

SPECIFICATION FOR LOW-ALLOY STEEL ELECTRODES FOR SHIELDED METAL ARC WELDING



SFA-5.5



(Identical with AWS Specification A5.5-96.)

1. Scope

This specification prescribes requirements for the classification of low-alloy steel electrodes for shielded metal arc welding of carbon and low-alloy steels. These electrodes include steel alloys in which no single alloying element exceeds 10.5 percent.

PART A — GENERAL REQUIREMENTS

2. Classification

2.1 The welding electrodes covered by this specification are classified according to the following:

- (a) Type of current (Table 1)
- (b) Type of covering (Table 1)
- (c) Welding position (Table 1)
- (d) Chemical composition of the weld metal (Table 2)
- (e) Mechanical properties of the weld metal in the as-welded or postweld heat-treated condition (Tables 3 and 4)

2.2 Material classified under one classification shall not be classified under any other classification in this specification.

3. Acceptance

Acceptance¹ of the welding electrode shall be in accordance with the provisions of the ANSI/AWS A5.01, *Filler Metal Procurement Guidelines*.

¹ See Section A3, Acceptance (in the Appendix), for further information concerning acceptance, testing of the material shipped, and ANSI/AWS A5.01, *Filler Metal Procurement Guidelines*.

4. Certification

By affixing the AWS specification and classification designations to the packaging, or the classification to the product, the manufacturer certifies that the product meets the requirements of this specification.²

5. Units of Measure and Rounding-Off Procedure

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

5.2 For the purpose of determining conformance with this specification, an observed or calculated value shall be rounded "to the nearest unit" in the last right-hand place of figures used in expressing the limiting value in accordance with the rounding-off rules given in ASTM E29, *Standard Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications*.

² See Section A4, Certification (in the Annex), for further information concerning certification and the testing called for to meet this requirement.

TABLE 1
ELECTRODE CLASSIFICATION

AWS Classification ^a	Type of Covering	Welding Positions for Classification ^b	Type of Current ^c
E7010-X	High-cellulose sodium	F,V,OH,H	DCEP
E7011-X	High-cellulose potassium	F,V,OH,H	ac or DCEP
E7015-X ^{d,e}	Low-hydrogen sodium	F,V,OH,H	DCEP
E7016-X ^{d,e}	Low-hydrogen potassium	F,V,OH,H	ac or DCEP
E7018-X ^{d,e}	Low-hydrogen potassium, iron powder	F,V,OH,H	ac or DCEP
E7020-X	High-iron oxide	H-fillets	ac or DCEN
		F	ac, DCEP or DCEN
E7027-X	High-iron oxide, iron powder	H-fillets	ac or DCEN
		F	ac, DCEP or DCEN
E8010-X	High-cellulose sodium	F,V,OH,H	DCEP
E8011-G	High-cellulose potassium	F,V,OH,H	ac or DCEP
E8013-G	High-titania potassium	F,V,OH,H	ac, DCEP or DCEN
E8015-X ^{d,e}	Low-hydrogen sodium	F,V,OH,H	DCEP
E8016-X ^{d,e}	Low-hydrogen potassium	F,V,OH,H	ac or DCEP
E8018-X ^{d,e}	Low-hydrogen potassium, iron powder	F,V,OH,H	ac or DCEP
E9010-G	High-cellulose sodium	F,V,OH,H	DCEP
E9011-G	High-cellulose potassium	F,V,OH,H	ac or DCEP
E9013-G	High-titania potassium	F,V,OH,H	ac, DCEP or DCEN
E9015-X ^{d,e}	Low-hydrogen sodium	F,V,OH,H	DCEP
E9016-X ^{d,e}	Low-hydrogen potassium	F,V,OH,H	ac or DCEP
E9018-X ^{d,e}	Low-hydrogen potassium, iron powder	F,V,OH,H	ac or DCEP
E9018M ^{d,e}	Iron-powder, low hydrogen	F,V,OH,H	DCEP
E10010-G	High-cellulose sodium	F,V,OH,H	DCEP
E10011-G	High-cellulose potassium	F,V,OH,H	ac or DCEP
E10013-G	High-titania potassium	F,V,OH,H	ac, DCEP or DCEN
E10015-X ^{d,e}	Low-hydrogen sodium	F,V,OH,H	DCEP
E10016-X ^{d,e}	Low-hydrogen potassium	F,V,OH,H	ac or DCEP
E10018-X ^{d,e}	Low-hydrogen potassium, iron powder	F,V,OH,H	ac or DCEP
E10018M ^{d,e}	Iron-powder, low hydrogen	F,V,OH,H	DCEP
E11010-G	High-cellulose sodium	F,V,OH,H	DCEP
E11011-G	High-cellulose potassium	F,V,OH,H	ac or DCEP
E11013-G	High-titania potassium	F,V,OH,H	ac, DCEP or DCEN
E11015-G ^{d,e}	Low-hydrogen sodium	F,V,OH,H	DCEP
E11016-G ^{d,e}	Low-hydrogen potassium	F,V,OH,H	ac or DCEP
E11018-G ^{d,e}	Low-hydrogen potassium, iron powder	F,V,OH,H	ac or DCEP
E11018M ^{d,e}	Iron-powder, low hydrogen	F,V,OH,H	DCEP
E12010-G	High-cellulose sodium	F,V,OH,H	DCEP
E12011-G	High-cellulose potassium	F,V,OH,H	ac or DCEP
E12013-G	High-titania potassium	F,V,OH,H	ac, DCEP or DCEN
E12015-G ^{d,e}	Low-hydrogen sodium	F,V,OH,H	DCEP
E12016-G ^{d,e}	Low-hydrogen potassium	F,V,OH,H	ac or DCEP
E12018-G ^{d,e}	Low-hydrogen potassium, iron powder	F,V,OH,H	ac or DCEP
E12018M ^{d,e}	Iron-powder, low hydrogen	F,V,OH,H	DCEP
E12018M1 ^{d,e}	Iron-powder, low hydrogen	F,V,OH,H	DCEP

TABLE 1 (CONT'D)
ELECTRODE CLASSIFICATION

NOTES:

- a. The letter suffix "X" as used in this table stands for the suffixes A1, B1, B3, etc. (see Table 2) and designates the chemical composition of the weld metal. See A2.2.3 for more information on "G" classification.
- b. The abbreviations, F, V, OH, H, and H-fillets indicate the welding position as follows:
F = Flat
H = Horizontal
H-fillets = Horizontal fillets
V = Vertical (For electrodes $\frac{3}{16}$ in. (4.8 mm) and under, except $\frac{3}{32}$ in. (4.0 mm) and under for classifications EXX15-X, EXX16-X, EXX18-X)
OH = Overhead (For electrodes $\frac{3}{16}$ in. (4.8 mm) and under, except $\frac{3}{32}$ in. (4.0 mm) and under for classifications EXX15-X, EXX16-X, EXX18-X).
- c. The term "DCEP" refers to direct current, electrode positive (dc, reverse polarity). The term "DCEN" refers to direct current, electrode negative (dc, straight polarity).
- d. Electrodes classified as EXX15-X, EXX16-X, EXX18-X, or EXX18M(1) which meet supplemental absorbed moisture requirements in Table 11 may be further identified as shown in Table 11 and Figure 12.
- e. Electrodes classified as EXX15-X, EXX16-X, EXX18-X, or EXX18M(1) which produce weld metal that meets the maximum average level of diffusible hydrogen in Table 12 may be further identified as specified in Table 12 and Figure 12.

PART B — TESTS, PROCEDURES, AND
REQUIREMENTS

6. Summary of Tests

The tests required for each classification are specified in Table 5. The purpose of these tests is to determine the chemical composition, mechanical properties and soundness of the weld metal, the usability of the electrode, and the moisture content of the low-hydrogen electrode covering. The base metal for the weld test assemblies, the welding and testing procedures to be employed, and the results required are given in Sections 8 through 14.

The supplemental tests for absorbed moisture (see Section 15, Absorbed Moisture Test), and for diffusible hydrogen (see Section 16, Diffusible Hydrogen Test), are not required for classification of the low-hydrogen electrodes (see Note i of Table 5).

7. Retest

If the results of any test fail to meet the requirement, that test shall be repeated twice. The results of both retests shall meet the requirement. Specimens for the retest may be taken from the original test assembly or from a new test assembly. For chemical analysis, retest need be only for those specific elements that failed to meet the test requirement.

8. Weld Test Assemblies

8.1 One or more of the following weld test assemblies are required for classification testing.

(1) The weld pad in Fig. 1 for chemical analysis of the undiluted weld metal.

(2) The groove weld in Fig. 2 for mechanical properties and soundness of the weld metal for all classifications except EXX18M(1).

(3) The fillet weld in Fig. 3 for the usability of the electrode.

(4) The groove weld in Fig. 4, an alternate to (2) above, for mechanical properties and soundness of the weld metal made with the E9018M, E10018M, E11018M, E12018M, or E12018M1 electrode.

The sample for chemical analysis may be taken from the reduced section of the fractured tension test specimen or from a corresponding location (or any location above it) in the weld metal in the groove weld in Figs. 2 or 4. In case of dispute, the weld pad in Fig. 1 shall be the referee method.

8.2 The preparation of each weld test assembly shall be as prescribed in 8.3 through 8.5. The base metal for each assembly shall be as required in Table 6 and shall meet the requirements of the ASTM specification shown there or an equivalent specification. Testing of the assemblies shall be as prescribed in Sections 9 through 13.

Electrodes other than low hydrogen, as defined in Table 1, shall be tested without conditioning. Low-hydrogen electrodes, that have not been adequately protected against moisture absorption in storage, shall be held at a temperature of 500° to 800°F (260° to 427°C) for a minimum of one hour prior to testing.

8.3 Weld Pad. A weld pad, when required, shall be prepared as specified in Fig. 1. Base metal of any

TABLE 2
CHEMICAL COMPOSITION REQUIREMENTS FOR UNDILUTED WELD METAL

AWS Classification ^c	UNS Number ^d	Wt. Percent ^{a,b}										Additional Elements	
		C	Mn	Si	P	S	Ni	Cr	Mo	Type	Amt.		
												Carbon-Molybdenum Steel Electrodes	
E7010-A1	W17010	0.12	0.60	0.40	0.03	0.03	—	—	0.40-0.65	—	—		
E7011-A1	W17011	0.12	0.60	0.40	0.03	0.03	—	—	0.40-0.65	—	—		
E7015-A1	W17015	0.12	0.90	0.60	0.03	0.03	—	—	0.40-0.65	—	—		
E7016-A1	W17016	0.12	0.90	0.60	0.03	0.03	—	—	0.40-0.65	—	—		
E7018-A1	W17018	0.12	0.90	0.80	0.03	0.03	—	—	0.40-0.65	—	—		
E7020-A1	W17020	0.12	0.60	0.40	0.03	0.03	—	—	0.40-0.65	—	—		
E7027-A1	W17027	0.12	1.00	0.40	0.03	0.03	—	—	0.40-0.65	—	—		
Chromium-Molybdenum Steel Electrodes													
E8016-B1	W51016	0.05-0.12	0.90	0.60	0.03	0.03	—	0.40-0.65	0.40-0.65	—	—		
E8018-B1	W51018	0.05-0.12	0.90	0.80	0.03	0.03	—	0.40-0.65	0.40-0.65	—	—		
E8016-B2	W52016	0.05-0.12	0.90	0.60	0.03	0.03	—	1.00-1.50	0.40-0.65	—	—		
E8018-B2	W52018	0.05-0.12	0.90	0.80	0.03	0.03	—	1.00-1.50	0.40-0.65	—	—		
E7015-B2L	W52115	0.05	0.90	1.00	0.03	0.03	—	1.00-1.50	0.40-0.65	—	—		
E7016-B2L	W52116	0.05	0.90	0.60	0.03	0.03	—	1.00-1.50	0.40-0.65	—	—		
E7018-B2L	W52118	0.05	0.90	0.80	0.03	0.03	—	1.00-1.50	0.40-0.65	—	—		
E9015-B3	W53015	0.05-0.12	0.90	1.00	0.03	0.03	—	2.00-2.50	0.90-1.20	—	—		
E9016-B3	W53016	0.05-0.12	0.90	0.60	0.03	0.03	—	2.00-2.50	0.90-1.20	—	—		
E9018-B3	W53018	0.05-0.12	0.90	0.80	0.03	0.03	—	2.00-2.50	0.90-1.20	—	—		
E8015-B3L	W53115	0.05	0.90	1.00	0.03	0.03	—	2.00-2.50	0.90-1.20	—	—		
E8018-B3L	W53118	0.05	0.90	0.80	0.03	0.03	—	2.00-2.50	0.90-1.20	—	—		
E8015-B4L	W53415	0.05	0.90	1.00	0.03	0.03	—	1.75-2.25	0.40-0.65	—	—		
E8016-B5	W51316	0.07-0.15	0.40-0.70	0.30-0.60	0.03	0.03	—	0.40-0.60	1.00-1.25	V	0.05		
E8015-B6 ^e	W50215	0.05-0.10	1.0	0.90	0.03	0.03	0.40	4.0-6.0	0.45-0.65	—	—		
E8016-B6 ^e	W50216	0.05-0.10	1.0	0.90	0.03	0.03	0.40	4.0-6.0	0.45-0.65	—	—		
E8018-B6 ^e	W50218	0.05-0.10	1.0	0.90	0.03	0.03	0.40	4.0-6.0	0.45-0.65	—	—		
E8015-B6L ^e	W50205	0.05	1.0	0.90	0.03	0.03	0.40	4.0-6.0	0.45-0.65	—	—		

(continued)

(continued)

PART C — SPECIFICATIONS FOR WELDING RODS,
ELECTRODES, AND FILLER METALS

SFA-5.5

TABLE 2 (CONT'D)
CHEMICAL COMPOSITION REQUIREMENTS FOR UNDILUTED WELD METAL

AWS Classification ^c	UNS Number ^d	C	Mn	Si	P	S	Ni	Cr	Mo	Additional Elements			
										Type	Amt.		
Chromium-Molybdenum Steel Electrodes (continued)													
E8016-B6L ^e	W50206	0.05	1.0	0.90	0.03	0.03	0.40	4.0-6.0	0.45-0.65	—	—	—	—
E8018-B6L ^e	W50208	0.05	1.0	0.90	0.03	0.03	0.40	4.0-6.0	0.45-0.65	—	—	—	—
E8015-B7 ^e	W50315	0.05-0.10	1.0	0.90	0.03	0.03	0.40	6.0-8.0	0.45-0.65	—	—	—	—
E8016-B7 ^e	W50316	0.05-0.10	1.0	0.90	0.03	0.03	0.40	6.0-8.0	0.45-0.65	—	—	—	—
E8018-B7 ^e	W50318	0.05-0.10	1.0	0.90	0.03	0.03	0.40	6.0-8.0	0.45-0.65	—	—	—	—
E8015-B7L ^e	W50305	0.05	1.0	0.90	0.03	0.03	0.40	6.0-8.0	0.45-0.65	—	—	—	—
E8016-B7L ^e	W50306	0.05	1.0	0.90	0.03	0.03	0.40	6.0-8.0	0.45-0.65	—	—	—	—
E8018-B7L ^e	W50308	0.05	1.0	0.90	0.03	0.03	0.40	6.0-8.0	0.45-0.65	—	—	—	—
E8015-B8 ^e	W50415	0.05-0.10	1.0	0.90	0.03	0.03	0.40	8.0-10.5	0.85-1.20	—	—	—	—
E8016-B8 ^e	W50416	0.05-0.10	1.0	0.90	0.03	0.03	0.40	8.0-10.5	0.85-1.20	—	—	—	—
E8018-B8 ^e	W50418	0.05-0.10	1.0	0.90	0.03	0.03	0.40	8.0-10.5	0.85-1.20	—	—	—	—
E8015-B8L ^e	W50405	0.05	1.0	0.90	0.03	0.03	0.40	8.0-10.5	0.85-1.20	—	—	—	—
E8016-B8L ^e	W50406	0.05	1.0	0.90	0.03	0.03	0.40	8.0-10.5	0.85-1.20	—	—	—	—
E8018-B8L ^e	W50408	0.05	1.0	0.90	0.03	0.03	0.40	8.0-10.5	0.85-1.20	—	—	—	—
E9015-B9	W50425	0.08-0.13	1.25	0.30	0.01	0.01	1.0	8.0-10.5	0.85-1.20	V	0.15-0.30	0.25	0.04
										Cu			
										Al			
										Nb(Cb)	0.02-0.10	0.02-0.07	0.15-0.30
E9016-B9	W50426	0.08-0.13	1.25	0.30	0.01	0.01	1.0	8.0-10.5	0.85-1.20	N	0.02-0.07	0.15-0.30	0.25
										V			
										Cu	0.25	0.04	
										Al			
										Nb(Cb)	0.02-0.10	0.02-0.07	0.15-0.30
E9018-B9	W50428	0.08-0.13	1.25	0.30	0.01	0.01	1.0	8.0-10.5	0.85-1.20	N	0.02-0.07	0.15-0.30	0.25
										V			
										Cu	0.25	0.04	
										Al			
										Nb(Cb)	0.02-0.10	0.02-0.07	0.15-0.30
										N			
										V	0.15-0.30	0.25	0.04
										Cu			
										Al			
										Nb(Cb)	0.02-0.10	0.02-0.07	0.15-0.30
										N			
										V	0.15-0.30	0.25	0.04
										Cu			
										Al			
										Nb(Cb)	0.02-0.10	0.02-0.07	0.15-0.30
										N			
										V	0.15-0.30	0.25	0.04
										Cu			
										Al			
										Nb(Cb)	0.02-0.10	0.02-0.07	0.15-0.30
										N			
										V	0.15-0.30	0.25	0.04
										Cu			
										Al			
										Nb(Cb)	0.02-0.10	0.02-0.07	0.15-0.30
										N			
										V	0.15-0.30	0.25	0.04
										Cu			
										Al			
										Nb(Cb)	0.02-0.10	0.02-0.07	0.15-0.30
										N			
										V	0.15-0.30	0.25	0.04
										Cu			
										Al			
										Nb(Cb)	0.02-0.10	0.02-0.07	0.15-0.30
										N			
										V	0.15-0.30	0.25	0.04
										Cu			
										Al			
										Nb(Cb)	0.02-0.10	0.02-0.07	0.15-0.30
										N			
										V	0.15-0.30	0.25	0.04
										Cu			
										Al			
										Nb(Cb)	0.02-0.10	0.02-0.07	0.15-0.30
										N			
										V	0.15-0.30	0.25	0.04
										Cu			
										Al			
										Nb(Cb)	0.02-0.10	0.02-0.07	0.15-0.30
										N			
										V	0.15-0.30	0.25	0.04
										Cu			
										Al			
										Nb(Cb)	0.02-0.10	0.02-0.07	0.15-0.30
										N			
										V	0.15-0.30	0.25	0.04
										Cu			
										Al			
										Nb(Cb)	0.02-0.10	0.02-0.07	0.15-0.30
										N			
										V	0.15-0.30	0.25	0.04
										Cu			
										Al			
										Nb(Cb)	0.02-0.10	0.02-0.07	0.15-0.30
										N			
										V	0.15-0.30	0.25	0.04
										Cu			
										Al			
										Nb(Cb)	0.02-0.10	0.02-0.07	0.15-0.30
										N			
										V	0.15-0.30	0.25	0.04
										Cu			
										Al			
										Nb(Cb)	0.02-0.10	0.02-0.07	0.15-0.30
										N			
										V	0.15-0.30	0.25	0.04
										Cu			
										Al			
										Nb(Cb)	0.02-0.10	0.02-0.07	0.15-0.30
										N			
										V	0.15-0.30	0.25	0.04
										Cu			
										Al			
										Nb(Cb)	0.02-0.10	0.02-0.07	0.15-0.30
										N			
										V	0.15-0.30	0.25	0.04
										Cu			
										Al			
										Nb(Cb)	0.02-0.10	0.02-0.07	0.15-0.30
										N			
										V	0.15-0.30	0.25	0.04
										Cu			
										Al			
										Nb(Cb)	0.02-0.10	0.02-0.07	0.15-0.30
										N			
										V	0.15-0.30	0.25	0.04
										Cu			
										Al			
										Nb(Cb)	0.02-0.10	0.02-0.07	0.15-0.30
										N			
										V	0.15-0.30	0.25	0.04
										Cu			
										Al			
										Nb(Cb)	0.02-0.10	0.02-0.07	0.15-0.30
										N			
										V	0.15-0.30	0.25	0.04

