indications. Indications with a maximum length of three times the width or less on the radiograph are defined as rounded indications. These indications may be circular, elliptical, conical, or irregular in shape and may have tails. When evaluating the size of an indication, the tail shall be included. The indication may be from any imperfection in the weld, such as porosity, slag, or tungsten.

C3.3.1.2 Aligned Indications. A sequence of four or more rounded indications shall be considered to be aligned when they touch a line parallel to the length of the weld drawn through the center of the two outer rounded indications.

C3.3.1.3 Thickness, t . Thickness, t , is the thickness of the weld, excluding any allowable reinforcement. For a butt weld joining two members having different thicknesses at the weld, t is the thinner of these two thicknesses. If a full-penetration weld includes a fillet weld, the thickness of the throat of the fillet shall be included in t .

C3.3.2 Acceptance Criteria

C3.3.2.1 Image Density. Density within the image of the indication may vary and is not a criterion for acceptance or rejection.

C3.3.2.2 Relevant Indications (See Table C3 for examples). Only those rounded indications which exceed the following dimensions shall be considered relevant.

(1/10 of t) for t less than 1/8 in. (3.2 mm)

1/64 in. (0.4 mm) for t from 1/8 in. (3.2 mm) to 1/4 in. (6.4 mm), incl.

1/32 in. (0.8 mm) for t greater than 1/4 in. (6.4 mm) to 2 in. (50 mm), incl.

1/16 in. (1.6 mm) for t greater than 2 in. (50 mm)

C3.3.2.3 Maximum Size of Rounded Indications. The maximum permissible size of any indication shall be 1/4 of t , or 5/32 in. (4 mm), whichever is smaller; except that an isolated indication separated from an adjacent indication by 1 in. (25 mm) or more may be 1/3 t or 1/4 in. (3.2 mm), whichever is less.

Table C3*
Examples of Acceptance Indications

Thickness t , in.	Maximum Size of Acceptable Rounded Indication, in.			Maximum Size of Nonrelevant Indication, in.
	Random	Isolated		
Less than 1/8	1/4 t	1/3 t		1/10 t
1/8	0.031	0.042		0.015
3/16	0.047	0.063		0.015
1/4	0.063	0.083		0.015
5/16	0.078	0.104		0.031
3/8	0.091	0.125		0.031
7/16	0.109	0.146		0.031
1/2	0.125	0.168		0.031
9/16	0.142	0.188		0.031
5/8	0.156	0.210		0.031
11/16	0.156	0.230		0.031
3/4 to 2, incl.	0.156	0.250		0.031
Over 2	0.156	0.375		0.063

*This table contains examples only.

C3.3.2.4 Aligned Rounded Indications. Aligned rounded indications are acceptable when the summation of the diameters of the indications is less than t in a length of $12t$ (see Figure C7). The length of groups of aligned rounded indications and the spacing between the groups shall meet the requirements of Figure C8.

C3.3.2.5 Spacing. The distance between adjacent rounded indications is not a factor in determining acceptance or rejection, except as required for isolated indications or groups of aligned indications.

C3.3.2.6 Rounded Indication Charts. The rounded indications characterized as imperfections shall not exceed that shown in the charts. The charts in Figures C9 through C14 illustrate various types of assorted, randomly dispersed and clustered rounded indications for different weld thicknesses greater than $1/8$ in. (3.2 mm). These charts represent the maximum acceptable concentration limits for rounded indications. The charts for each thickness range represent full-scale 6 in. (150 mm) radiographs and shall not be enlarged or reduced. The distributions shown are not necessarily the patterns that may appear on the radiograph, but are typical of the concentration and size of indications permitted.

C3.3.2.7 Weld Thickness t less than $1/8$ in. For t less than $1/8$ in. (3.2 mm), the maximum number of rounded indications shall not exceed 12 in a 6 in. (150 mm) length of weld. A proportionally fewer number of indications shall be permitted in welds less than 6 in. in length.

C3.3.2.8 Clustered Indications. The illustrations for clustered indications show up to four times as many indications in a local area as that shown in the illustrations for random indications. The length of an acceptable cluster shall not exceed the lesser of 1 in. (25 mm) or $2t$. Where more than one cluster is present, the sum of the

lengths of the clusters shall not exceed 1 in. (25 mm) in a 6 in. (150 mm) length weld.

C3.3.2.9 Unacceptable Indications. Any type of crack, nonfusion zone, or incomplete penetration is not acceptable.

C3.4 Defect Removal and Repair. Unacceptable imperfections shall be removed and re-examination made to assure the complete removal. Whenever a defect is removed and subsequent repair by welding is not required, the excavated area shall be blended into the surrounding surface so as to avoid sharp notches, crevices, or corners. Where welding is required after removal of a defect, the area shall be cleaned, and the welding shall be performed in conformance to a qualified welding procedure. Complete repairs shall be re-examined by the method originally used for detection of the defect. (See section 8, Modifications and Repair, for mandatory requirements.)

C3.5 Examination, Report, and Disposition of Radiographs

C3.5.1 The manufacturer shall provide a suitable high intensity viewer with sufficient capacity to illuminate radiographs with a density of 4.0 without difficulty. (It is recommended that a two level or variable intensity illuminator be used.)

C3.5.2 Before a weld subject to radiographic testing by the manufacturer is accepted, all of its final radiographs and the report interpreting them shall be available to the purchaser's inspector.

C3.5.3 A full set of final radiographs for welds subject to radiographic testing by the manufacturer shall be delivered to the purchaser upon completion of the work, if required by contract.

C3.5.4 The manufacturer shall maintain final radiographs for a minimum of five years after completion of contract.

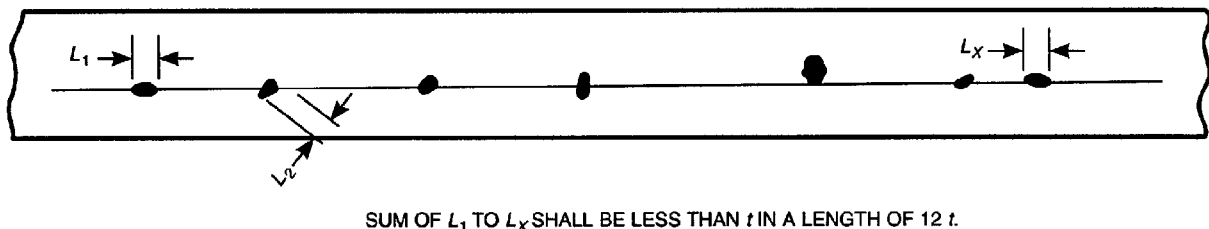
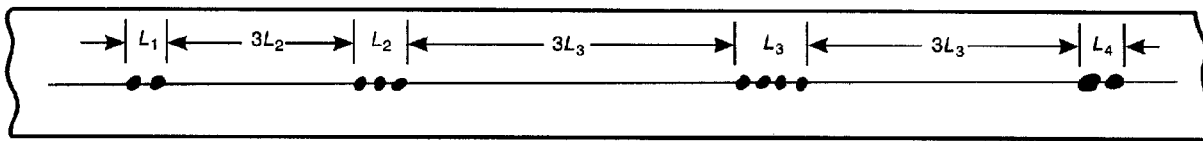


Figure C7—Aligned Rounded Indications

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THE SUM OF THE GROUP LENGTHS SHALL BE LESS THAN t IN A LENGTH OF $12t$.

MAXIMUM GROUP LENGTH

$L = 1/4$ in. FOR t LESS THAN $3/4$ in.

$L = 1/3$ FOR t $3/4$ in. TO $2-1/4$ in.

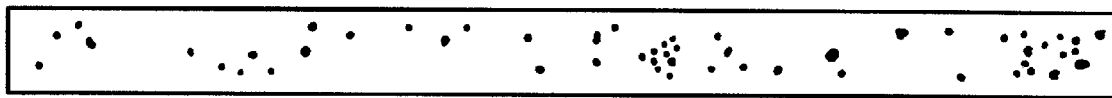
$L = 3/4$ in. FOR t GREATER THAN $2-1/4$ in.