TABLE 2 (CONT'D)
CHEMICAL COMPOSITION REQUIREMENTS FOR UNDILUTED WELD METAL

Wt. Percent ^{a,b}										Additional Elements	
AWS Classification ^c	UNS Number ^d	C	Mn	Si	P	S	Ni	Cr	Mo	Type	Amt.
Nickel Steel Electrodes											
E8016-C1	W22016	0.12	1.25	0.60	0.03	0.03	2.00-2.75	—	—	—	—
E8018-C1	W22018	0.12	1.25	0.80	0.03	0.03	2.00-2.75	—	—	—	—
E7015-C1L	W22115	0.05	1.25	0.50	0.03	0.03	2.00-2.75	—	—	—	—
E7016-C1L	W22116	0.05	1.25	0.50	0.03	0.03	2.00-2.75	—	—	—	—
E7018-C1L	W22118	0.05	1.25	0.50	0.03	0.03	2.00-2.75	—	—	—	—
E8016-C2	W23016	0.12	1.25	0.60	0.03	0.03	3.00-3.75	—	—	—	—
E8018-C2	W23018	0.12	1.25	0.80	0.03	0.03	3.00-3.75	—	—	—	—
E7015-C2L	W23115	0.05	1.25	0.50	0.03	0.03	3.00-3.75	—	—	—	—
E7016-C2L	W23116	0.05	1.25	0.50	0.03	0.03	3.00-3.75	—	—	—	—
E7018-C2L	W23118	0.05	1.25	0.50	0.03	0.03	3.00-3.75	—	—	—	—
E8016-C3	W21016	0.12	0.40-1.25	0.80	0.03	0.03	0.80-1.10	0.15	0.35	V	0.05
E8018-C3 ^l	W21018	0.12	0.40-1.25	0.80	0.03	0.03	0.80-1.10	0.15	0.35	V	0.05
E7018-C3L	W20918	0.08	0.40-1.40	0.50	0.03	0.03	0.80-1.10	0.15	0.35	V	0.05
E8016-C4	W21916	0.10	1.25	0.60	0.03	0.03	1.10-2.00	—	—	—	—
E8018-C4	W21918	0.10	1.25	0.80	0.03	0.03	1.10-2.00	—	—	—	—
E9015-C5L	W25018	0.05	0.40-1.00	0.50	0.03	0.03	6.00-7.25	—	—	—	—
Nickel-Molybdenum Steel Electrodes											
E8018-NM1	W21118	0.10	0.80-1.25	0.60	0.02	0.02	0.80-1.10	0.10	0.40-0.65	V	0.02
E8018-D1	W18118	0.12	1.00-1.75	0.80	0.03	0.03	0.90	—	0.25-0.45	Cu	0.10
E9015-D1	W19015	0.12	1.00-1.75	0.60	0.03	0.03	0.90	—	0.25-0.45	Al	0.05
E9018-D1	W19018	0.12	1.00-1.75	0.80	0.03	0.03	0.90	—	0.25-0.45	—	—

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TABLE 2 (CONT'D)
CHEMICAL COMPOSITION REQUIREMENTS FOR UNDILUTED WELD METAL

Wt. Percent ^{a,b}											Additional Elements
AWS Classification ^c	UNS Number ^d	C	Mn	Si	P	S	Ni	Cr	Mo	Type	
E10015-D2	W10015	0.15	1.65-2.00	0.60	0.03	0.03	0.90	—	0.25-0.45	—	—
E10016-D2	W10016	0.15	1.65-2.00	0.60	0.03	0.03	0.90	—	0.25-0.45	—	—
E10018-D2	W10018	0.15	1.65-2.00	0.60	0.03	0.03	0.90	—	0.25-0.45	—	—
E8016-D3	W18016	0.12	1.00-1.80	0.60	0.03	0.03	0.90	—	0.40-0.65	—	—
E8018-D3	W18018	0.12	1.00-1.80	0.60	0.03	0.03	0.90	—	0.40-0.65	—	—
E9018-D3	W19118	0.12	1.00-1.80	0.80	0.03	0.03	0.90	—	0.40-0.65	—	—
General Low-Alloy Steel Electrodes											
EXX10-G ^e	—	—	1.00 ^h min	0.80 ^h min	—	—	0.50 ^h min	0.30 ^h min	0.20 ^h min	V	0.10 ^h min
EXX11-G ^e	—	—	1.00 ^h min	0.80 ^h min	—	—	0.50 ^h min	0.30 ^h min	0.20 ^h min	Cu	0.20 ^h min
EXX13-G ^f	—	—	1.00 ^h min	0.80 ^h min	—	—	0.50 ^h min	0.30 ^h min	0.20 ^h min	V	0.10 ^h min
EXX15-G ^g	—	—	1.00 ^h min	0.80 ^h min	—	—	0.50 ^h min	0.30 ^h min	0.20 ^h min	Cu	0.20 ^h min
EXX16-G ^g	—	—	1.00 ^h min	0.80 ^h min	—	—	0.50 ^h min	0.30 ^h min	0.20 ^h min	V	0.10 ^h min
EXX18-G ^g	—	—	1.00 ^h min	0.80 ^h min	—	—	0.50 ^h min	0.30 ^h min	0.20 ^h min	Cu	0.20 ^h min
E7020-G	—	—	1.00 ^h min	0.80 ^h min	—	—	0.50 ^h min	0.30 ^h min	0.20 ^h min	V	0.10 ^h min
E7027-G	—	—	1.00 ^h min	0.80 ^h min	—	—	0.50 ^h min	0.30 ^h min	0.20 ^h min	Cu	0.20 ^h min
Military-Similar Electrodes											
E9018M ⁱ	W21218	0.10	0.60-1.25	0.80	0.030	0.030	1.40-1.80	0.15	0.35	V	0.05
E10018M ⁱ	W21318	0.10	0.75-1.70	0.60	0.030	0.030	1.40-2.10	0.35	0.25-0.50	V	0.05
E11018M ⁱ	W21418	0.10	1.30-1.80	0.60	0.030	0.030	1.25-2.50	0.40	0.25-0.50	V	0.05
E12018M ⁱ	W22218	0.10	1.30-2.25	0.60	0.030	0.030	1.75-2.50	0.30-1.50	0.30-0.55	V	0.05
E12018M1 ⁱ	W23218	0.10	0.80-1.60	0.65	0.015	0.012	3.00-3.80	0.65	0.20-0.30	V	0.05

TABLE 2 (CONT'D)
CHEMICAL COMPOSITION REQUIREMENTS FOR UNDILUTED WELD METAL

AWS Classification ^c	UNS Number ^d	Wt. Percent ^{a,b}										Additional Elements	
		C	Mn	Si	P	S	Ni	Cr	Mo	Type		Amt.	
Pipeline Electrodes													
E7010-P1	W17110	0.20	1.20	0.60	0.03	0.03	1.00	0.30	0.50		V		0.10
E8010-P1	W18110	0.20	1.20	0.60	0.03	0.03	1.00	0.30	0.50		V		0.10
Weathering Steel Electrodes													
E7018-W1 ^j	W20018	0.12	0.40-0.70	0.40-0.70	0.025	0.025	0.20-0.40	0.15-0.30	—		V		0.08
E8018-W2 ^j	W20118	0.12	0.50-1.30	0.35-0.80	0.03	0.03	0.40-0.80	0.45-0.70	—		Cu		0.30-0.60
											Cu		0.30-0.75

- NOTES:
- a. Single values are maximum, except where specified otherwise.
 - b. Weld metal shall be analyzed for those elements for which specific values are shown. Other elements listed without specified values shall be reported, if intentionally added. The total of these latter unspecified elements and all other elements not intentionally added shall not exceed 0.50%.
 - c. The suffixes A1, B3, C3, etc. designate the chemical composition of the electrode classification.
 - d. SAE/ASTM Unified Numbering System for Metals and Alloys.
 - e. The E8015-B6 and E8015-B6L electrodes were formerly classified as E502-15 in AWS A5.4-81, *Specification for Covered Corrosion-Resisting Chromium and Chromium Nickel Steel Welding Electrodes*. The E8016-B6 and E8016-B6L were formerly classified as E502-16 in A5.4-81. The E8018-B6 and E8018-B6L were not formerly classified but were produced to the E502 composition ranges in A5.4-81 but with the EXX18 covering of this specification. Similarly, the E80XX-B7(L) classifications were formerly classified as E7Cr-XX in A5.4-81; and the E80XX-B8(L) classifications were formerly classified as E505-XX in A5.4-81.
 - f. The letters "XX" used in the classification designation for EXX13-G in this table stand for various tensile-strength levels (80, 90, 100, 110, and 120 ksi) of weld metal.
 - g. The letters "XX" used in the classification designations for all electrodes except EXX13-G in this table stand for the various tensile-strength levels (70, 80, 90, 100, 110, and 120 ksi) of electrodes.
 - h. In order to meet the alloy requirements of the "G" group, the undiluted weld metal shall have the minimum of at least one of the elements listed in this table. Additional chemical requirements may be agreed to between supplier and purchaser.
 - i. These classifications are intended to be similar to types of electrodes covered by MIL-E-22200/1 and MIL-E-22200/10.
 - j. In AWS A5.5-81, E7018-W1 was designated E7018-W, and E8018-W2 was designated E8018-W.

PART C — SPECIFICATIONS FOR WELDING RODS,
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TABLE 3
TENSION TEST REQUIREMENTS^{a,b}

AWS Classification ^c	Tensile Strength		Yield Strength, at 0.2% Offset		Elongation Percent	Postweld Condition ^d
	ksi	MPa	ksi	MPa		
E7010-P1	70	480	60	415	22	AW
E7010-A1	70	480	57	390	22	PWHT
E7010-G	70	480	57	390	22	AW or PWHT
E7011-A1	70	480	57	390	22	PWHT
E7011-G	70	480	57	390	22	AW or PWHT
E7015-X	70	480	57	390	25	PWHT
E7015-B2L	75	520	57	390	19	PWHT
E7015-G	70	480	57	390	25	AW or PWHT
E7016-X	70	480	57	390	25	PWHT
E7016-B2L	75	520	57	390	19	PWHT
E7016-G	70	480	57	390	25	AW or PWHT
E7018-X	70	480	57	390	25	PWHT
E7018-B2L	75	520	57	390	19	PWHT
E7018-C3L	70	480	57	390	25	AW
E7018-W1	70	480	60	415	25	AW
E7018-G	70	480	57	390	25	AW or PWHT
E7020-A1	70	480	57	390	25	PWHT
E7020-G	70	480	57	390	25	AW or PWHT
E7027-A1	70	480	57	390	25	PWHT
E7027-G	70	480	57	390	25	AW or PWHT
E8010-P1	80	550	67	460	19	AW
E8010-G	80	550	67	460	19	AW or PWHT
E8011-G	80	550	67	460	19	AW or PWHT
E8013-G	80	550	67	460	16	AW or PWHT
E8015-X	80	550	67	460	19	PWHT
E8015-B3L	80	550	67	460	17	PWHT
E8015-G	80	550	67	460	19	AW or PWHT
E8016-X	80	550	67	460	19	PWHT
E8016-C3	80	550	68 to 80 ^e	470 to 550 ^e	24	AW
E8016-C4	80	550	67	460	19	AW
E8016-G	80	550	67	460	19	AW or PWHT
E8018-X	80	550	67	460	19	PWHT
E8018-B3L	80	550	67	460	17	PWHT
E8018-C3	80	550	68 to 80 ^e	470 to 550 ^e	24	AW
E8018-C4	80	550	67	460	19	AW
E8018-NM1	80	550	67	460	19	AW
E8018-W2	80	550	67	460	19	AW
E8018-G	80	550	67	460	19	AW or PWHT
E9010-G	90	620	77	530	17	AW or PWHT
E9011-G	90	620	77	530	17	AW or PWHT
E9013-G	90	620	77	530	14	AW or PWHT
E9015-X	90	620	77	530	17	PWHT
E9015-G	90	620	77	530	17	AW or PWHT
E9016-X	90	620	77	530	17	PWHT
E9016-G	90	620	77	530	17	AW or PWHT
E9018M	90	620	78 to 90 ^e	540 to 620 ^e	24	AW
E9018-X	90	620	77	530	17	PWHT
E9018-G	90	620	77	530	17	AW or PWHT

TABLE 3 (CONT'D)
TENSION TEST REQUIREMENTS

AWS Classification ^c	Tensile Strength		Yield Strength, at 0.2% Offset		Elongation Percent	Postweld Condition ^d
	ksi	MPa	ksi	MPa		
E10010-G	100	690	87	600	16	AW or PWHT
E10011-G	100	690	87	600	16	AW or PWHT
E10013-G	100	690	87	600	13	AW or PWHT
E10015-X	100	690	87	600	16	PWHT
E10015-G	100	690	87	600	16	AW or PWHT
E10016-X	100	690	87	600	16	PWHT
E10016-G	100	690	87	600	16	AW or PWHT
E10018M	100	690	88 to 100	610 to 690 ^e	20	AW
E10018-X	100	690	87	600	16	PWHT
E10018-G	100	690	87	600	16	AW or PWHT
E11010-G	110	760	97	670	15	AW or PWHT
E11011-G	110	760	97	670	15	AW or PWHT
E11013-G	110	760	97	670	13	AW or PWHT
E11015-G	110	760	97	670	15	AW or PWHT
E11016-G	110	760	97	670	15	AW or PWHT
E11018-G	110	760	97	670	15	AW or PWHT
E11018M	110	760	98 to 110	680 to 760 ^e	20	AW
E12010-G	120	830	107	740	14	AW or PWHT
E12011-G	120	830	107	740	14	AW or PWHT
E12013-G	120	830	107	740	11	AW or PWHT
E12015-G	120	830	107	740	14	AW or PWHT
E12016-G	120	830	107	740	14	AW or PWHT
E12018-G	120	830	107	740	14	AW or PWHT
E12018M	120	830	108 to 120	745 to 830 ^e	18	AW
E12018M1	120	830	108 to 120	745 to 830 ^e	18	AW

NOTES:

- See Table 5 for sizes to be tested.
- Single values are minimum, except as otherwise specified.
- The letter suffix "X" as used in this table represents the suffixes (A1, B1, B2, etc.) except for those classifications which are tested in the as-welded condition.
- "AW" signifies as-welded with aging when it is specified in 11.2, "PWHT" signifies postweld heat treated as specified in 8.4.2 and in Table 7, except that the "G" designated classifications, marked as "AW or PWHT" in this table, may have weld metal tested with or without PWHT as agreed between the supplier and purchaser.
- For $\frac{3}{32}$ in. (2.4 mm) electrodes, the upper value for the yield strength may be 5 ksi (35 MPa) higher than the indicated value.

convenient size of the type specified in Table 6 shall be used as the base for the weld pad. The surface of the base metal on which the filler metal is deposited shall be clean. The pad shall be welded in the flat position with multiple layers to obtain undiluted weld metal. The preheat temperature shall not be less than 60°F (16°C) and the interpass temperature shall not exceed 300°F (150°C). Each weld pass shall be a single straight pass with the pass width not exceeding $2\frac{1}{2}$ times the diameter of the core wire. The slag shall be removed after each pass. The pad may be quenched in water between passes. The dimensions of the completed pad shall be as shown in Fig. 1. Testing of this

assembly shall be as specified in Section 9. Chemical Analysis.

8.4 Groove Weld

8.4.1 Mechanical Properties and Soundness. A test assembly shall be prepared and welded as specified in Fig. 2 or 4 using base metal of the appropriate type specified in Table 6, of thickness specified in Fig. 2 or 4. Testing of this assembly shall be as specified in Sections 10, Radiographic Test; 11, Tension Test; and 12, Impact Test. The assembly shall be tested in the as-welded condition or the postweld heat treated condition as specified in Table 3, except for the

PART C — SPECIFICATIONS FOR WELDING RODS,
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TABLE 4
CHARPY V-NOTCH IMPACT REQUIREMENTS

AWS Classification	Limits for 3 out of 5 Specimens ^c	
	Average, min. ^b	Single Value, min. ^b
E7018-W1 E8018-W2	20 ft-lbf at 0°F (27J at -18°C)	15 ft-lbf at 0°F (20J at -18°C)
E12018M1	50 ft-lbf at 0°F (67J at -18°C)	40 ft-lbf at 0°F (54J at -18°C)
E7010-P1 E8010-P1	20 ft-lbf at -20°F (27J at -29°C)	15 ft-lbf at -20°F (20J at -29°C)
E8018-NM1 E8016-C3 E8018-C3	20 ft-lbf at -40°F (27J at -40°C)	15 ft-lbf at -40°F (20J at -40°C)
E8016-D3, E8018-D1 E8018-D3, E9015-D1 E9018-D1, E9018-D3 E10015-D2, E10016-D2 E10018-D2	20 ft-lbf at -60°F ^a (27J at -51°C)	15 ft-lbf at -60°F ^a (20J at -51°C)
E7018-C3L E8016-C4, E8018-Cr E9018M, E10018M E11018M, E12018M	20 ft-lbf at -60°F (27J at -51°C)	15 ft-lbf at -60°F (20J at -51°C)
E8016-C1 E8018-C1	20 ft-lbf at -75°F ^a (27J at -59°C)	15 ft-lbf at -75°F ^a (20J at -59°C)
E7015-C1L E7016-C1L E7018-C1L E8016-C2 E8018-C2	20 ft-lbf at -100°F ^a (27J at -73°C)	15 ft-lbf at 100°F ^a (20J at -73°C)
E7015-C2L E7016-C2L E7018-C2L	20 ft-lbf at -150°F ^a (27J at -101°C)	15 ft-lbf at -150°F ^a (20J at -101°C)
E9015-C5L	20 ft-lbf at -175°F ^a (27J at -115°C)	15 ft-lbf at -175°F ^a (20J at -115°C)
EXXXX-A1 EXXXX-BX EXXXX-BXL EXXXX-G	Not specified	

NOTES:

- These classifications are tested in the postweld heat treated condition. No thermal treatment shall be performed on the test specimens of all other classifications.
- Impact test values shall be recorded to "nearest whole unit" of energy absorbed in foot-pounds in accordance with the rounding-off method specified in 5.2.
- Both the highest and the lowest test values obtained shall be disregarded in computing the average value. Two of these three remaining values shall equal or exceed the minimum average value listed; one of these three remaining values may be lower than minimum average value, but shall not be less than the minimum single value listed. The average of the three remaining values shall not be less than the minimum-average value listed.

TABLE 5
REQUIRED TESTS^{a,b}

AWS Classification ^a	Type of Current ^a	Electrode Size ^c		Chemical Analysis ^d	Welding Position for Test Assembly			
		In.	mm		Soundness Test All Weld Metal Tension Test ^{e,f}	Impact Test ^g	Fillet Weld Test ^h	Moisture Test ⁱ
E7010-X	DCEP	$\frac{3}{32}, \frac{1}{8}$	2.4, 3.2	NR ^b	NR ^b	NR	NR ^b	NR
E8010-X		$\frac{5}{32}$	4.0	F	F	NR	V,OH	NR
E9010-G		$\frac{3}{16}$	4.8	NR ^b	F	NR	V,OH	NR
E10010-G		$\frac{7}{32}$	5.6	NR ^b	NR ^b	NR	NR ^b	NR
E11010-G		$\frac{1}{4}$	6.4	F	F	NR	H	NR
E12010-G								
E7011-X	ac and DCEP	$\frac{3}{32}, \frac{1}{8}$	2.4, 3.2	NR ^b	NR ^b	NR	NR ^b	NR
E8011-X		$\frac{5}{32}$	4.0	F	F	NR	V,OH	NR
E9011-G		$\frac{3}{16}$	4.8	NR ^b	F	NR	V,OH	NR
E10011-G		$\frac{7}{32}$	5.6	NR ^b	NR ^b	NR	NR ^b	NR
E11011-G		$\frac{1}{4}$	6.4	F	F	NR	H	NR
E12011-G								
E8013-G	ac, DCEN, and DCEP	$\frac{3}{32}, \frac{1}{8}$	2.4, 3.2	NR ^b	NR ^b	NR	NR ^b	NR
E9013-G		$\frac{5}{32}$	4.0	FI	FI	NR	V,OH	NR
E10013-G		$\frac{3}{16}$	4.8	NR ^b	FI	NR	V,OH	NR
E11013-G								
E12013-G								
E7015-X	DCEP	$\frac{3}{32}, \frac{1}{8}$	2.4, 3.2	NR ^b	NR ^b	NR ^b	NR ^b	NR ^b
E8015-X		$\frac{5}{32}$	4.0	F	F	F	V,OH	Req'd.
E9015-X		$\frac{3}{16}$	4.8	NR ^b	F	F	H	NR ^b
E11015-X		$\frac{7}{32}$	5.6	NR ^b	NR ^b	NR ^b	NR ^b	NR ^b
E12015-G		$\frac{1}{4}$	6.4	F	F	F	H	Req'd.
E7016-X	ac and DCEP	$\frac{3}{32}, \frac{1}{8}$	2.4, 3.2	NR ^b	NR ^b	NR ^b	NR ^b	NR ^b
E8016-X		$\frac{5}{32}$	4.0	F	F	F	V,OH	Req'd.
E9016-X		$\frac{3}{16}$	4.8	NR ^b	F	F	H	NR ^b
E10016-X		$\frac{7}{32}$	5.6	NR ^b	NR ^b	NR ^b	NR ^b	NR ^b
E11016-G		$\frac{1}{4}$	6.4	F	F	F	H	Req'd.
E12016-G								
E7018-X	ac and DCEP	$\frac{3}{32}, \frac{1}{8}$	2.4, 3.2	NR ^b	NR ^b	NR ^b	NR ^b	NR ^b
E8018-X		$\frac{5}{32}$	4.0	F	F	F	V,OH	Req'd.
E9018-X		$\frac{3}{16}$	4.8	NR ^b	F	F	H	NR ^b
E10018-X		$\frac{7}{32}$	5.6	NR ^b	NR ^b	NR ^b	NR ^b	NR ^b
E11018-G		$\frac{1}{4}$	6.4	F	F	F	H	Req'd.
E12018-G								
E7020-X	For H-fillets, ac and DCEN	$\frac{1}{8}$	3.2	NR ^b	NR ^b	NR	NR ^b	NR
E7027-X		$\frac{5}{32}$	4.0	FI	FI	NR	H	NR
		$\frac{3}{16}$	4.8	NR ^b	FI	NR	H	NR
		$\frac{7}{32}$	5.6	NR ^b	NR ^{b,k}	NR	NR ^b	NR
		$\frac{1}{4}$	6.4	FI	FI,k	NR	H	NR
	For flat position, ac, DCEN and DCEP	$\frac{5}{16}$	8.0	NR ^b	FI,k	NR	NR ^b	NR

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**TABLE 5 (CONT'D)
REQUIRED TESTS^{a,b}**

AWS Classification ^a	Type of Current ^a	Electrode Size ^c		Chemical Analysis ^d	Welding Position for Test Assembly			
		In.	mm		Soundness Test All Weld Metal Tension Test ^{e,f}	Impact Test ^g	Fillet Weld Test ^h	Moisture Test ⁱ
E9018M	DCEP	$\frac{3}{32}, \frac{1}{8}$	2.4, 3.2	NR ^b	NR ^b	NR ^b	NR ^b	NR ^b
E10018M		$\frac{3}{32}$	4.0	F	F	F	V,OH	Req'd.
E11018M		$\frac{3}{16}$	4.8	NR ^b	F	F	H	NR ^b
E12018M		$\frac{7}{32}$	5.6	NR ^b	NR ^b	NR ^b	NR ^b	NR ^b
E12018M1		$\frac{1}{4}$	6.4	F	F	F	H	Req'd.

NOTES:

- NR means "not required". The abbreviations, F, H, H-fillet, V, and OH, are defined in Note b of Table 1. The terms "DCEP" and "DCEN" are defined in Note c of Table 1. The letter suffix "X" as used in this table is defined in Note a of Table 1.
- Standard electrode sizes not requiring this specific test can be classified, provided at least two other sizes of that classification have passed the tests required for them, or the size to be classified meets specification requirements by having been tested in accordance with Sections 8 through either 13, 14, 15, or 16, depending on the electrode being classified.
- Electrodes manufactured in sizes not shown shall be tested to the requirement of the nearest standard size. 6.0 mm electrode shall be tested to the requirements of $\frac{3}{4}$ in. (6.4 mm) electrode.
- See Section 9.
- See Section 10.
- See Section 11.
- See Section 12. Impact tests are required for classifications listed in Table 4.
- See Section 13.
- The moisture test given in Section 14 is the required test for measurement of moisture content of the covering. The absorbed moisture test, in Section 15, and the diffusible hydrogen test, in Section 16, are supplemental tests required only when their corresponding optional supplemental designators are to be used with the classification designators.
- When DCEP and DCEN are specified, only DCEN need be tested.
- Electrodes longer than 18 in. (450 mm) will require a double length test assembly in accordance with Note 2 of Figure 2, to ensure uniformity of the entire electrode.

E(X)XXYY-G classifications, which shall be tested in the postweld condition agreed to by the purchaser and supplier (see Note a of Table 7).

8.4.2 When required, the weld test assembly shall be postweld heat treated before removal of mechanical test specimens. This postweld heat treatment may be done either before or after the radiographic examination.

8.4.2.1 Temperature of the weld test assembly shall be raised, in a suitable furnace, at the rate of 150° to 500°F (65° to 260°C) per hour until the postweld heat treatment temperature, specified in Table 7 for the electrode classification, is attained. Temperature shall be maintained for one hour.

8.4.2.2 The weld test assembly shall then be cooled in the furnace at a maximum rate of 350°F (177°C) per hour. The test assembly may be removed from the furnace when the temperature has reached 600°F (316°C) and allowed to cool in still air.

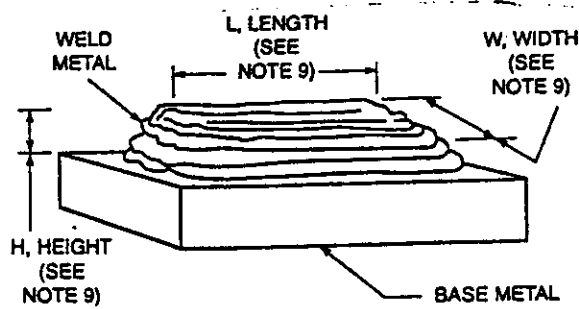
8.5 Fillet Weld. A weld test assembly shall be prepared for particular sizes of electrodes of all classifications and welded as specified in Table 5 and Fig.

3 using base metal of the appropriate type specified in Table 6. The welding positions and conditions shall be as specified in Table 8 and Fig. 5 according to the size and classification of electrode. Testing of the assembly shall be as specified in Section 13, Fillet Weld Test.

9. Chemical Analysis

9.1 The sample for chemical analysis shall be taken from weld metal obtained with the electrode. The sample shall be taken from a weld pad, or the reduced section of the fractured tension test specimen or from a corresponding location (or any location above it) in the weld metal in the groove weld in Figs. 2 or 4. Areas where arc starts or craters exist shall be avoided.

The top surface of the pad described in 8.3 and shown in Fig. 1 shall be removed and discarded and a sample for analysis shall be obtained from the underlying metal by any appropriate mechanical means. The sample shall be free of slag and shall be taken from metal that is at least the minimum distance from the original base metal surface as specified in Fig. 1.



Notes:

- 1. Base metal of any convenient size, of any type specified in Table 6, shall be used as the base for the weld pad.
- 2. The surface of the base metal on which the filler metal is to be deposited shall be clean.
- 3. The pad shall be welded in the flat position with successive layers to obtain undiluted weld metal.
- 4. One pad shall be welded for each type of current shown in Table 5 except for those classifications identified by note j in Table 5.
- 5. The number and size of the beads will vary according to the size of the electrode and the width of the weave, as well as the amperage employed. The width of each weld pass in each weld layer shall be no more than 2-1/2 times the diameter of the core wire.
- 6. The preheat temperature shall not be less than 60°F (16°C) and the interpass temperature shall not exceed 300°F (150°C).
- 7. The slag shall be removed after each pass.
- 8. The test assembly may be quenched in water between passes to control interpass temperature.
- 9. The minimum completed pad size shall be at least four layers in height (H) with length (L) and width (W) sufficient to perform analysis. The sample for analysis shall be taken from weld metal that is at least the following distance above the original base metal surface:

Electrode Size		Minimum Distance From Surface of Base Plates	
in.	mm	in.	mm
3/32	2.4	1/4	6.4
1/8	3.2		
5/32	4.0	5/16	8.0
3/16	4.8		
7/32	5.6		
1/4	6.4	3/8	9.5
5/16	8.0		

FIG. 1 PAD FOR CHEMICAL ANALYSIS OF UNDILUTED WELD METAL

The sample from the reduced section of the fractured tension test specimen or from a corresponding location (or any location above it) in the groove weld in Figs. 2 or 4 shall be prepared for analysis by any suitable mechanical means.

9.2 The sample described in 9.1 shall be analyzed by accepted analytical methods. The referee method shall be ASTM E350, *Method for Chemical Analysis of Carbon Steel, Low Alloy Steel, Silicon Electrical Steel, Ingot Iron and Wrought Iron*.

9.3 The results of the chemical analysis shall meet the requirements of Table 2 for the classification of the electrode under test.

10. Radiographic Test

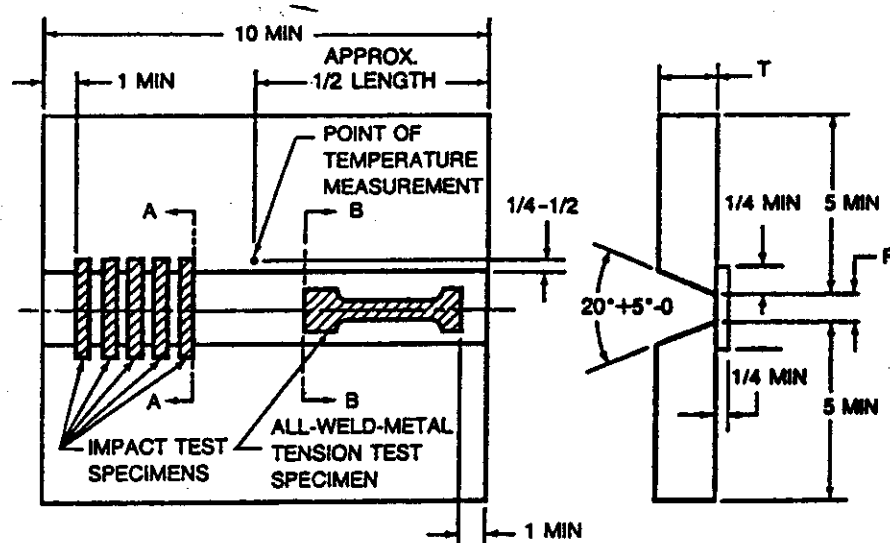
10.1 The groove weld described in 8.4.1 and shown in Fig. 2 or 4 shall be radiographed to evaluate the soundness of the weld metal for all classifications as specified in Table 5. In preparation for radiography, the backing shall be removed and both surfaces of the weld shall be machined or ground smooth. The finished surface of the weld may be flush with the plate or have a reasonably uniform reinforcement not exceeding 3/32 in. (2.4 mm). Both surfaces of the test assembly shall be smooth enough to avoid difficulty in interpreting the radiograph.

10.2 The weld shall be radiographed in accordance with ASTM E142, *Method for Controlling Quality of Radiographic Testing*. The quality level of inspection shall be 2-2T.

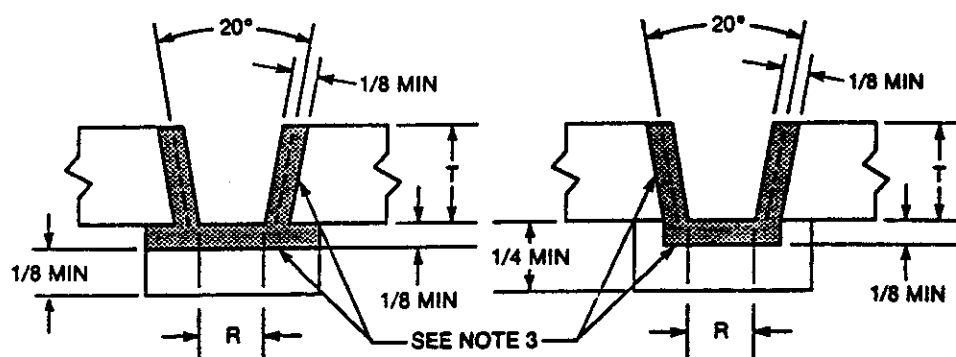
10.3 The soundness of the weld metal meets the requirements of this specification if the radiograph shows:

- (1) no cracks or incomplete fusion.
- (2) no slag inclusions longer than 1/4 in. (6 mm) or 1/3 of the thickness of the weld, whichever is greater, or no groups of slag inclusions in line that have an aggregate length greater than the thickness of the weld in a length 12 times the thickness of the weld except when the distance between the successive inclusions exceeds 6 times the length of the longest inclusion in the group.
- (3) no rounded indications in excess of those permitted by the radiographic standards in Fig. 6 according to the grade specified in Table 9.

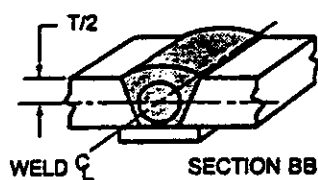
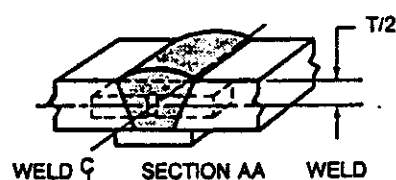
One inch (25 mm) of the weld measured from each end of the assembly shall be excluded from radiographic examination.



(A) TEST PLATE SHOWING LOCATION OF TEST SPECIMENS



(B) GROOVE PREPARATION OF TEST PLATE



SI EQUIVALENTS	
in.	mm
1/8	3.2
1/4	6.4
1/2	13
1	25
5	125
10	250

**(C) ORIENTATION AND LOCATION OF
IMPACT TEST SPECIMEN**

(D) LOCATION OF ALL-WELD-METAL TENSION TEST SPECIMEN

FIG. 2 GROOVE WELD TEST ASSEMBLY FOR MECHANICAL PROPERTIES AND SOUNDNESS OF WELD METAL PRODUCED BY USING ALL ELECTRODE CLASSIFICATIONS EXCEPT EXX18M(1)

Electrode Size		(T) Plate Thickness		(R) Root Opening		Passes Per Layer	Total Layers
in.	mm	in.	mm	in.	mm		
3/32	2.4	1/2	13	3/8	10	2	not specified
1/8	3.2	1/2	13	1/2	13	2	5 to 7
5/32	4.0	3/4	19	5/8	16	2	7 to 9
3/16	4.8	3/4	19	3/4	19	2	6 to 8
7/32	5.6	3/4	19	7/8	23	2	6 to 8
1/4	6.4	1	25	1	25	2	9 to 11
5/16	8.0	1-1/4	32	1-1/8	28	2	10 to 12

- Notes:
1. All dimensions except angles are in inches.
 2. For electrodes longer than 18 in. (450 mm), a 20 in. (500 mm) long test assembly shall be welded.
 3. Base metal shall be as specified in Table 6. Edges of the grooves and the contacting face of the backing shall be surfaced as shown by any size of the electrode being tested before welding the joint.
 4. The surfaces to be welded shall be clean.
 5. Prior to welding, the assembly may be preset to yield a welded joint sufficiently flat to facilitate removal of the test specimens. As an alternative, restraint or a combination of restraint and presetting may be used to keep the welded joint within 5 degrees of plane. A test assembly that is more than 5 degrees out of plane shall be discarded. Straightening of the test assembly is prohibited.
 6. Welding shall be in the flat position, using each type of current specified in Table 5 except for classifications identified by Note j in Table 5.
 7. The preheat and interpass temperature shall be as specified in Table 7 for the classification being tested.
 8. For electrode size larger than 1/8 in. (3.2 mm) the joint root may be seal welded with 3/32 or 1/8 in. (2.4 or 3.2 mm) electrodes using stringer beads.
 9. In addition to the stops and starts at the ends, each pass shall contain a stop and start in between the ends.
 10. The completed weld shall be at least flush with the surface of the test plate.
 11. The test assemblies shall be postweld heat treated as specified in Table 7 for the classification being tested.

FIG. 2 GROOVE WELD TEST ASSEMBLY FOR MECHANICAL PROPERTIES AND SOUNDNESS OF WELD METAL PRODUCED BY USING ALL ELECTRODE CLASSIFICATIONS EXCEPT EXX18M(1) (CONT'D)

10.4 A rounded indication is an indication (on the radiograph) whose length is no more than three times its width. Rounded indications may be circular, elliptical, conical, or irregular in shape, and they may have tails. The size of a rounded indication is the largest dimension of the indication, including any tail that may be present. The indication may be porosity or slag. Indications whose largest dimension does not exceed 1/64 in. (0.4 mm) shall be disregarded. Test assemblies with indications larger than the large indications permitted in the radiographic standards do not meet the requirements of this specification.

11. Tension Test

- 11.1 One all-weld-metal tension test specimen shall be machined from the groove weld described in 8.4.1 and shown in Fig. 2 or 4. The dimensions of the specimen shall be as shown in Fig. 7.
- 11.2 The tension specimens for electrodes E7010-G, E7010-P1, E8010-G, E8010-P1, and E9010-G classifications shall be aged at 200° to 220°F (95° to 105°C) for 48 hours plus or minus 2 hours, and cooled in air to room temperature. Other tension test specimens to

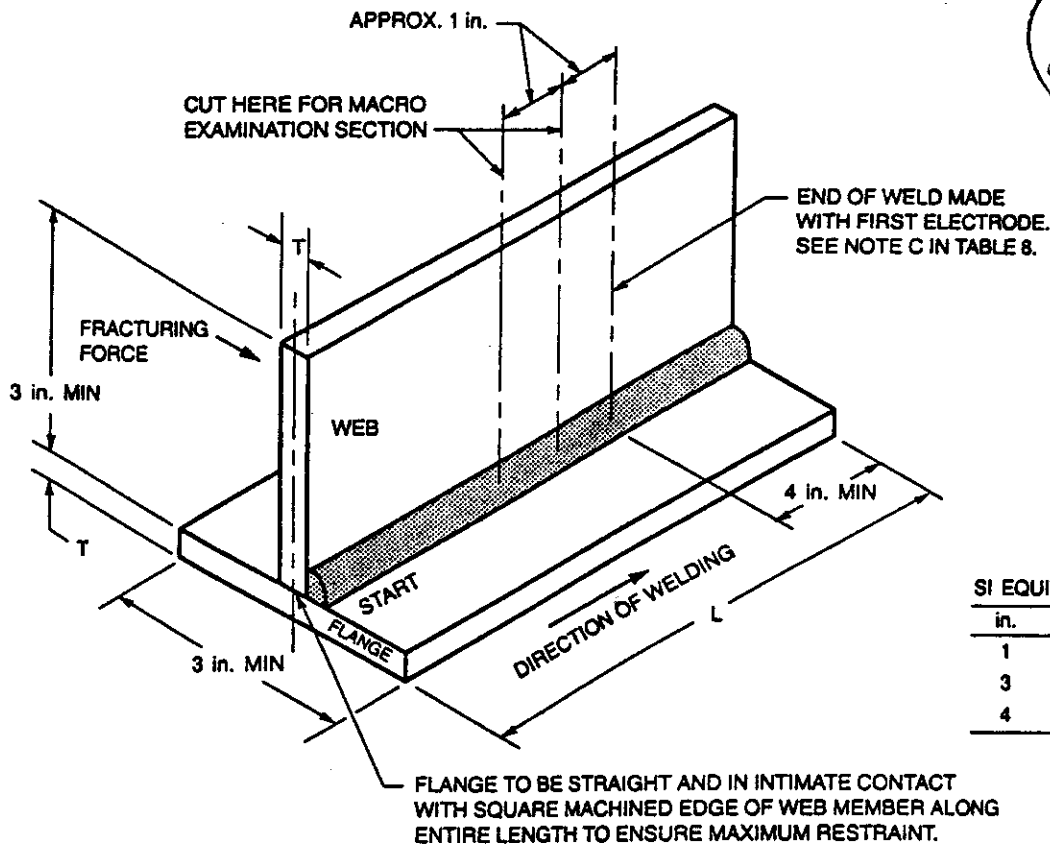
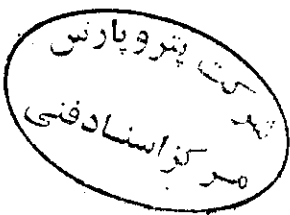
be tested in the as-welded condition may be aged at 200° to 220°F (95° to 105°C) for up to 48 hours and cooled to room temperature. See A6.3 for a discussion of the purpose of aging treatments. All specimens shall be tested in the manner described in the tension testing section of ANSI/AWS B4.0, *Standard Methods for Mechanical Testing of Welds*.