MAXIMUM GROUP SPACING

$3L$ WHERE L IS THE LENGTH OF THE LONGEST ADJACENT GROUP BEING EVALUATED.

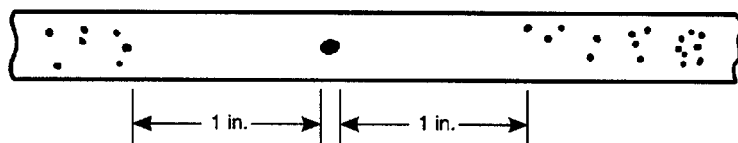
Figure C8—Groups of Aligned Rounded Indications

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RANDOM ROUNDED INDICATIONS

TYPICAL CONCENTRATION AND SIZE PERMITTED
IN ANY 6 in. LENGTH OF WELD



ISOLATED INDICATION

MAXIMUM SIZE PER C3.3.2



CLUSTER

Figure C9—Charts for t Equal to $1/8$ in. to $1/4$ in., Inclusive

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RANDOM ROUNDED INDICATIONS

TYPICAL CONCENTRATION AND SIZE PERMITTED
IN ANY 6 in. LENGTH OF WELD

ISOLATED INDICATION

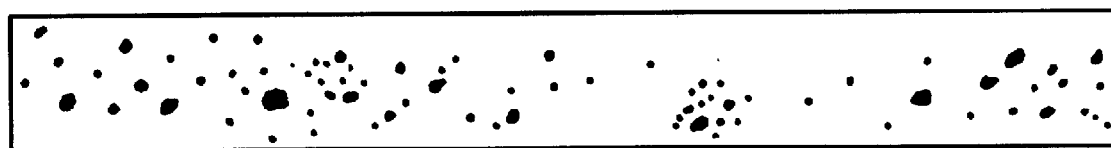
MAXIMUM SIZE PER C3.3.2



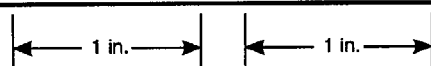
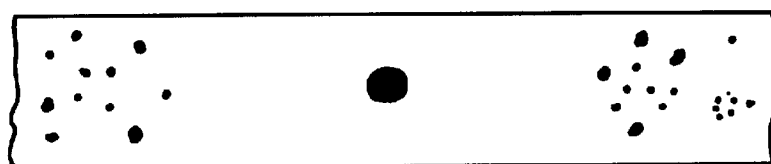
CLUSTER

Figure C10—Charts for t Over 1/4 in. to 3/8 in., Inclusive

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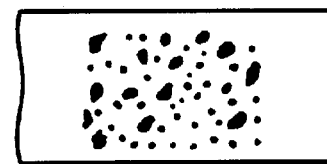