11.3 Results of the tension test shall meet the requirements specified in Table 3.

12. Impact Test

- 12.1 Five Charpy V-notch impact specimens, as specified in Fig. 8, shall be machined from the test assembly shown in Fig. 2 or 4 for those classifications for which impact testing is required in Table 5.
- 12.2 The five specimens shall be tested in accordance with the fracture toughness testing section of ANSI/AWS B4.0, *Standard Methods for Mechanical Testing of Welds*. The test temperature shall be that specified in Table 4 for the classification under test.

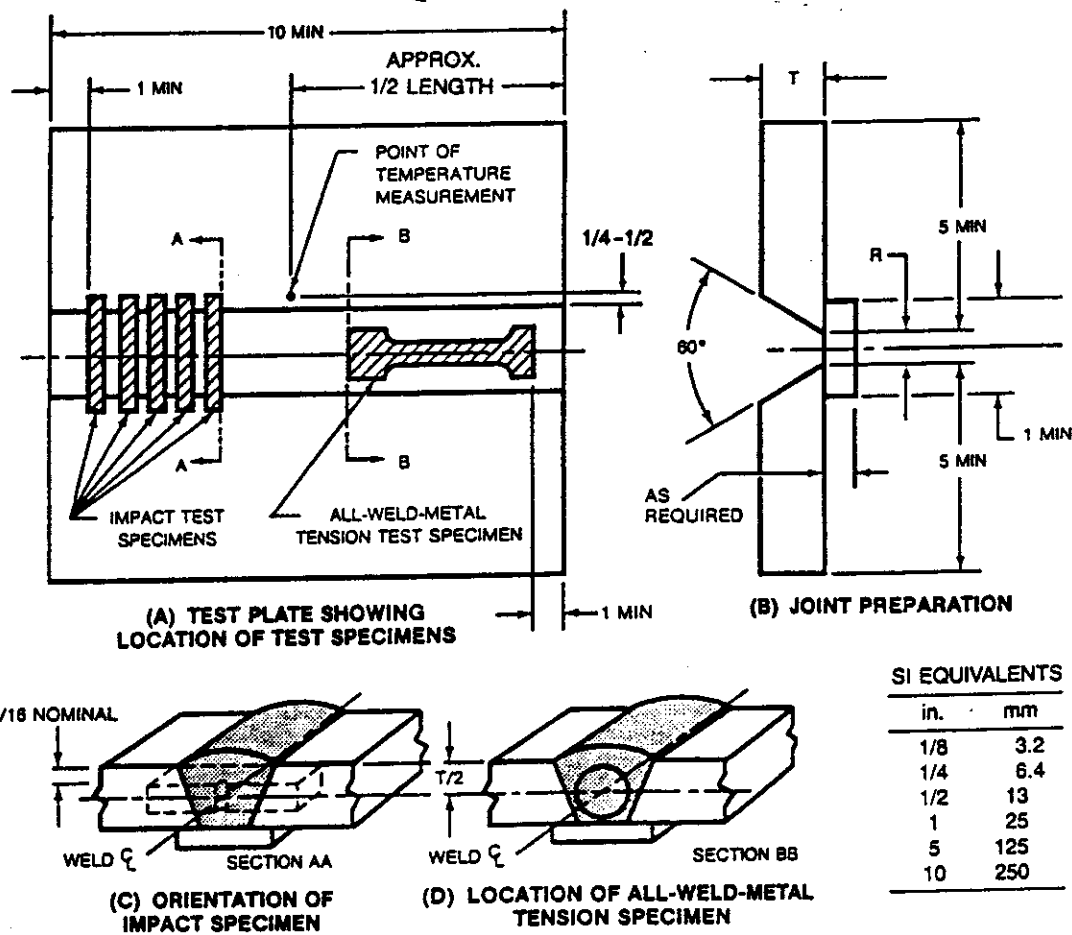
12.3 In evaluating the results for all the classifications that require impact testing, the lowest and the highest



SI EQUIVALENTS	
in.	mm
1	25
3	75
4	100

- Notes:
1. See Table 8 for values of T and L.
 2. Base metal shall be as specified in Table 6.
 3. The surfaces to be welded shall be clean.
 4. One assembly shall be welded for each position specified in Table 8 and shown in Figure 5 using each type of current and polarity specified in Table 5.
 5. The preheat shall be 60°F (16°C) minimum.
 6. A single-pass fillet weld shall be made on one side of the joint. The first electrode shall be consumed to a stub length of no greater than 2 in. (50 mm).
 7. Welding in the vertical position shall be with upward progression, except for the E7010-X, E8010-X, E9010-X, and E10010-X classifications, where progression may be either upward or downward.
 8. Weld cleaning shall be limited to slag chipping, brushing, and needle scaling. Grinding or filing of the weld surface is prohibited.
 9. The tests shall be conducted without postweld heat treatment.

FIG. 3 FILLET WELD TEST ASSEMBLY



Electrode Size		(T) Min. Plate Thickness		(R) Max. Root Opening		Number of Layers	
in.	mm	in.	mm	in.	mm	Minimum	Maximum
3/32	2.4	1/2	13	1/4	6.4	See Note 2	
1/8	3.2	1/2	13	1/4	6.4	See Note 2	
5/32	4.0	3/4	19	1/2	13	7	9
3/16	4.8	3/4	19	1/2	13	7	9
7/32	5.6	3/4	19	1/2	13	7	8
1/4	6.4	1	25	1/2	13	9	11

Notes:

1. All dimensions except angles are in inches.
2. Pass and layer sequence shall be reported.
3. Base metal shall be as specified in Table 6.
4. The surfaces to be welded shall be clean.
5. Prior to welding, the assembly may be preset to yield a welded joint sufficiently flat to facilitate removal of the test specimens. As an alternative, restraint or a combination of restraint and presetting may be used to keep the welded joint within 5 degrees of plane. A welded test assembly that is more than 5 degrees out of plane shall be discarded. Straightening of the test assembly is prohibited.
6. Welding shall be performed in the flat position, using the type of current specified in Table 5 for the classification being tested.
7. The preheat and interpass temperature shall be as specified in Table 7 for the classification being tested.
8. Layers should be approximately 1/8 in. thick with each layer being started at the finishing end of the preceding layer.
9. The weld shall be made with stringer beads or with maximum weave no wider than 2-1/2 times the diameter of the core wire.
10. The completed weld shall have a reinforcement of standard proportions, 1/32 in. minimum; 1/8 in. maximum. For electrodes larger than 1/8 in. (3.2 mm), the root beads may be made with 3/32 or 1/8 in. (2.4 or 3.2 mm) electrodes.

FIG. 4 GROOVE WELD TEST ASSEMBLY FOR MECHANICAL PROPERTIES AND SOUNDNESS OF WELD METAL PRODUCED BY USING EXX18M(1)

SFA-5.5

AWS Classification	Base Metals	ASTM Specification	UNS Number*
All except E(X)XXYYM(1)	Carbon Steel	A29 Grade 1015 or equiv.	G10150
All except E(X)XXYYM(1)	Carbon Steel	A29 Grade 1020 or equiv.	G10200
All except E(X)XXYYM(1)	Carbon Steel	A283 Grade D or equiv.	K02702
All except E(X)XXYYM(1)	Carbon Steel	A285 Grade A or equiv.	K01700
All except E(X)XXYYM(1)	Carbon Steel	A285 Grade B or equiv.	K02200
All except E(X)XXYYM(1)	Carbon Steel	A285 Grade C or equiv.	K02801
All	Carbon Steel	A36 or equivalent	K02600
All	Carbon Steel	A131 Grade B or equiv.	K02102

*SAE/ASTM Unified Numbering System for Metals and Alloys

AWS Classification	Preheat and Interpass Temperature		Postweld Heat Treatment Temperature	
	°F	°C	°F	°C
E7010-A1	200 to 225	93 to 107	1150 ± 25	620 ± 14
E7011-A1				
E7015-A1				
E7016-A1				
E7018-A1				
E7020-A1				
E7027-A1				
E8018-D1				
E9015-D1				
E9018-D1				
E10015-D2				
E10016-D2				
E10018-D2				
E9016-D3				
E8018-D3				
E9018-D3				
E8016-B1	325 to 375	163 to 191	1275 ± 25	690 ± 14
E8018-B1				
E8015-B2				
E8016-B2				
E8018-B2				
E7015-B2L				
E7016-B2L				
E7018-B2L				
E9015-B3				
E9016-B3				
E9018-B3				
E8015-B3L				
E8018-B3L				
E8015-B4L				
E8016-B5				

(continued)

TABLE 7 (CONT'D)
PREHEAT, INTERPASS, AND POSTWELD HEAT TREATMENT TEMPERATURES

AWS Classification	Preheat and Interpass Temperature		Postweld Heat Treatment Temperature	
	°F	°C	°F	°C
E8015-B6 E8016-B6 E8018-B6 E8015-B6L E8016-B6L E8018-B6L E8015-B7 E8016-B7 E8018-B7 E8015-B7L E8016-B7L E8018-B7L	350 to 450	177 to 232	1375 ± 25	740 ± 14
E8015-B8 E8016-B8 E8018-B8 E8015-B8L E8016-B8L E8018-B8L	400 to 500	205 to 260	1375 ± 25	740 ± 14
E9015-B9 E9016-B9 E9018-B9	450 to 550	232 to 288	1375 ± 25	740 ± 14
E8016-C1 E8018-C1 E7015-C1L E7016-C1L E7018-C1L E8016-C2 E8018-C2 E7015-C2L E7016-C2L E7018-C2L	200 to 225	93 to 107	1125 ± 25	605 ± 14
E9015-C5L	200 to 250	93 to 121	1075 ± 25	579 ± 14
E8018-G E8011-G E8013-G E9010-G E9011-G E9013-G E10010-G E10011-G E10013-G E11010-G E11011-G E11013-G E12010-G E12011-G E12013-G	325 to 375	163 to 191	See Note a	

TABLE 7 (CONT'D)
PREHEAT, INTERPASS, AND POSTWELD HEAT TREATMENT TEMPERATURES

AWS Classification	Preheat and Interpass Temperature		Postweld Heat Treatment Temperature	
	°F	°C	°F	°C
E7010-G E7011-G E7015-G E7016-G E7018-G E7020-G E7027-G E8015-G E8016-G E8018-G E9015-G E9016-G E9018-G E10015-G E10016-G E10018-G E11015-G E11016-G E11018-G E12015-G E12016-G E12018-G	200 to 225	93 to 107	See Note a	
E7010-P1 E7018-C3L E7018-W1 E8016-C3 E8018-C3 E8016-C4 E8018-C4 E8018-NM1 E8018-W2 E9018M E10018M E11013M E12018M E12018M1				
E8018-P1	325 to 375	163 to 191	Not specified ^b	

NOTES:

- a. The need and specific values for postweld heat treatment of weld test assemblies made with these "G" electrodes shall be as agreed between supplier and purchaser.
- b. Postweld heat treatment is not required for those classifications listed as "as-welded" in Table 3.

TABLE 8
REQUIREMENTS FOR PREPARATION OF FILLET WELD TEST ASSEMBLIES

AWS Classification ^a	Electrode				Plate Size ^b				Position of Welding	Size of Fillet Weld		
	Size		Length		Thickness (T)		Length min (L) ^c			in.	mm	
	in.	mm	in.	mm	in.	mm	in.	mm				
EXX10-X EXX11-X	{	3/32	2.4	12	300	1/8	3.2	10	250	V,OH	5/32 max.	4.0
		1/8	3.2	14	350	1/4	6.4	12	300	V,OH	3/16 max.	4.8
		5/32	4.0	14	350	3/8	9.5	12	300	V,OH	1/4 max.	6.4
		3/16	4.8	14	350	3/8	9.5	12	300	V,OH	5/16 max.	8.0
		7/32	5.6	14 or 18	350 or 450	1/2	12.5	12 or 16	300 or 400	H	1/4 min.	6.4
		1/4	6.4	18	450	1/2	12.5	16	400	H	1/4 min.	6.4
EXX13-X	{	3/32	2.4	12	300	1/8	3.2	10	250	V,OH	5/32 max.	4.0
		1/8	3.2	14	350	1/4	6.4	12	300	V,OH	3/16 max.	4.8
		5/32	4.0	14	350	3/8	9.5	12	300	V,OH	1/4 max.	6.4
		3/16	4.8	14	350	3/8	9.5	12	300	V,OH	3/8 max.	9.5
		7/32	5.6	14 or 18	350 or 450	1/2	12.5	12 or 16	300 or 400	H	1/4 min.	6.4
EXX15-X	{	3/32	2.4	12 or 14	300 or 350	1/8	3.2	10 or 12	250 or 300	V,OH	3/16 max.	4.8
1/8		3.2	14	350	1/4	6.4	12	300	V,OH	1/4 max.	6.4	
5/32		4.0	14	350	3/8	9.5	12	300	V,OH	5/16 max.	8.0	
3/16		4.8	14	350	3/8	9.5	12	300	H	3/16 min.	4.8	
E12018M1		7/32	5.6	14 or 18	350 or 450	1/2	12.5	12 or 16	300 or 400	H	1/4 min.	6.4
EXX18-X		1/4	6.4	18	450	1/2	12.5	16	400	H	5/16 min.	8.0
E7020-X E7027-X	{	1/8	3.2	14	350	1/4	6.4	12	300	H	1/8 min.	3.2
		3/32	4.0	14	350	3/8	9.5	12	300	H	3/16 min.	4.8
		5/32	4.8	14 or 18	350 or 450	3/8	9.5	12 or 16	300 or 400	H	1/4 min.	6.4
		7/32	5.6	18 or 28	450 or 700	1/2	12.5	16 or 26	400 or 650	H	1/4 min.	6.4
		1/4	6.4	18 or 28	450 or 700	1/2	12.5	16 or 26	400 or 650	H	5/16 min.	8.0
		5/16	8.0	18 or 28	450 or 700	1/2	12.5	16 or 26	400 or 650	H	3/8 min.	9.5

- NOTES:
- a. The letters "XX" used in the classification designations in this table represent the various strength levels (70, 80, 90, 100, 110, and 120 ksi) of the weld metal. The letter suffix "X" as used in this table is defined in Note a of Table 1.
- b. See Figure 3.
- c. A starting tab, or a longer test assembly shall be used to ensure that the end of the first bead is more than 4 in. (100 mm) from the end of the test assembly.

values obtained shall be disregarded. Two of the three remaining values shall equal, or exceed, the minimum average energy level specified in Table 4. One of the three may be lower, but not lower than the minimum single value specified in Table 4. The average of the three shall not be less than the minimum average energy level specified in Table 4.

13. Fillet Weld Test

13.1 The fillet weld test, when required in Table 5, shall be made in accordance with 8.5 and Fig. 3. The entire face of the completed fillet weld shall be examined visually. The test specimen shall be free of cracks,

overlap, slag, and porosity, and shall be substantially free of undercut. An infrequent short undercut up to $\frac{1}{32}$ in (0.8 mm) in depth shall be allowed. After the visual examination, a specimen, approximately 1 in. (25 mm) in length, shall be removed as shown in Fig. 3. One cross-sectional surface of the specimen shall be polished, etched, and then examined as required in 13.2.

13.2 Scribe lines shall be placed on the prepared surface, as shown in Fig. 9, and the fillet weld size, fillet weld leg, and convexity shall be determined to the nearest $\frac{1}{64}$ in. (0.4 mm) by actual measurement (see Fig. 9). These measurements shall meet the require-

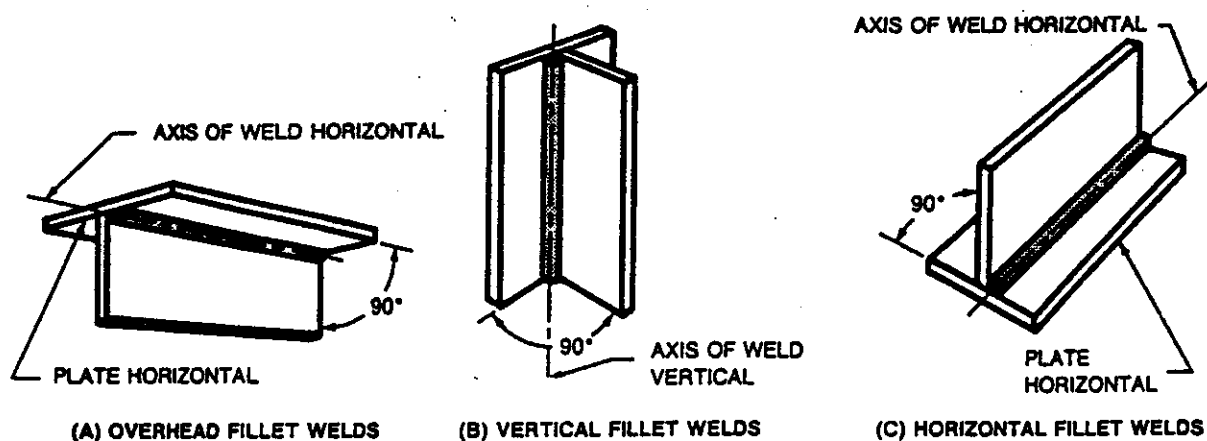


FIG. 5 WELDING POSITIONS FOR FILLET WELD TEST ASSEMBLIES

ments of Table 8 with respect to minimum or maximum fillet weld size and the requirements of Table 10 with respect to maximum convexity and maximum difference between fillet weld legs according to fillet weld size measured.

13.3 The remaining two sections of the test assembly shall be broken through the fillet weld by a force exerted as shown in Fig. 10. When necessary to facilitate fracture through the fillet weld, one or more of the following procedures may be used:

- (1) A reinforcing bead, as shown in Fig. 10, may be added to each leg of the weld.
- (2) The position of the web on the flange may be changed, as shown in Fig. 10.
- (3) The face of the fillet may be notched, as shown in Fig. 10.

Tests in which the weld metal pulls out of the base metal during bending are invalid tests. Specimens in which this occurs shall be replaced, specimen for specimen, and the test completed. In this case, the doubling of specimens required for retest in Section 7, Retest, does not apply.

13.4 The fractured surfaces shall be visually examined without magnification. The fractured surface shall be free of cracks. Incomplete joint penetration or incomplete fusion at the weld root, in cumulative length, shall not be greater than 20 percent of the total length of the weld. There shall be no continuous length of incomplete joint penetration or incomplete fusion greater than 1 in. (25 mm), as measured along the weld axis, except for electrodes of the E(X)XX13-G classifications.

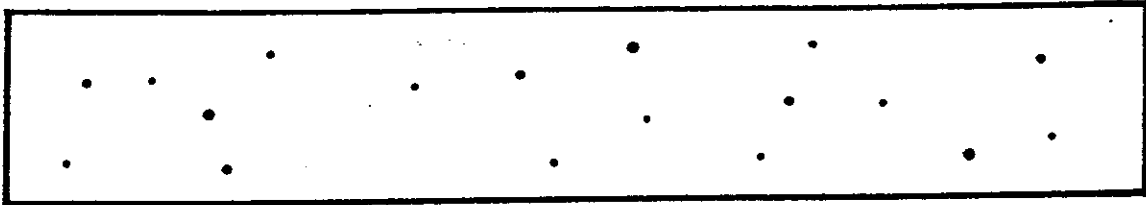
Fillet welds made with electrodes of these classifications may exhibit incomplete joint penetration through the entire weld length, provided that at no point this incomplete joint penetration exceeds 25 percent of the smaller leg of the fillet weld.

14. Moisture Test

14.1 The moisture content of the covering on the low-hydrogen electrodes, when required in Table 5, shall be determined by any suitable method. In case of dispute, the method described in 14.3 through 14.9 shall be the referee method.

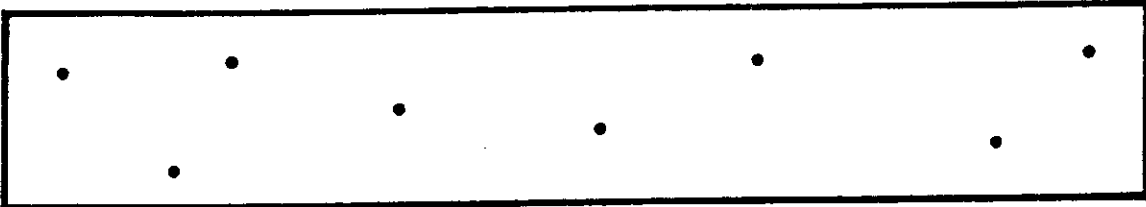
14.2 The electrode shall be tested without conditioning unless the manufacturer recommends otherwise. If the electrodes are conditioned, that fact, along with the method used for conditioning, and the time and temperature involved in the conditioning shall be noted on the test record. The moisture content shall not exceed the limit specified in Table 11.

14.3 The referee method for moisture consists of heating a sample of the covering in a nickel or clay boat placed inside a combustion tube in order to remove the moisture from the covering. A stream of oxygen is used to carry the moisture to an absorption tube, where the moisture is collected. The moisture content of the covering is determined by the increase in weight of the absorption tube and is expressed as a percentage of the original weight of the sample of covering.



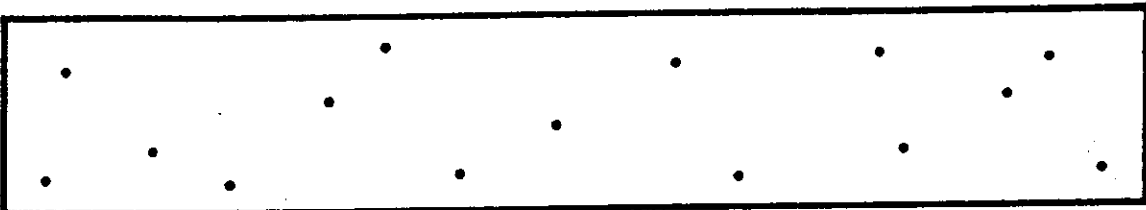
(A) ASSORTED ROUNDED INDICATIONS

SIZE $1/64$ in. (0.4 mm) TO $1/16$ in. (1.6 mm) IN DIAMETER OR IN LENGTH. MAXIMUM NUMBER OF INDICATIONS IN ANY 6 in. (150 mm) OF WELD = 18, WITH THE FOLLOWING RESTRICTIONS:
 MAXIMUM NUMBER OF LARGE $3/64$ in. (1.2 mm) TO $1/16$ in. (1.6 mm) IN DIAMETER OR IN LENGTH INDICATIONS = 3.
 MAXIMUM NUMBER OF MEDIUM $1/32$ in. (0.8 mm) TO $3/64$ in. (1.2 mm) IN DIAMETER OR IN LENGTH INDICATIONS = 5.
 MAXIMUM NUMBER OF SMALL $1/64$ in. (0.4 mm) TO $1/32$ in. (0.8 mm) IN DIAMETER OR IN LENGTH INDICATIONS = 10.



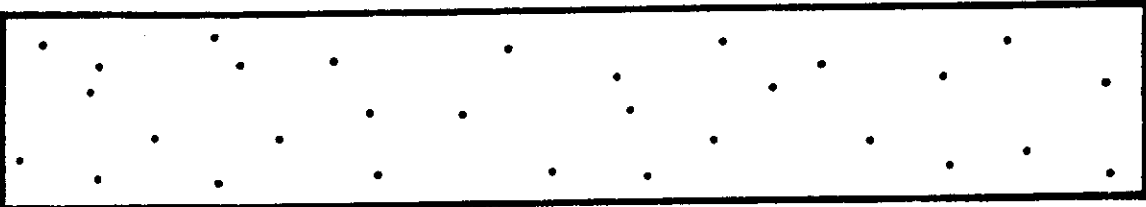
(B) LARGE ROUNDED INDICATIONS

SIZE $3/64$ in. (1.2 mm) TO $1/16$ in. (1.6 mm) IN DIAMETER OR IN LENGTH.
 MAXIMUM NUMBER OF INDICATIONS IN ANY 6 in. (150 mm) OF WELD = 8.



(C) MEDIUM ROUNDED INDICATIONS

SIZE $1/32$ in. (0.8 mm) TO $3/64$ in. (1.2 mm) IN DIAMETER OR IN LENGTH.
 MAXIMUM NUMBER OF INDICATIONS IN ANY 6 in. (150 mm) OF WELD = 15.



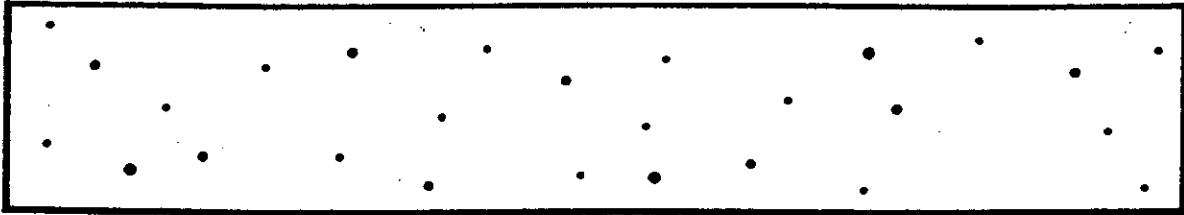
(D) SMALL ROUNDED INDICATIONS

SIZE $1/64$ in. (0.4 mm) TO $1/32$ in. (0.8 mm) IN DIAMETER OR IN LENGTH.
 MAXIMUM NUMBER OF INDICATIONS IN ANY 6 in. (150 mm) OF WELD = 30.

Notes:

1. In using these standards, the chart which is most representative of the size of the rounded indications present in the test specimen radiograph shall be used for determining conformance to these radiographic standards.
2. Since these are test welds specifically made in the laboratory for classification purposes, the radiographic requirements for these test welds are more rigid than those which may be required for general fabrication.
3. Indications whose largest dimension does not exceed $1/64$ in. (0.4 mm) shall be disregarded.

FIG. 6 RADIOGRAPHIC ACCEPTANCE STANDARDS FOR ROUNDED INDICATIONS (GRADE 1)



(E) ASSORTED ROUNDED INDICATIONS

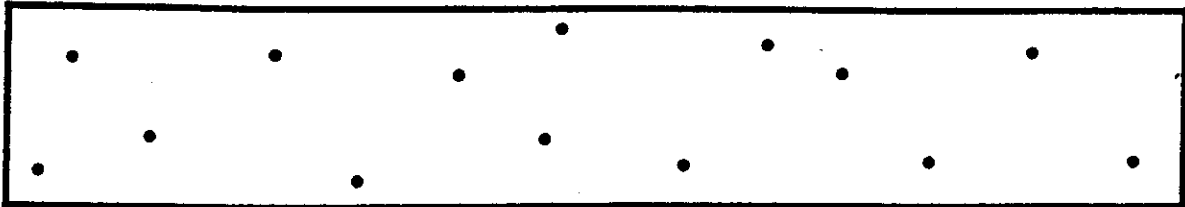
SIZE 1/64 in. (0.4 mm) TO 5/64 in. (2.0 mm) IN DIAMETER OR IN LENGTH.

MAXIMUM NUMBER OF INDICATIONS IN ANY 6 in. (150 mm) OF WELD = 27, WITH THE FOLLOWING RESTRICTIONS:

MAXIMUM NUMBER OF LARGE 1/16 in. (1.6 mm) TO 5/64 in. (2.0 mm) IN DIAMETER OR IN LENGTH INDICATIONS = 3.

MAXIMUM NUMBER OF MEDIUM 3/64 in. (1.2 mm) TO 1/16 in. (1.6 mm) IN DIAMETER OR IN LENGTH INDICATIONS = 8.

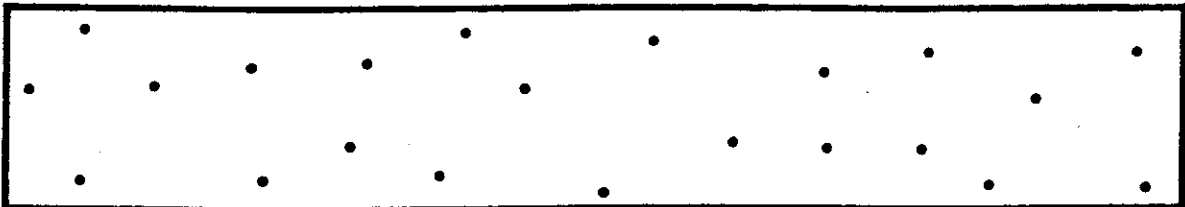
MAXIMUM NUMBER OF SMALL 1/64 in. (0.4 mm) TO 3/64 in. (1.2 mm) IN DIAMETER OR IN LENGTH INDICATIONS = 16.



(F) LARGE ROUNDED INDICATIONS

SIZE 1/16 in. (1.6 mm) TO 5/64 in. (2.0 mm) IN DIAMETER OR IN LENGTH.

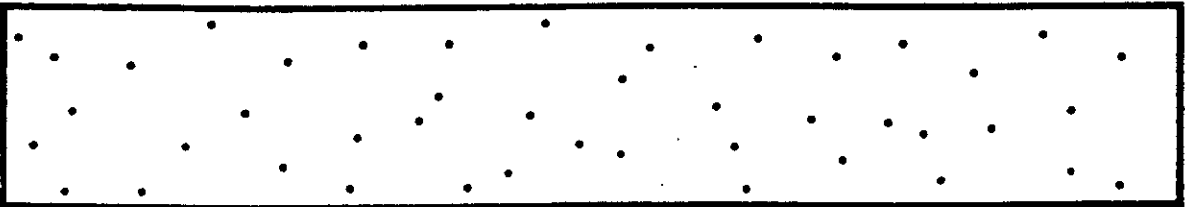
MAXIMUM NUMBER OF INDICATIONS IN ANY 6 in. (150 mm) OF WELD = 14.



(G) MEDIUM ROUNDED INDICATIONS

SIZE 3/64 in. (1.2 mm) TO 1/16 in. (1.6 mm) IN DIAMETER OR IN LENGTH.

MAXIMUM NUMBER OF INDICATIONS IN ANY 6 in. (150 mm) OF WELD = 22.



(H) SMALL ROUNDED INDICATIONS

SIZE 1/64 in. (0.4 mm) TO 3/64 in. (1.2 mm) IN DIAMETER OR IN LENGTH.

MAXIMUM NUMBER OF INDICATIONS IN ANY 6 in. (150 mm) OF WELD = 44.

Notes:

1. In using these standards, the chart which is most representative of the size of the rounded indications present in the test specimen radiograph shall be used for determining conformance to these radiographic standards.
2. Since these are test welds specifically made in the laboratory for classification purposes, the radiographic requirements for these test welds are more rigid than those which may be required for general fabrication.
3. Indications whose largest dimension does not exceed 1/64 in. (0.4 mm) shall be disregarded.

FIG. 6 RADIOGRAPHIC ACCEPTANCE STANDARDS FOR ROUNDED INDICATIONS (GRADE 2) (CONT'D)

TABLE 9
RADIOGRAPHIC SOUNDNESS REQUIREMENTS

AWS Classification ^a	Radiographic Standard ^{b,c}
EXX15-X EXX16-X EXX18-X E7020-X EXX18M E12018M1	Grade 1
EXX10-X EXX11-X EXX13-G E7027-X	Grade 2

- NOTES:
- a. The letters "XX" used in the classification designations in this table, stand for the various strength levels (70, 80, 90, 100, 110, and 120) of electrodes. The letter suffix "X" as used in this table stands for the suffixes A1, B1, B2, etc. (see Table 2).
- b. See Figure 6.
- c. The radiographic soundness obtainable under actual industrial conditions employed for the various electrode classifications is discussed in A6.10.1 in the Annex.

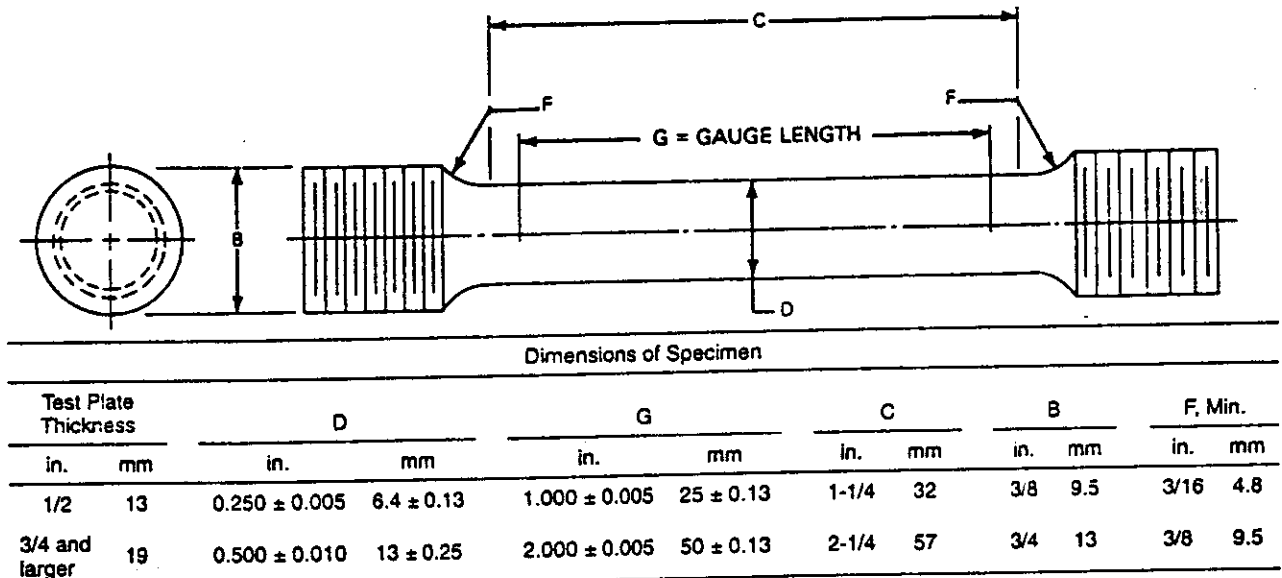
14.4 The apparatus used for moisture testing with the referee method³ shall be as shown in Fig. 11 and shall consist of the following:

(1) A tube furnace with a heating element long enough to heat at least 6 in. (150 mm) of the middle portion of the combustion tube to 2000°F (1093°C).

(2) An oxygen purifying train consisting of a needle valve, a flow meter, a 96 percent sulfuric acid wash bottle, a spray trap, and an anhydrous magnesium perchlorate drying tower.

(3) A fused silica combustion tube of at least 7/8 in. (22 mm) inside diameter with plain ends and a devitrification point above 2000°F (1093°C). (A high-temperature ceramic tube can be used, but a higher value will be obtained for the blanks.) A plug of glass wool, fine enough to filter the gases, shall be inserted far enough into the exit end of the combustion tube to be heated to a temperature of 400° to 500°F (204° to 260°C).

³ Modifications of the type described in A8, Modification of Moisture Test Apparatus, which give equivalent results, also meet the requirements of this specification.

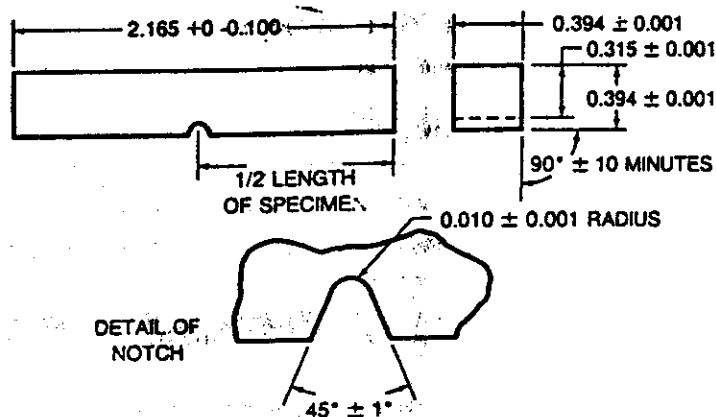


- Notes:
1. Dimensions G and C shall be as shown, but ends may be of any shape to fit the testing machine holders as long as the load is axial.
2. The diameter of the specimen within the gauge length shall be slightly smaller at the center than at the ends. The difference shall not exceed one percent of the diameter.
3. When the extensometer is required to determine yield strength, dimension C may be modified. However, the percent of the elongation shall be based on dimension G.
4. The surface finish within the C dimension shall be no rougher than 63 µin. (1.6 µm).

FIG. 7 ALL-WELD-METAL TENSION TEST SPECIMEN DIMENSIONS

PART C — SPECIFICATIONS FOR WELDING RODS,
ELECTRODES, AND FILLER METALS

SFA-5.5



SI EQUIVALENTS

in.	mm
0.001	0.025
0.010	0.255
0.100	2.5
0.315	8.0
0.394	10
2.165	55

Notes:

1. All dimensions except angles are in inches.
2. The notched surface and the surface to be struck shall be parallel within 0.002 in. (0.05 mm) and have at least 63 μ n. (1.6 μ m) finish. The other two surfaces shall be square with the notched or struck surface within ± 10 minutes of the degree and have at least 125 μ n. (3.2 μ m) finish.
3. The notch shall be smoothly cut by mechanical means and shall be square with the longitudinal edge of the specimen within one degree.
4. The geometry of the notch shall be measured on at least one specimen in a set of five specimens. Measurement shall be done at minimum 50 times magnification on either a shadowgraph or a metallograph.
5. The correct location of the notch shall be verified by etching before or after machining.
6. If a specimen does not break upon being struck, the value for energy absorbed shall be reported as the capacity of the impact testing machine followed by a plus sign (+).

FIG. 8 CHARPY V-NOTCH IMPACT TEST SPECIMEN

(4) A water absorption train consisting of a U-tube (Schwartz-type) filled with anhydrous magnesium perchlorate and a concentrated sulfuric acid gas-sealing bottle.

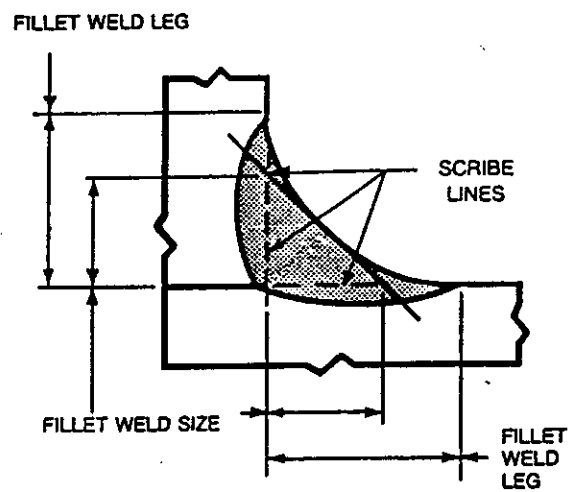
14.5 In conducting the moisture test, a sample of approximately 4 grams of covering shall be prepared as a composite of the covering from the middle of three electrodes taken from the same package. The covering shall be removed by bending the electrode or by pinching the covering with clean, dry pliers or forceps. Immediately upon removal, the sample of covering shall be transferred to a dried, stoppered vial or sample bottle.

14.6 The furnace shall be operated at 1775° to 1825°F (968° to 996°C) with an oxygen flow of 200 to 250 mL per minute. The empty boat (see 14.3) shall be placed in the hot zone of the combustion tube, for drying, and the absorption U-tube assembly shall be attached to the system for "conditioning." After 30 minutes, the absorption U-tube shall be removed and placed in the balance case. The boat shall be removed and placed in a desiccator in which anhydrous magnesium perchlorate is used as a desiccant. After a cooling

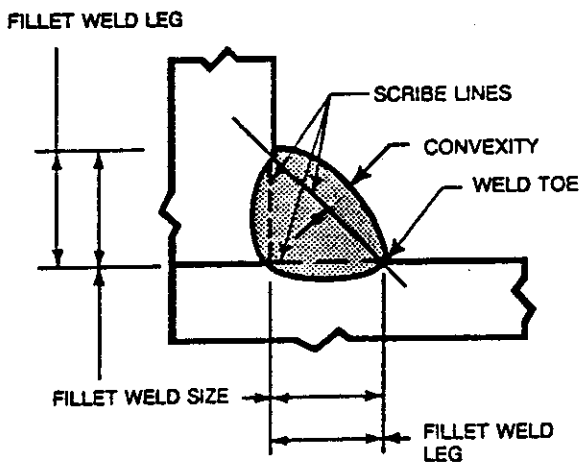
period of 20 minutes, the absorption U-tube shall be weighed.