RANDOM ROUNDED INDICATIONS

TYPICAL CONCENTRATION AND SIZE PERMITTED
IN ANY 6 in. LENGTH OF WELD

ISOLATED INDICATION

MAXIMUM SIZE PER C3.3.2



CLUSTER

Figure C11—Charts for t Over 3/8 in. to 3/4 in., Inclusive

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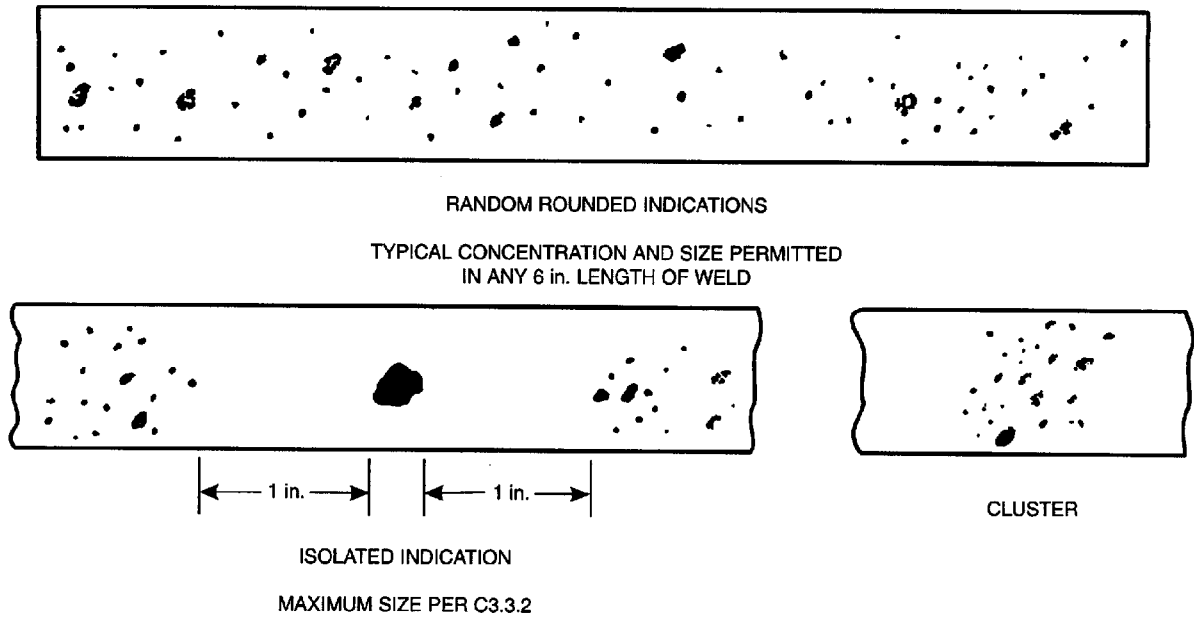


Figure C12—Charts for t Over $3/4$ in. to 2 in., Inclusive

(Reproduced by permission of ASME to use Section VIII – Div. 1, Appendix 4, 1992)