14.7 In the determination of the blank value, the procedure for an actual moisture determination shall be followed step-by-step with the single exception of omitting the sample. The boat shall be removed from the desiccator and exposed to the atmosphere for a period approximating the time required to transfer a sample from the balance pan to the boat. The combustion tube shall be opened, the weighed absorption U-tube attached, the empty boat placed in the hot zone of the combustion tube, and the tube closed. After a heating period of 30 minutes, the absorption U-tube shall be removed and placed in the balance case. The boat shall be transferred to the desiccator. After the 20 minute cooling period, the absorption U-tube shall be weighed and the gain in weight shall be taken as the blank value.

14.8 Immediately after weighing the absorption U-tube, the sample of the covering shall be weighed and quickly transferred to the boat. The combustion tube shall be opened, the weighed absorption U-tube attached, the boat with sample transferred to the hot zone of



(A) CONCAVE FILLET WELD



(B) CONVEX FILLET WELD

- Notes:
1. Fillet weld size is the leg lengths of the largest isosceles right triangle which can be inscribed within the fillet weld cross section.
 2. Convexity is the maximum distance from the face of a convex fillet weld perpendicular to a line joining the weld toes.
 3. Fillet weld leg is the distance from the joint root to the toe of the fillet weld.

FIG. 9 DIMENSIONS OF FILLET WELDS

the combustion tube, and the tube closed. After heating for 30 minutes, the absorption U-tube shall be removed and placed in the balance case. If another sample is to be run, the boat shall be taken from the combustion tube, the sample removed, and the boat transferred to the desiccator. The absorption U-tube shall be weighed after the 20 minute cooling period. Another determination may be started immediately, since it is not necessary to repeat the blank determination provided the same combustion boat can be used.

14.9 The calculation shall be made according to the following formula:

$$\text{Percent Moisture} = \frac{A - B}{\text{initial weight of sample}} \times 100$$

where:

- A = gain in weight of absorption tube in moisture determination
B = gain in weight of absorption tube in blank determination

15. Absorbed Moisture Test

15.1 In order for a low-hydrogen electrode to be designated as low-moisture-absorbing with the "R" suffix designator, sufficient electrodes shall be exposed to an environment of 80°F and 80% relative humidity for a period of not less than 9 hours by any suitable method. In case of dispute, the exposure method described in 15.2 through 15.6 shall be the referee method. The moisture content of the electrode covering on the low-moisture-absorbing, low-hydrogen electrodes (EXX15-X-R, EXX16-X-R, EXX18-X-R) shall be determined by any suitable method. In case of dispute, the method described in 14.3 through 14.9 shall be the referee method for determination of moisture content. The moisture content of the exposed covering shall not exceed the maximum specified moisture content for the "R" designated electrode and classification in Table 11.

15.2 An electrode sample of the smallest and the largest sizes of the "R" designated electrode shall be used for controlled environmental exposure. If the electrodes are conditioned prior to exposure, that fact, along with the method used for conditioning, and the time and temperature involved in conditioning, shall be noted on the test record. Conditioning of electrodes after exposure is not permitted.

15.3 The electrode samples described in 15.2 shall be exposed in a suitably calibrated and controlled environmental chamber for nine hours minimum at

TABLE 10
DIMENSIONAL REQUIREMENTS FOR FILLET WELD USABILITY TEST SPECIMENS

Measured Fillet Weld Size		Maximum Convexity		Maximum Difference Between Fillet Weld Legs	
in.	mm	in.	mm	in.	mm
1/8 or less	3.2	3/64	1.2	1/32	0.8
9/64	3.6	3/64	1.2	3/64	1.2
5/32	4.0	3/64	1.2	3/64	1.2
11/64	4.4	1/16	1.6	1/16	1.6
3/16	4.8	1/16	1.6	1/16	1.6
13/64	5.2	1/16	1.6	5/64	2.0
7/32	5.6	1/16	1.6	5/64	2.0
15/64	6.0	1/16	1.6	3/32	2.4
1/4	6.4	1/16	1.6	3/32	2.4
17/64	6.7	1/16	1.6	7/64	2.8
9/32	7.1	1/16	1.6	7/64	2.8
19/64	7.5	5/64	2.0	1/8	3.2
5/16	8.0	5/64	2.0	1/8	3.2
21/64	8.3	5/64	2.0	9/64	3.6
11/32	8.7	5/64	2.0	9/64	3.6
23/64	9.1	5/64	2.0	5/32	4.0
3/8 or more	9.5	5/64	2.0	5/32	4.0

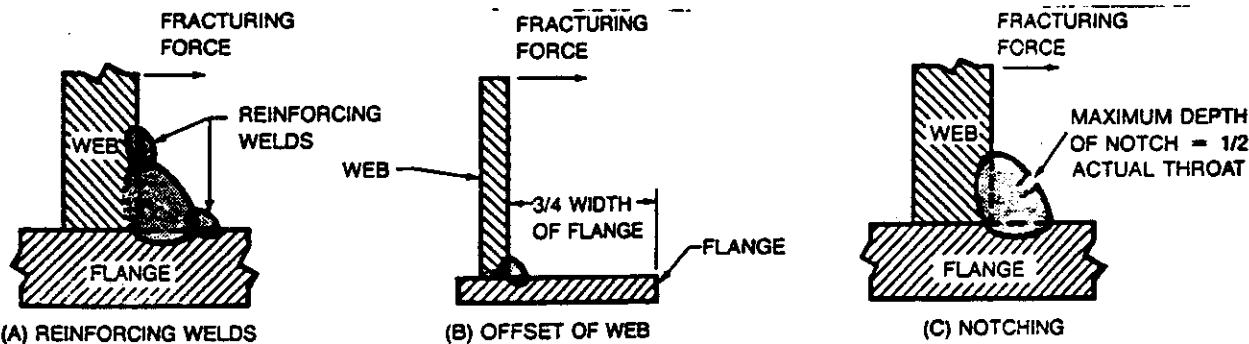


FIG. 10 ALTERNATE METHODS FOR FACILITATING FRACTURE OF THE FILLET WELD

80°F, minus 0, plus 5°F (26.7°C, minus 0, plus 2.8°C) and 80% relative humidity, minus 0, plus 5%.

15.4 The environmental chamber described in 15.3 shall meet the following design requirements:

(1) The apparatus shall be an insulated humidifier which produces the temperature of adiabatic saturation through regenerative evaporation or vaporization of water.

(2) The apparatus shall have an average air speed within the envelope of air surrounding the covered electrodes of 100 to 325 fpm (0.5 to 1.7 m/sec).

(3) The apparatus shall have a drip-free area where covered electrodes up to 18 in. (450 mm) in length can be positioned with length as perpendicular as practical to the general air flow.

(4) The apparatus shall have a calibrated means of continuously measuring and recording the dry bulb

TABLE 11
MOISTURE CONTENT LIMITS IN ELECTRODE COVERINGS

AWS Classification	Electrode Designation ^a	Limit of Moisture Content, % by wt., max.	
		As-Received or Reconditioned ^b	As-Exposed ^c
E7015-X E7016-X E7018-X	E7015-X, E7015-X-HZ E7016-X, E7016-X-HZ E7018-X, E7018-X-HZ	0.4	Not specified
E7015-X E7016-X E7018-X	E7015-X-R, E7015-X-HZR E7016-X-R, E7016-X-HZR E7018-X-R, E7018-X-HZR	0.3	0.4
E8015-X E8016-X E8018-X	E8015-X, E8015-X-HZ E8016-X, E8016-X-HZ E8018-X, E8018-X-HZ	0.2	Not specified
E8015-X E8016-X E8018-X	E8015-X-R, E8015-X-HZR E8016-X-R, E8016-X-HZR E8018-X-R, E8018-X-HZR	0.2	0.4
E9015-X E9016-X E9018-X E9018M	E9015-X, E9015-X-HZ E9016-X, E9016-X-HZ E9018-X, E9018-X-HZ E9018M, E9018M-HZ	0.15	Not specified
E9015-X E9016-X E9018-X E9018M	E9015-X-R, E9015-X-HZR E9016-X-R, E9016-X-HZR E9018-X-R, E9018-X-HZR E9018M-R, E9018M-HZR	0.15	0.4
E10015-X E10016-X E10018-X E10018M	E10015-X, E10015-X-HZ E10016-X, E10016-X-HZ E10018-X, E10018-X-HZ E10018M, E10018M-HZ	0.15	Not specified
E10015-X E10016-X E10018-X E10018M	E10015-X-R, E10015-X-HZR E10016-X-R, E10016-X-HZR E10018-X-R, E10018-X-HZR E10018M-R, E10018M-HZR	0.15	0.4
E11015-G E11016-G E11018-G E11018M	E11015-G, E11015-G-HZ E11016-G, E11016-G-HZ E11018-G, E11018-G-HZ E11018M, E11018M-HZ	0.15	Not specified
E11015-G E11016-G E11018-G E11018M	E11015-G-R, E11015-G-HZR E11016-G-R, E11016-G-HZR E11018-G-R, E11018-G-HZR E11018M-R, E11018M-HZR	0.15	0.4
E12015-G E12016-G E12018-G E12018M	E12015-G, E12015-G-HZ E12016-G, E12016-G-HZ E12018-G, E12018-G-HZ E12018M, E12018M-HZ	0.15	Not specified
E12015-G E12016-G E12018-G E12018M	E12015-G-R, E12015-G-HZR E12016-G-R, E12016-G-HZR E12018-G-R, E12018-G-HZR E12018M-R, E12018M-HZR	0.15	0.4
E12018M1	E12018M1, E12018M1-HZ	0.10	Not specified
E12018M1	E12018M1-R, E12018M1-HZR	0.10	0.4

NOTES:

a. See Section 16 and Table 12.

b. As-received or reconditioned electrode coverings shall be tested as specified in Section 14.

c. As-exposed electrode coverings shall be treated with a moist environment as specified in 15.2 through 15.6 before being tested as specified in 15.1.

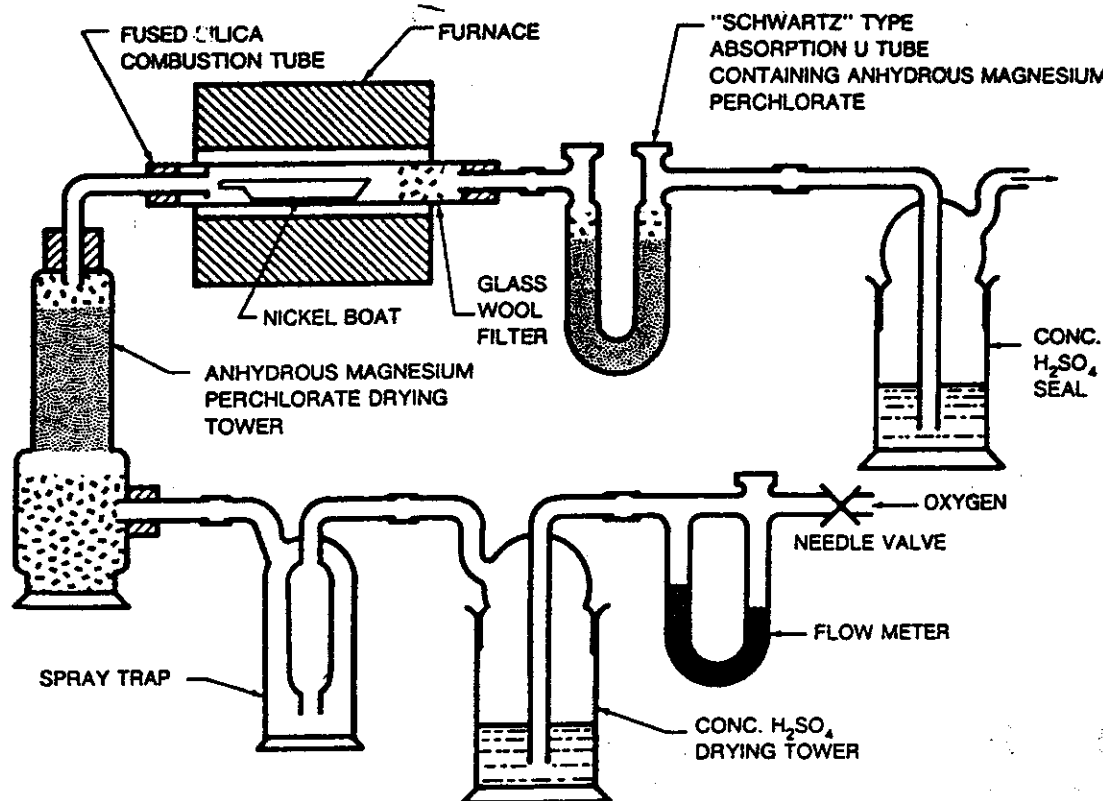


FIG. 11 SCHEMATIC OF TRAIN FOR MOISTURE DETERMINATION

temperature and either the wet bulb temperature or the differential between the dry bulb and the wet bulb temperature over the period of time required.

(5) The apparatus shall have an air speed of at least 900 fpm (4.5 m/sec) over the wet bulb sensor unless the wet bulb sensor can be shown to be insensitive to air speed or has a known correction factor that will provide for an adjusted wet bulb reading equal to the temperature of adiabatic saturation.

(6) The apparatus shall have the wet bulb sensor located on the suction side of the fan so that there is an absence of heat radiation on the sensor.

15.5 The exposure procedure for electrode samples shall be as follows:

(1) The electrode sample in unopened packages, or from reconditioned lots, shall be heated to a temperature, minus 0, plus 10°F above the dew point of the chamber at the time of loading. In this case, the dew point temperature is 73°F (22.8°C).

(2) The electrode sample shall be loaded into the chamber without delay after the packages are opened.

(3) The electrodes shall be placed in the chamber in a vertical or horizontal position on one inch centers, with the length of the electrode as perpendicular as practical to the general air flow.

(4) Time, temperature, and humidity shall be continuously recorded for the period that the electrodes are in the chamber.

(5) Counting of the exposure time shall start when the required temperature and humidity in the chamber are established.

(6) At the end of the exposure time, the electrode shall be removed from the chamber and a sample of the electrode covering taken for moisture determination, as specified in Section 14, Moisture Test.

15.6 The manufacturer shall control other test variables which are not defined, but which must be controlled to ensure a greater consistency of results.

TABLE 12
DIFFUSIBLE HYDROGEN REQUIREMENTS FOR WELD METAL AND OPTIONAL SUPPLEMENTAL DESIGNATORS

AWS Classification	Diffusible Hydrogen Designator ^a	Diffusible Hydrogen Content, Average, Maximum ^b mL(H ₂)/100g Deposited Metal
E(X)XX15-X, E(X)XX16-X, E(X)XX18-X, or E(X)XX18M(1) }	H16	16.0
	H8	8.0
	H4	4.0

NOTES:
a. Diffusible hydrogen testing of low hydrogen electrode classifications is only required when the diffusible hydrogen designator is added to the classification as specified in Figure 12. See Section 16.
b. The lower average diffusible hydrogen levels (H8 and H4) may not be available in all low hydrogen classifications.

16. Diffusible Hydrogen Test

The smallest and the largest sizes of the electrode of each classification to be designated by the optional supplemental diffusible hydrogen designator shall be tested according to one of the methods given in ANSI/AWS A4.3, *Standard Methods for Determination of the Diffusible Hydrogen Content of Martensitic, Bainitic, and Ferritic Weld Metal Produced by Arc Welding*. Testing shall be done without conditioning of the electrode, unless the manufacturer recommends otherwise. If the electrodes are conditioned, that fact, along with the method used for conditioning, and the time and temperature involved in conditioning, shall be noted on the test record. The diffusible hydrogen designator may be added to the classification according to the average test value as compared to the requirements of Table 12.

For purposes of certifying compliance with diffusible hydrogen requirements, the reference atmospheric condition⁴ shall be an absolute humidity of 10 grains of water vapor per pound (1.43 g/kg) of dry air at the time of welding. The actual atmospheric conditions shall be reported along with the average value for the test according to ANSI/AWS A4.3.

When the absolute humidity equals or exceeds the reference condition at the time of preparation of the test assembly, the test shall be acceptable as demonstrating compliance with the requirements of this specification, provided the actual test results satisfy the diffusible hydrogen requirements for the applicable designator. Likewise, if the actual test results for an electrode meet the requirements for the lower, or lowest hydrogen designator, as specified in Table 12, the electrode

also meets the requirements for all higher hydrogen designators in Table 12 without the need to retest.

PART C — MANUFACTURE, IDENTIFICATION, AND PACKAGING

17. Method of Manufacture

The electrodes classified according to this specification may be manufactured by any method that will produce electrodes that meet the requirements of this specification.

18. Standard Sizes and Lengths

18.1 Standard sizes (diameter of the core wire) and lengths of electrodes are shown in Table 13.

18.2 The diameter of the core wire shall not vary more than plus or minus 0.002 in. (0.05 mm) from the diameter specified. The length shall not vary more than plus or minus 1/4 in. (6.4 mm) from that specified.

19. Core Wire and Covering

19.1 The core wire and covering shall be free of defects that would interfere with uniform deposition of the electrode.

19.2 The core wire and the covering shall be concentric to the extent that the maximum core-plus-one covering dimension shall not exceed the minimum core-plus-one covering dimension by more than:

- (1) seven percent of the mean dimension in sizes 3/32 in. (2.4 mm) and smaller;
- (2) five percent of the mean dimension in sizes 1/8 in. (3.2 mm) and 5/32 in. (4.0 mm); and

⁴See A9.2 (in the Annex) for further explanation of reference atmospheric condition in psychometric terms.

TABLE 13
STANDARD SIZES AND LENGTHS

Standard Sizes, (Core Wire Diameter) ^d			Standard Lengths ^{a,b,c}			
			All Classifications except E7020-A1, E7020-G, E7027-A1 and E7027-G		E7020-A1, E7020-G, E7027-A1 and E7027-G	
in.		mm	in.	mm	in.	mm
$\frac{3}{32}$ ^e	(0.093)	2.4 ^e	12 or 14	300 or 350	12	300
$\frac{1}{8}$	(0.125)	3.2	14	350	14	350
$\frac{5}{32}$	(0.156)	4.0	14	350	14	350
$\frac{3}{16}$	(0.187)	4.8	14	350	14 or 18	350 or 450
$\frac{7}{32}$ ^e	(0.218)	5.6 ^e	14 or 18	350 or 450	18 or 28	450 or 700
$\frac{1}{4}$ ^e	(0.250)	6.4 ^e	18	450	18 or 28	450 or 700
$\frac{5}{16}$ ^e	(0.312)	8.0 ^e			18 or 28	450 or 700

NOTES:

- Tolerance on the length shall be $\pm \frac{1}{4}$ in. (± 10 mm).
- In all cases, end gripping is standard.
- Other lengths are acceptable and shall be as agreed upon by the supplier and purchaser.
- Tolerance on the core wire diameter shall be ± 0.002 in. (± 0.05 mm). Electrodes produced in sizes other than those shown may be classified. See Note c of Table 5.
- These diameters are not manufactured in all electrode classifications (see Table 5).

(3) four percent of the mean dimension in sizes $\frac{3}{16}$ in. (4.8 mm) and larger.

Concentricity may be measured by any suitable means.

20. Exposed Core

20.1 The grip end of each electrode shall be bare (free of covering) for a distance of not less than $\frac{1}{2}$ in. (12.5 mm), nor more than $1\frac{1}{4}$ in. (30 mm) for $\frac{5}{32}$ in. (4.0 mm) and smaller sizes, and not less than $\frac{3}{4}$ in. (19 mm) nor more than $1\frac{1}{2}$ in. (40 mm) for $\frac{3}{16}$ in. (4.8 mm) and larger sizes, to provide for electrical contact with the electrode holder.