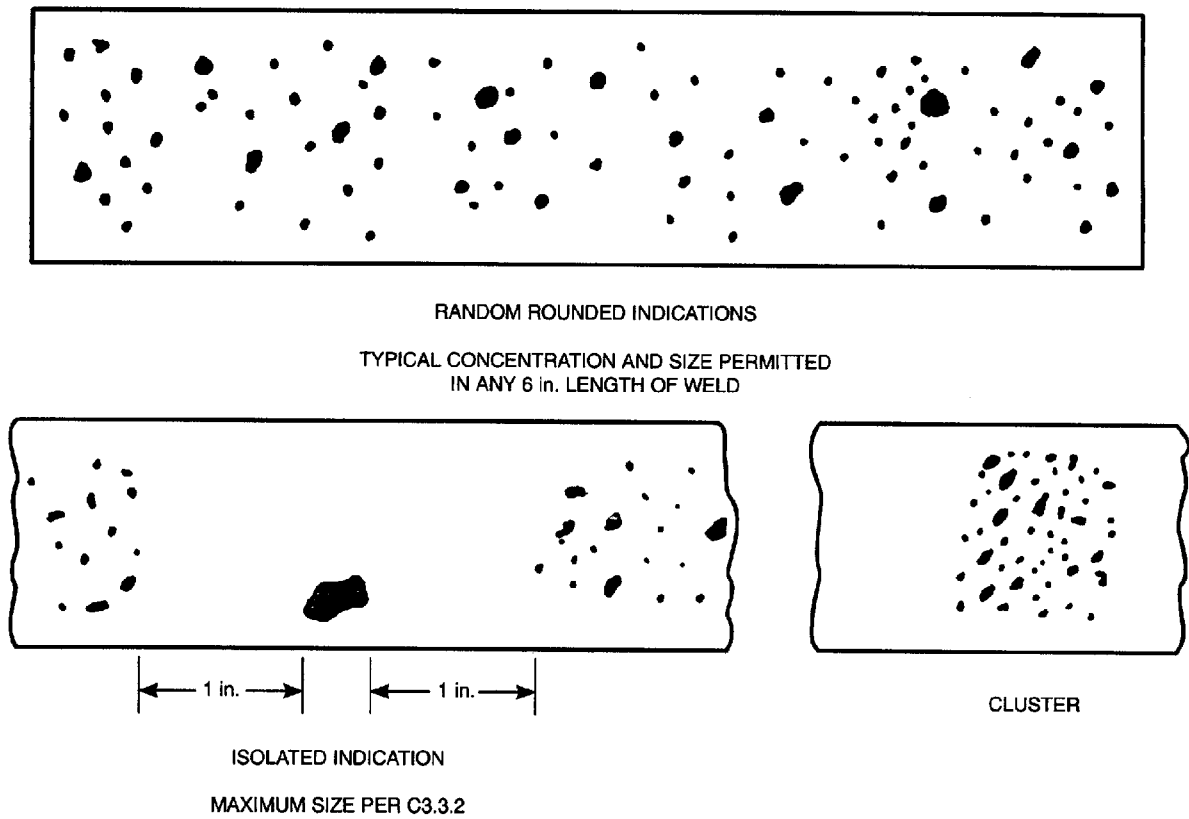
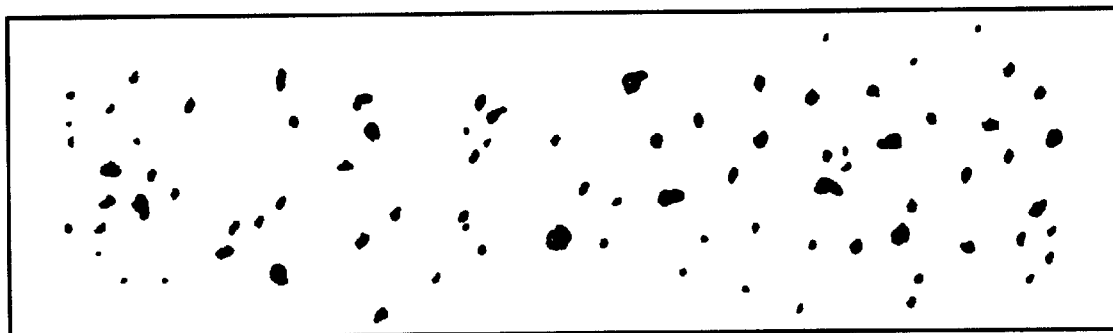


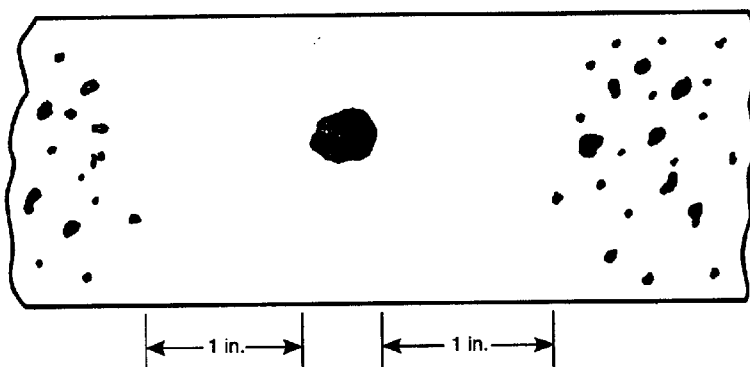
Figure C13—Charts for t Over 2 in. to 4 in., Inclusive

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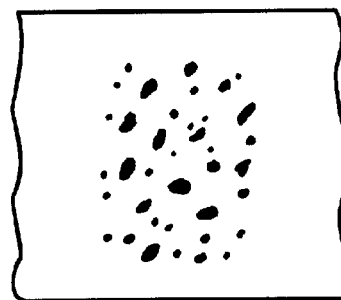
RANDOM ROUNDED INDICATIONS

TYPICAL CONCENTRATION AND SIZE PERMITTED
IN ANY 6 in. LENGTH OF WELD



ISOLATED INDICATION

MAXIMUM SIZE PER C3.3.2



CLUSTER

Figure C14—Charts for t Over 4 in.