20.2 The arc end of each electrode shall be sufficiently bare and the covering sufficiently tapered to permit easy striking of the arc. The length of the bare portion (measured from the end of the core wire to the location where the full cross-section of the covering is obtained) shall not exceed $\frac{1}{8}$ in. (3.2 mm) or the diameter of the core wire, whichever is less. Electrodes with chipped coverings near the arc end, baring the core wire no more than the lesser of $\frac{1}{4}$ in. (6.4 mm) or twice the diameter of the core wire, meet the requirements of this specification provided no chip uncovers more than 50 percent of the circumference of the core.

21. Electrode Identification

All electrodes shall be identified as follows:

21.1 At least one imprint of the electrode designation (classification plus any optional designators) shall be applied to the electrode covering in the order specified in Fig. 12 within $2\frac{1}{2}$ in. (65 mm) of the grip end of the electrode.

21.2 The numbers and letters of the imprint shall be of bold block type of a size large enough to be legible.

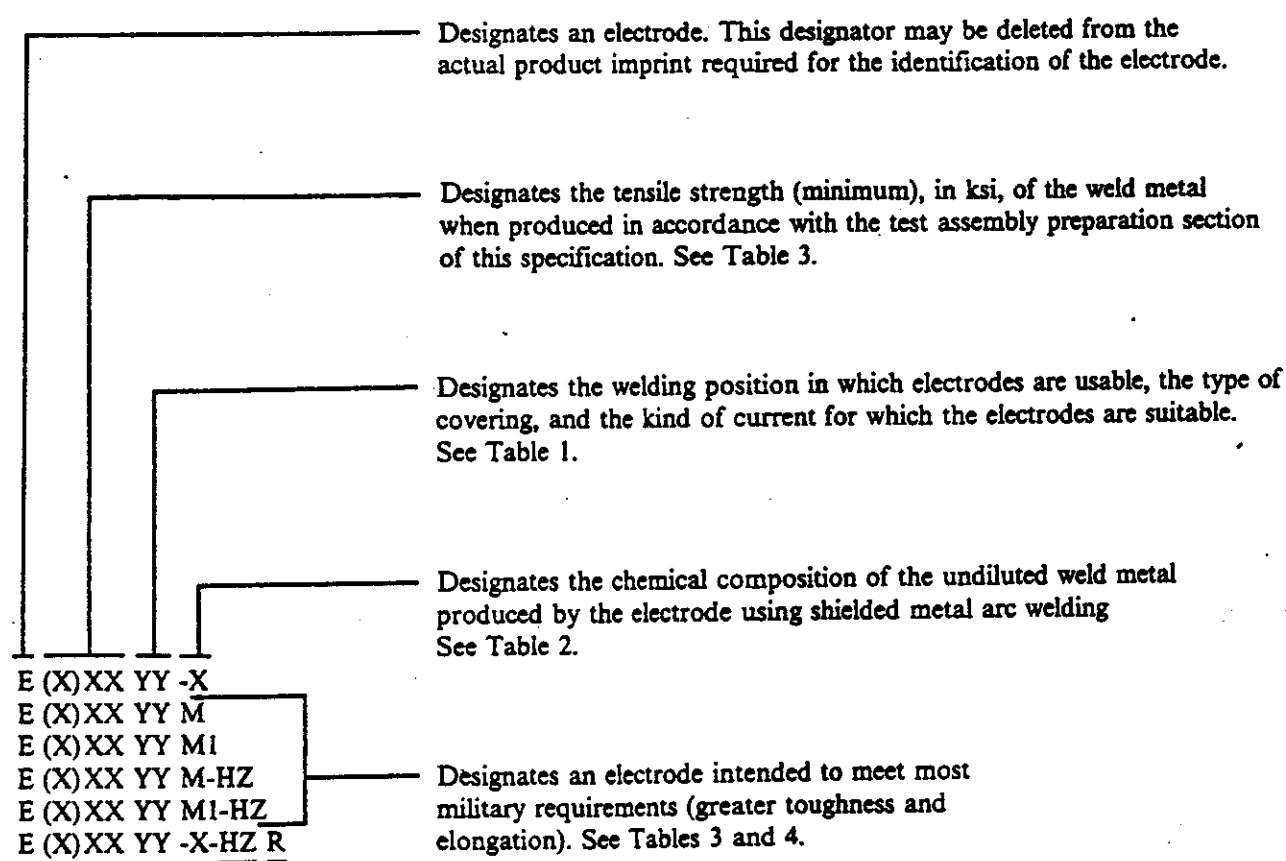
21.3 The ink used for imprinting shall provide sufficient contrast with the electrode covering so that, in normal use, the numbers and letters are legible both before and after welding.

21.4 The prefix letter "E" in the electrode classification may be omitted from the designation imprint.

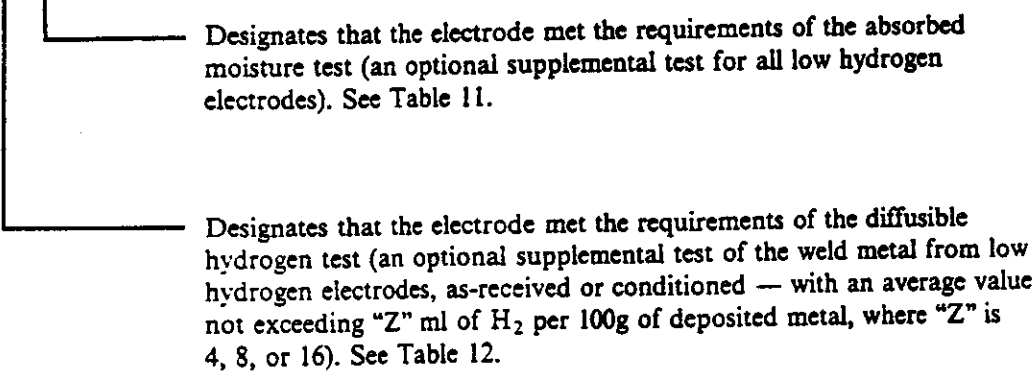
22. Packaging

22.1 Electrodes shall be suitably packaged to protect them from damage during shipment and storage under normal conditions. When electrodes are packaged in hermetically-sealed containers, the type of hermetically-sealed container shall be capable of passing the test specified in 22.2.

Mandatory Classification Designators*:



Optional Supplemental Designators:



*The combination of these designators constitutes the electrode classification.

FIG. 12 ORDER OF ELECTRODE MANDATORY AND OPTIONAL SUPPLEMENTAL DESIGNATORS

22.2 For test, a representative container shall be immersed in water that has been heated to a temperature of at least 50°F (28°C) above that of the packaged material (room temperature). The container shall be immersed so that the surface under observation is 1 in. (25 mm) below the water level and the greatest basic dimension is parallel to the water surface. A container with a steady stream of bubbles that lasts for 30 seconds or more does not meet the requirements of the specification.

22.3 Standard package weights shall be as agreed between purchaser and supplier.

23. Marking of Packages

23.1 The following product information (as a minimum) shall be legibly marked on the outside of each unit package:

- (1) AWS specification (year of issue may be excluded) and electrode designation (classification plus any optional supplemental designators)
- (2) Supplier's name and trade designation
- (3) Size and net weight
- (4) Lot, control, or heat number

23.2 The following precautionary information (as a minimum) shall be prominently displayed in legible print on all packages of electrode, including individual unit packages enclosed within a larger package:

WARNING: Protect yourself and others. Read and understand this information.

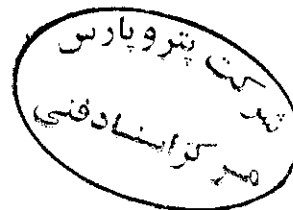
FUMES AND GASES can be dangerous to your health.

ARC RAYS can injure eyes and burn skin.

ELECTRIC SHOCK can kill.

- Before use, read and understand the manufacturer's instructions, Material Safety Data Sheets (MSDSs), and your employer's safety practices.
- Keep your head out of the fumes.
- Use enough ventilation, exhaust at the arc, or both, to keep fumes and gases away from your breathing zone and the general area.
- Wear correct eye, ear, and body protection.
- Do not touch electrical parts.
- See American National Standard Z49.1, *Safety in Welding and Cutting*, published by the American Welding Society, 550 N.W. LeJeune Road, Miami, Florida 33126; OSHA Safety and Health Standards, 29 CFR 1910, available from the U.S. Government Printing Office, Washington, DC 20402.

DO NOT REMOVE THIS INFORMATION



Annex

Guide to AWS Specification for Low-Alloy Steel Electrodes for Shielded Metal Arc Welding

(This Annex is not a part of AWS A5.5-96, *Specification for Low Alloy Steel Electrodes for Shielded Metal Arc Welding*, but is included for information purposes only.)

A1. Introduction

This guide is appended to the specification as a source of information. The guide is not mandatory and does not form a part of the specification. This guide was designed to correlate the covered electrode classifications with the intended applications so the specification can be used effectively. Such correlations are intended as examples rather than complete listings of the base metals for which each filler metal is suitable.

A2. Classification System

A2.1 The system for electrode classification in this specification follows the standard pattern used in other AWS filler metal specifications. The letter "E" at the beginning of each classification designation stands for electrode. The first two (or three) digits, 70 (or 110), for example, designate tensile strength of at least 70 (or 110) ksi of the weld metal, welded and postweld heat treated (if required) in accordance with the test assembly preparation section of this specification. The third (or fourth) digit designates position usability that will allow satisfactory welds to be produced with the electrode. Thus, the "1," as in E7018-C2L (or E11018M), means that the electrode is usable in all positions (flat, horizontal, vertical, and overhead). The "2," as in E7020-A1, designates that the electrode is suitable for use in the flat position and for making fillet welds in the horizontal position. The last two digits taken together designate the type of current with which the electrode can be used and the type of covering on the electrode, as listed in Table 1.

With the exception of the military similar electrodes [e.g., E(X)XX18M(1)], the classifications in this specification also include a suffix designator, separated by a hyphen from the tensile strength and usability designators, and by a second hyphen, if necessary, from any optional supplemental designators which are not part of the classification designation. This composition designator, such as A1, B3, or W1, immediately identifies the classification as different from those in ANSI/AWS A5.1, *Specification for Carbon Steel Electrodes for Shielded Metal Arc Welding*. The composition designator identifies the chemical composition of the weld metal as specified in Table 2. For example, an "A1" composition designator identifies the electrode as one that produces carbon-molybdenum steel weld metal, when the electrode is deposited using shielded metal arc welding.

A2.2 "G" Classifications

A2.2.1 The specification includes filler metals classified as E(X)XXYY-G. The "G" indicates that the filler metal is of a general classification. It is "general" because not all of the particular requirements specified for each of the other classifications are specified for this classification. The intent, in establishing this classification, is to provide a means by which filler metals that differ in one respect or another (chemical composition, for example) from all other classifications (meaning that the composition of the filler metal—in the case of the example—does not meet the composition specified for any of the classifications in the specification) can still be classified according to the specification. The purpose is to allow a useful filler metal, one that otherwise would have to await a revision of the

specification, to be classified immediately, under the existing specification. This means, then, that two filler metals, each bearing the same "G" classification, may be quite different in some certain respect (chemical composition, again, for example).

A2.2.2 The point of difference (although not necessarily the amount of difference) referred to above will be readily apparent from the use of the words "not required" and "not specified" in the specification. The use of these words is as follows:

Not Specified is used in those areas of the specification that refer to the results of some particular test. It indicates that the requirements for that test are not specified for that particular classification.

Not Required is used in those areas of the specification that refer to the test that must be conducted in order to classify a filler metal. It indicates that the test is not required because the requirements for the test have not been specified for that particular classification.

Restating the case, when a requirement is not specified, it is not necessary to conduct the corresponding test in order to classify a filler metal to that classification. When a purchaser wants the information provided by that test, in order to consider a particular product of that classification for a certain application, the purchaser will have to arrange for that information with the supplier of that product. The purchaser will also have to establish with that supplier just what the testing procedure and the acceptance requirements are to be, for that test. The purchaser may want to incorporate that information (via ANSI/AWS A5.01, *Filler Metal Procurement Guidelines*) in the purchase order.

A2.2.3 Request for Filler Metal Classification

A2.2.3.1 When a filler metal cannot be classified according to some classification other than a "G" classification, the manufacturer may request that a classification be established for that filler metal by using the procedure given here. When the manufacturer elects to use the "G" classification, the Filler Metal Committee recommends that the manufacturer still request that a classification be established for that filler metal, as long as the filler metal is of commercial significance.

A2.2.3.2 A request to establish a new filler metal classification must be a written request, and it needs to provide sufficient detail to permit the Filler Metal Committee or the Subcommittee to determine whether a new classification or the modification of an existing classification is more appropriate, and whether either is necessary to satisfy the need. The request needs to state the variables and their limits for such a classification or modification. The request should

contain some indication of the time by which completion of the new classification or modification is needed.

A2.2.3.3 The request should be sent to the Secretary of the Filler Metal Committee at AWS Headquarters. Upon receipt of the request, the Secretary will do the following:

(a) Assign an identifying number to the request. This number will include the date the request was received.

(b) Confirm receipt of the request and give the identification number to the person who made the request.

(c) Send a copy of the request to the Chairman of the Filler Metal Committee and the Chairman of the particular Subcommittee involved.

(d) File the original request.

(e) Add the request to the log of outstanding requests.

A2.2.3.4 All necessary action on each request will be completed as soon as possible. If more than 12 months lapse, the Secretary shall inform the requestor of the status of the request, with copies to the Chairman of the Committee and the Subcommittee. Requests still outstanding after 18 months shall be considered not to have been answered in a "timely manner" and the Secretary shall report these to the Chairman of the Filler Metal Committee, for action.

A2.2.3.5 The Secretary shall include a copy of the log of all requests pending and those completed during the preceding year with the agenda for each Filler Metal Committee meeting. Any other publication of requests that have been completed will be at the option of the American Welding Society, as deemed appropriate.

A2.3 Optional supplemental designators are also used in this specification in order to identify electrode classifications that have met certain supplemental requirements as agreed to between the supplier and the purchaser. The optional supplemental designators are not part of the classification nor of its designation.

An optional supplemental designator "HZ" following the classification designation, which consists of four or five digits plus "M," or a composition suffix such as "-A1," "-B2," or "-C2L," indicates an average diffusible hydrogen content of not more than "Z" mL/100g of deposited metal when tested in the "as-received" or conditioned state in accordance with ANSI/AWS A4.3. See Section 16 and Table 12. Electrodes that are designated as meeting the lower, or lowest hydrogen limits, as specified in Table 12, also are understood

to be able to meet any higher hydrogen limits. Therefore, as an example, an electrode designated as "H4" also meets "H8" and "H16" requirements without being designated as such. The letter "R" is an example of a supplemental designator used with certain low-hydrogen electrode classifications. It identifies classifications that have been exposed to a humid environment for a given length of time and tested for low moisture absorption in addition to the standard moisture test required for classification of low-hydrogen electrodes. See Note d to Table 1, as well as Tables 11 and 12.

A3. Acceptance

Acceptance of all welding materials classified under this specification is in accordance with ANSI/AWS A5.01, *Filler Metal Procurement Guidelines*, as the specification states. Any testing a purchaser requires of the supplier, for material shipped in accordance with this specification, shall be clearly stated in the purchase order, according to the provisions of ANSI/AWS A5.01. In the absence of any such statement in the purchase order, the supplier may ship the material with whatever testing is normally conducted on material of that classification, as specified in Schedule F, Table 1, of ANSI/AWS A5.01. Testing in accordance with any other Schedule in that Table must be specifically required by the purchase order. In such cases, acceptance of the material shipped will be in accordance with those requirements.

A4. Certification

The act of placing the AWS specification and classification designations on the packaging enclosing the product, or the classification on the product itself, constitutes the supplier's (manufacturer's) certification that the product meets all of the requirements of the specification.

The only testing requirement implicit in this certification is that the manufacturer has actually conducted the tests required by the specification on material that is representative of that being shipped and that the material met the requirements of the specification. Representative material, in this case, is any production run of that classification using the same formulation. "Certification" is not to be construed to mean that tests of any kind were necessarily conducted on samples of the specific material shipped. Tests on such material may or may not have been made. The basis for the certification required by the specification is the classification test of "representative material" cited above,

and the "Manufacturer's Quality Assurance System" in ANSI/AWS A5.01.

A5. Ventilation During Welding

A5.1 Five major factors govern the quantity of fumes in the atmosphere to which welders and welding operators are exposed during welding:

- (1) Dimensions of the space in which welding is done (with special regard to the height of the ceiling)
- (2) Number of welders and welding operators working in that space
- (3) Rate of evolution of fumes, gases, or dust, according to the materials and processes used
- (4) The proximity of welders and welding operators to the fumes as they issue from the welding zone, and to the gases and dust in the space in which they are working
- (5) The ventilation provided to the space in which the welding is done

A5.2 American National Standard ANSI/ASC Z49.1, *Safety in Welding, Cutting, and Allied Processes* (published by the American Welding Society), discusses the ventilation that is required during welding and should be referred to for details. Attention is drawn particularly to the section of that document entitled Ventilation.

A6. Welding Considerations

A6.1 Weld metal properties may vary widely, according to size of the electrode and amperage used, size of the weld beads, base-metal thickness, joint geometry, preheat and interpass temperatures, surface condition, base-metal composition, dilution, etc. Because of the profound effect of these variables, a test procedure was chosen for this specification which would represent good welding practice and minimize variation of the most potent of these variables.

A6.2 It should be recognized, however, that production practices may be different. The differences encountered may alter the properties of the weld metal. For instance, interpass temperatures may range from sub-freezing to several hundred degrees. No single temperature or reasonable range of temperatures can be chosen for classification tests which would be representative of all of the conditions encountered in production work. Properties of production welds may vary accordingly, depending on the particular welding conditions.

Weld metal properties may not duplicate, or even closely approach, the values listed and prescribed for test welds. For example, ductility in single pass welds

PART C — SPECIFICATIONS FOR WELDING RODS,
ELECTRODES, AND FILLER METALS



in thick base-metal made outdoors in cold weather without adequate preheating may drop to little more than half that required herein and normally obtained. This does not indicate that either the electrodes or the welds are below standards in this specification. It indicates only that the particular production conditions are more severe than the test conditions prescribed by this specification.

A6.3 Hydrogen is another factor to be considered in welding. Weld metals, other than those from low-hydrogen electrodes [E(X)XX15-X, E(X)XX16-X, E(X)XX18M(1), and E(X)XX18-X], contain significant quantities of hydrogen for some period of time after they have been made. Most of this hydrogen gradually escapes. After two to four weeks at room temperature or in 24 to 48 hours at 200° to 220°F (95° to 105°C), most of it has escaped. As a result of this change in hydrogen content, ductility of the weld metal increases towards its inherent value, while yield, tensile, and impact strengths remain relatively unchanged.

This specification requires aging of the test specimens of cellulosic electrodes at 200° to 220°F (95° to 105°C) for 48 hours before subjecting them to tension testing. This is done to minimize discrepancies in testing. Aging treatments are sometimes used for low-hydrogen electrodes, especially when testing high-strength deposits. Note that aging may involve holding test specimens at room temperature for several days or holding at a higher temperature for a shorter period of time. Consequently, users are cautioned to employ adequate preheat and interpass temperatures to avoid the deleterious effects of hydrogen in production welds.

A6.4 Welds made with electrodes of the same classifications and the same welding procedure will have significantly different tensile and yield strengths in the as-welded and postweld heat-treated conditions. Even weld metal produced from the same classification and the same welding procedure but with different postweld heat-treatment holding temperatures or times at holding temperatures will have different strength levels. With the low-alloy steel weld metals produced by the classifications in this specification, postweld heat treatment can produce tempering (softening) or secondary hardening of the weld metal. It is recommended that users conduct their own evaluation of the welding procedure to be used in production in order to verify that the weld metal properties obtained in actual production are those desired.