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Annex D

Safety Considerations

(This Annex is not a part of ANSI/AWS D14.6-96, *Specification for Welding of Rotating Elements of Equipment*, but is included for information purposes only.)

WARNING: Protect Yourself and Others from Possible Serious Injury or Death.

D1. ELECTRIC SHOCK CAN KILL

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

(2) In semiautomatic or automatic wire welding, the electrode, electrode reel, welding head, nozzle or semi-automatic welding gun are also electrically “hot.”

(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.

(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.

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

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

(7) Never dip the electrode holder in water for cooling.

(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.

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

(10) Also see items D4(3) and D6.

D2. ARC RAYS CAN BURN

(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. For proper headshield and filter lens refer to ANSI Z87.1 standards.

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

(3) Protect other nearby personnel with suitable non-flammable screening and warn them not to watch the arc nor expose themselves to the arc rays or to hot spatter or metal.

D3. FUMES AND GASES CAN BE DANGEROUS

(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, 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.

(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.

(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.

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

(5) Also see item D7(2).

D4. WELDING SPARKS CAN CAUSE FIRE OR EXPLOSION

(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.

(2) Where compressed gases are to be used at the job site, special precautions should be used to prevent hazardous situations. Refer to ANSI Z49.1, *Safety in Welding, Cutting, and Allied Processes*, and the operating information for the equipment being used.

(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.

(4) Do not heat, cut or weld tanks, drums, or containers until the proper steps have been taken to insure that such containers are free from flammable or toxic vapors that have been stored inside these containers. These vapors can cause these containers to explode even though they have been have been "cleaned." For information, see AWS F4.1, *Recommended Practices for the Preparation for Welding and Cutting of Containers and Piping*.

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

(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.

(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.

(8) Also see item D7(3).

D5. GAS CYLINDERS MAY EXPLODE IF DAMAGED

(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.

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

(3) Cylinders should be located:

(a) Away from areas where they may be struck or subjected to physical damage.

(b) A safe distance from arc welding or cutting operations and any other source of heat, sparks, or flame.

(4) Never allow the electrode, electrode holder, or any other electrically "hot" parts to touch a cylinder.

(5) Never strike an arc on a compressed gas cylinder.

(6) Keep your head and face away from the cylinder valve outlet when opening the cylinder valve.

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

(8) Read and follow the instructions on compressed gas cylinders, associated equipment, and CGA publication P-1, *Safe Handling of Compressed Gases in Containers*, available from the Compressed Gas Association, Inc., 1725 Jefferson Davis Highway, Suite 1004, Arlington, VA 22202-4102.

D6. FOR ELECTRICALLY POWERED EQUIPMENT

- (1) Turn off input power using the disconnect switch at the fuse box before working on the equipment.
- (2) Install equipment in conformance to the National Electrical Code, all local codes and the manufacturer's recommendations.
- (3) Ground the equipment in conformance to the National Electrical Code and the manufacturer's recommendations.

D7. FOR ENGINE POWERED EQUIPMENT

- (1) Turn the engine off before troubleshooting and maintenance work unless the maintenance work requires it to be running.
- (2) Operate engines in open, well-ventilated areas or vent the engine exhaust fumes outdoors.
- (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.
- (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.
- (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.
- (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.
- (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.
- (8) To avoid scalding, do not remove the radiator pressure cap when the engine is hot.

Commonly Used Metric Conversions
Inch-millimeter conversion
1 in. = 25.4 mm exactly

To convert inches to millimeters,
multiply the inch

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

Inch and Millimeter Decimal Equivalents of Fractions of an Inch

Inch			Inch		
Fraction	Decimal	Millimeter	Fraction	Decimal	Millimeter
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

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AWS Documents on Machinery and Equipment	
Document Code	Document 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 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, Miami, FL 33126 (Phone) 1-800-334-9353.