A6.5 Preheat and interpass minimum temperatures also have a significant effect on the strength levels attained with certain low-alloy steel weld metals. These

weld metals are affected by rapid cooling rates which tend to produce more martensitic or bainitic microstructures. These microstructures will often exhibit higher yield and tensile strengths with a decrease in ductility. The cooling rate can be retarded by utilizing a higher preheat and interpass temperature. The preheat and interpass temperature ranges given in Table 7 of this specification are adequate for the preparation of the test assemblies. However, in actual production, users are encouraged to test their own procedures to verify that they have selected preheat and interpass temperatures which will produce desirable results in production.

A6.6 Heat input usually is measured as Joules per linear inch, J/in. (kJ/cm). However, in this specification the heat input is governed in the preparation of the test assembly by the bead sequence and the total weld layer count upon completion of the groove weld test assembly.

Heat input will have a significant effect on the strength levels attained in many of the higher strength weld metals produced from the electrode classifications in this specification. For instance, weld metal produced with E11018M electrode at a 35 000 J/in. (13.8 kJ/cm) heat input rate may exceed 110 ksi (760 MPa) yield strength in the as-welded condition and 95 ksi (655 MPa) yield strength after postweld heat treatment. On the other hand, if the heat input is raised to 55 000 J/in. (21.7 kJ/cm), this same electrode will produce weld metal that does not exceed 110 ksi (760 MPa) as-welded yield strength and after postweld heat treatment may be below 95 ksi (655 MPa) yield strength. It is, therefore, recommended that, if the user is going to use either lower or higher heat inputs than normally used for classification testing of electrodes, the user should test the welding procedure to be used to determine that the strength levels expected will be attained in production. This is especially true if out-of-position welding is to be performed.

A6.7 Electrodes which meet all the requirements of any given classification may be expected to have similar characteristics. Certain minor differences continue to exist from one brand to another due to differences in preferences that exist regarding specific operating characteristics.

A6.8 Since the electrodes within a given classification have similar operating characteristics and mechanical properties, the user can usually limit the study of available electrodes to those within a single classification after determining which classification best suits the user's particular requirements.

A6.9 This specification does not establish values for all characteristics of the electrodes falling within a given classification, but it does establish values to measure those of major importance. In some instances, the characteristics are so intangible that no adequate tests are available. This specification does not necessarily provide all the information needed to determine which classification will best fulfill a particular need. Therefore, a discussion of each classification group is included in Section A7, Description and Intended Use of Electrodes, to supplement information given elsewhere in the specification.

A6.10 Some important tests for measuring major electrode characteristics are as follows:

A6.10.1 Radiographic Test. Nearly all of the low-alloy steel electrodes covered by this specification are capable of producing welds that meet most radiographic soundness requirements. However, if incorrectly applied, unsound welds may be produced by any of the electrodes. For electrodes of some classifications, the radiographic requirements in Table 9 are not necessarily indicative of the average radiographic soundness to be expected in production use. Electrodes of the E(X)XX10-X, E(X)XX11-X, and E7020-X classifications can be expected to produce acceptable radiographic results. Under certain conditions, notably in welding long, continuous joints in relatively thick base metal, low-hydrogen electrodes of the E(X)XX15-X, E(X)XX16-X, E(X)XX18M(1), and E(X)XX18-X classifications will often produce even better results.

On the other hand, in joints open to the atmosphere on the root side, at the ends of joints, in joints with many stops and starts, and in welds on small diameter pipe or in small, thin, irregularly-shaped joints, the low-hydrogen electrodes tend to produce welds of poor radiographic soundness. E(X)XX13-X electrodes usually produce the best radiographic soundness in welding small, thin parts. E7027-X electrodes produce welds which may be either quite good or rather inferior in radiographic soundness. The tendency seems to be in the latter direction.

A6.10.2 Fillet Weld Test. This test is included as a means of demonstrating the usability of an electrode. This test is concerned with the appearance of the weld (i.e., weld face contour and smoothness, undercut, overlap, size, and resistance to cracking). It also provides an excellent and inexpensive method of determining the adequacy of fusion at the weld root (one of the important considerations for an electrode). Test results may be influenced by the level of welded skill.

A6.10.3 Toughness. Charpy V-notch impact requirements are included in the specification. All classifications of electrodes in the specification can produce weld metal of sufficient toughness for many applications. The inclusion of impact requirements for certain electrode classifications allows the specification to be used as a guide in selecting electrodes where low-temperature toughness is required. There can be considerable variation in the weld-metal toughness unless particular attention is given to the welding procedure and the preparation and testing of the specimens. The impact energy values are for Charpy V-notch (ISO-V) specimens and should not be confused with values obtained with other toughness tests.

A6.11 Electrode Covering Moisture Content and Conditioning

A6.11.1 Hydrogen can have adverse effects on welds in some steels under certain conditions. One source of this hydrogen is moisture in the electrode coverings. For this reason, the proper storage, treatment, and handling of electrodes is necessary.

A6.11.2 Electrodes are manufactured to be within acceptable moisture limits, consistent with the type of covering and strength of the weld metal. They are then normally packaged in a container which has been designed to provide the degree of moisture protection considered necessary for the type of covering involved.

A6.11.3 If there is a possibility that the noncellulosic covered electrodes may have absorbed excessive moisture, they may be reconditioned by rebaking. Some electrodes require rebaking at a temperature as high as 800°F (425°C) for approximately 1 to 2 hours. The manner in which the electrodes have been produced and the relative humidity and temperature conditions under which the electrodes are stored determine the proper length of time and temperature used for conditioning. Some typical storage and drying conditions are included in Table A1.

A6.11.4 Cellulosic coverings for E(X)XX10-X and E(X)XX11-X classifications need moisture levels of 3 to 7 percent for proper operation. Therefore, storage or conditioning above ambient temperature may dry these electrodes too much and adversely affect their operation (see Table A1).

A6.12 Core Wire. The core wire for all the electrodes in this specification is usually a steel having a typical composition which may differ significantly from that of the weld metal produced by the covered electrode.

TABLE A1
TYPICAL STORAGE AND DRYING CONDITIONS FOR COVERED ARC WELDING ELECTRODES

AWS Classifications	Storage Conditions ^a		
	Ambient Air	Holding Ovens	Drying Conditions ^b
EXX10-X EXX11-X	Ambient temperature	100–120°F (38–49°C)	Not recommended
EXX13-X E7020-X E7027-X	60–100°F (16–38°C) 50 percent max relative humidity	100–120°F (38–49°C)	250–300°F (121–149°C) 1 hour at temperature
EXX15-X EXX16-X EXX18M(1) EXX18-X	Not recommended ^c	250–300°F (121–149°C)	500–800°F (260–427°C) 1 hour at temperature

NOTES:

- After removal from manufacturer's packaging.
- Because of inherent differences in covering compositions the manufacturer should be consulted for the exact drying conditions.
- Some of these electrode classifications may be designated as meeting low moisture absorbing requirements. This designation does not imply that storage in ambient air is recommended.

A6.13 Coverings

A6.13.1 Electrodes of some classifications have substantial quantities of iron powder added to their coverings. The iron powder fuses with the core wire and other metals in the covering, as the electrode melts, and is deposited as part of the weld metal, just as is the core wire. Relatively high amperages can be used since a considerable portion of the electrical energy passing through the electrode is used to melt the thicker covering containing iron powder. The result is that more weld metal may be obtained from a single electrode with iron powder in its covering than from a single electrode of the same size without iron powder.

A6.13.2 Due to the thick covering and deep cup produced at the arcing end of the electrode, iron powder electrodes can be used very effectively with a "drag" technique. This technique consists of keeping the electrode covering in contact with the workpiece at all times, which makes for easy handling. However, a technique using a short arc length is preferable if the $\frac{3}{32}$ in. (2.4 mm) or $\frac{1}{8}$ in. (3.2 mm) electrodes are to be used in other than flat or horizontal fillet welding positions or for making groove welds.

A6.13.3 The E70YY-X electrodes were included in this specification to recognize the lowest strength levels obtained with low-alloy steel electrodes, as well as, to recognize the industry demand for low-alloy electrodes with 70 ksi (480 MPa) minimum tensile strength. Unlike the E70YY classifications in ANSI/

AWS A5.1, *Specification for Carbon Steel Electrodes for Shielded Metal Arc Welding*, these electrodes do contain deliberate alloy additions, and some are required to meet minimum tensile properties after postweld heat treatment.

A6.13.4 Low-hydrogen electrodes have mineral coverings which are high in calcium carbonate and other ingredients that are low in moisture and organic materials and hence "low in hydrogen content." Low-hydrogen electrodes were developed for welding low-alloy, high-strength steels, some of which were high in carbon content. Electrodes with other than low-hydrogen coverings may produce "hydrogen induced cracking" in those steels.

Underbead cracks occur in the base metal, usually just below the weld bead. Weld cracks also may occur. These cracks are caused by the hydrogen absorbed from the arc atmosphere. Although these cracks do not generally occur in carbon steels which have a low carbon content, they may occur when welding higher carbon or low-alloy steels with other than low-hydrogen electrodes and without precautions, such as, increased preheat temperatures and postweld heating. For more information on special tests for low-hydrogen electrodes, see Sections 15 and 16 in the specification and A9.2 and A9.3 in this Annex.

A6.14 Amperage Ranges. Table A2 gives amperage ranges which are satisfactory for most classifications. When welding in the vertical position with upward

TABLE A2
TYPICAL AMPERAGE RANGES

Electrode Diameter		EXX10-X and EXX11-X	EXX13-X	E7020-X	E7027-X	EXX15-X and EXX16-X	EXX18M(1) and EXX18-X
in.	mm						
$\frac{3}{32}$	2.4	40 to 80	45 to 90	—	—	65 to 110	70 to 100
$\frac{1}{8}$	3.2	75 to 125	80 to 130	100 to 150	125 to 185	100 to 150	115 to 165
$\frac{5}{32}$	4.0	110 to 170	105 to 180	130 to 190	160 to 240	140 to 200	150 to 200
$\frac{3}{16}$	4.8	140 to 215	150 to 230	175 to 250	210 to 300	180 to 255	200 to 275
$\frac{7}{32}$	5.6	170 to 250	—	225 to 310	250 to 350	240 to 320	260 to 340
$\frac{1}{4}$	6.4	210 to 320	—	275 to 375	300 to 420	300 to 390	315 to 400
$\frac{5}{16}$	8.0	—	—	—	375 to 475	—	—

progression, currents near the lower limit of the range are generally used.

A7. Description and Intended Use of Electrodes

A7.1 Chemical Composition. The chemical composition of the weld metal produced is often the primary consideration for electrode selection. Together with appropriate heat treatments, each composition can achieve a wide range of corrosion resistance and mechanical properties at various service temperatures. It is usually desirable for weld metal to match the chemical composition and the mechanical properties of the base metal as closely as possible. In fact, many of the electrodes classified to this specification have been developed for specific base-metal grades or classes. If an optimum match is not possible, engineering judgment together with weld testing may be required to select the most suitable electrodes.

Table 2 provides detailed weld metal chemical composition requirements for each electrode classification. Tables 3 and 4 list the mechanical properties of the weld metal when the electrode is used in the flat downhand position, and the weldment is subjected to the postweld heat-treatment (PWHT) requirements in Tables 3 and 7. It should be noted that changes in welding position, welding variables, or heat treatment can be expected to affect the mechanical properties. However, except for the effects of dilution, the chemical composition can be expected to remain reasonably unchanged.

The suffixes, which are part of each alloy electrode classification, identify the chemical composition of the weld metal produced by the electrode. The following paragraphs highlight the differences between these electrodes and electrode groups and indicate typical applications.

A7.1.1 E70YY-A1 (C-Mo Steel) Electrodes. These electrodes are similar to the E70YY carbon steel electrodes classified in ANSI/AWS A5.1, except that $\frac{1}{2}\%$ molybdenum has been added. This addition increases the strength of the weld metal, especially at elevated temperatures, and provides some increase in corrosion resistance; however, it may reduce the notch toughness of the weld metal. Typical applications include the welding of C-Mo steel base metals such as ASTM A204 plate and A335-P1 pipe.

A7.1.2 EX01Y-BX and EX01Y-BXL (Cr-Mo Steel) Electrodes. These low-hydrogen electrodes produce weld metal that contains between $\frac{1}{2}\%$ and 9% chromium and between $\frac{1}{2}\%$ to 1% molybdenum. They are designed to produce weld metal for high-temperature service and for matching the properties of the typical base metals as shown in Table A3.

For many of these Cr-Mo electrode classifications, low carbon EXX1Y-BXL classifications have been established. While regular Cr-Mo electrodes produce weld metal with about 0.08% carbon, the "L-Grades" are limited to a maximum of 0.05% carbon. While the lower percent carbon in the weld metal will improve ductility and lower hardness, it will also reduce the high-temperature strength and creep resistance of the weld metal.

Since all Cr-Mo electrodes produce weld metal which will harden in still air, both preheat and PWHT are required for most applications.

No minimum notch toughness requirements have been established for any of the Cr-Mo electrode classifications. While it is possible to obtain Cr-Mo electrodes with minimum toughness values at ambient temperatures down to 32°F (0°C), specific values and testing must be agreed to by the supplier and the purchaser.

TABLE A3
TYPICAL BASE METAL APPLICATIONS FOR Cr-Mo STEEL ELECTRODES

AWS Classification	%Cr	%Mo	Typical Base Metals
E701Y-B2L	1¼	½	Thin wall A335-P11 Pipe or tube for use in the as-welded condition, A588 Plate for weathering applications where toughness is not a requirement
E801Y-B1	½	½	A335-P2 Pipe, A387 Gr. 2 Plate
E801Y-B2	1¼	½	A335-P11 Pipe, A387 Gr. 11 Plate
E801Y-B3L	2¼	1	Thin wall A335-P22 Pipe for use in the as-welded condition
E901Y-B3	2¼	1	A335-P22 Pipe, A387 Gr. 22 Plate
E8015-B4L	2	½	A213-87 Gr. T3b Tube*
E8016-B5	½	1	A356-58T Grs. 3 or 4 Castings*
E801Y-B6	5	½	A213-T5 Tube, A335-P5 Pipe
E801Y-B7	7	½	A213-T7 Tube, A335-P7 Pipe
E801Y-B8	9	1	A213-T9 Tube, A335-P9 Pipe
E901Y-B9	9	1	A213-T91 Tube, A335-P91 Pipe, A387 Gr. 91 Plate

NOTE:

Base metals followed by an asterisk (*) are no longer listed as grades in the current ASTM specification.

A7.1.2.1 E701Y-B2L and E801Y-B3L Electrodes. In previous revisions of ANSI/AWS A5.5, electrodes classified in this standard as E701Y-B2L were classified as E801Y-B2L. Likewise, electrodes herein classified as E801Y-B3L were classified as E901Y-B3L. The composition ranges were not changed from A5.5-81 to this standard for the corresponding classifications. The strength designations and room temperature strength requirements after postweld heat-treatment have been reduced to reflect the fact that commercial products have been producing marginal tensile strength results in classification tests over many years. The base metals with which these classifications are generally used have lower strength requirements than were reflected by the former electrode classifications. Therefore, unless the higher strength indicated by the former classifications of these electrodes is specifically necessary for a particular welding procedure, the E701Y-B2L classifications of this standard should be considered as identical to the corresponding E801Y-B2L classifications of A5.5-81. Likewise, the E801Y-B3L classifications of this standard should be considered as identical to the E901Y-B3L classifications of A5.5-81.

A7.1.2.2 E901Y-B9 Electrodes. E901Y-B9 is a 9% Cr - 1% Mo, low-hydrogen electrode modified with niobium (columbium) and vanadium designed to provide improved creep strength, toughness, fatigue

life, and oxidation and corrosion resistance at elevated temperatures. Due to the higher elevated temperature properties of this alloy, components that are now fabricated from stainless and ferritic steels may be fabricated from a single alloy, eliminating problems associated with dissimilar welds.

In addition to the classification requirements in this specification, either impact toughness or high temperature creep strength properties should be determined. Due to the influence of various levels of carbon and niobium (columbium), specific values and testing must be agreed to by the purchaser and supplier.

A7.1.3 EX01Y-CX and EX01Y-CXL (Ni Steel) Electrodes. These low-hydrogen electrodes have been designed to produce weld metal with increased strength without being air-hardenable or with increased notch toughness at temperatures as low as -175°F (-115°C). They have been specified with nickel contents which fall into five nominal levels of 1% Ni, 1½% Ni, 2½% Ni, 3½% Ni, and 6½% Ni in steel.

With carbon levels of up to 0.12%, strength increases and permits these Ni steel electrodes to be classified as E801Y-CX. However, with lower levels of carbon, low-temperature toughness improves to match the base-metal properties of nickel steels, such as ASTM A203 Gr. E, ASTM A352 LC3 and LC4 classifications. Thus, the intended application and the needed mechanical

properties determine whether or not "L-Grades" should be selected.

Many low-alloy steels require postweld heat treatment to stress relieve the weld or temper the weld metal and heat-affected zone to achieve increased ductility. It is often acceptable to exceed the PWHT holding temperatures shown in Table 7. However, for many applications, nickel steel weld metal can be used without postweld heat treatment. If PWHT is to be specified for a nickel steel weldment, the holding temperature should not exceed the maximum temperature given in Table 7 for the classification considered since nickel steels can be embrittled at higher temperatures.

A7.1.4 E8018-NM1 (Ni-Mo Steel) Electrodes. This low-hydrogen electrode, which contains about 1% nickel and $\frac{1}{2}\%$ molybdenum, is similar to the Mn-Mo steel electrodes discussed in A7.1.5. However, this electrode can often be welded without PWHT, but the resulting strength and notch toughness are lower than the values obtained with Mn-Mo electrodes. Some typical applications include the welding of high-strength, low-alloy or microalloyed structural steels.

A7.1.5 E(X)X01Y-DX (Mn-Mo Steel) Electrodes. These low-hydrogen electrodes produce weld metal which contains about $1\frac{1}{2}\%$ manganese and between $\frac{1}{3}$ and $\frac{2}{3}\%$ molybdenum. This weld metal provides higher strength and better notch toughness than the C- $\frac{1}{2}\%$ Mo and 1% Ni- $\frac{1}{2}\%$ Mo steel weld metal discussed in A7.1.1 and A7.1.4. However, the weld metal from these Mn-Mo steel electrodes is quite air-hardenable and usually requires preheat and PWHT. The individual electrodes classified under this electrode group have been designed to match the mechanical properties and corrosion resistance of the high-strength, low-alloy pressure vessel steels, such as ASTM A302 Gr. B.

A7.1.6 E(X)XXYY-G (General Low-Alloy Steel) Electrodes. These electrodes are described in A2.2. These electrode classifications may be either modifications of other discrete classifications or totally new classifications. Purchaser and user should determine from the supplier what the description and intended use of the electrode is.

A7.1.7 E(X)X01YM(1) (Military Similar) Electrodes. These low-hydrogen electrodes were originally designed for military applications such as welding HY80 and HY100 type steels. To achieve desired weld-metal properties and soundness, these electrodes have small alloy additions (especially some Ni) and require careful control of moisture in the electrode covering and from other sources of hydrogen. The latter must be maintained

during electrode fabrication, packaging, transport, and site storage.

These electrodes are usually employed without subsequent postweld-heat treatment. However, hydrogen-release treatments at lower temperatures (typically less than 500°F) are often applied. In the as-welded condition, the weld-metal mechanical properties include ultimate tensile strength minimums ranging from 90 to 120 ksi (620 to 830 MPa) and good notch toughness at temperatures ranging from 0°F to -60°F (-18°C to -51°C). With these properties, the E(X)X01YM(1) type electrodes are suitable for joining many high-strength, low-alloy or microalloyed steels to themselves or to lower strength steels, including carbon steels.

A7.1.8 EX010-P1 (Pipeline) Electrodes. These electrodes have been designed primarily for welding typical high-strength, pipe butt joints in the vertical welding position with downward or upward progression. With their cellulosic coverings, they produce deep penetrating, spray-type welding arcs and thin, easily removable slag. This combination is best suited for achieving full penetration and radiographic quality for the downhill welding of butt joints when the axis of the pipe is in the horizontal position.

While weld metals produced from these electrodes do not have any minimum chemical composition requirements, the supplier must provide sufficient alloying elements to meet the increased mechanical property requirements. Special emphasis must be placed upon the minimum yield strength values, since most transmission pipeline materials and systems are designed to yield strength limits. Typical application for E7010-P1 and E8010-P1 electrodes is the welding of API-5L-X52 and API-5L-X65 piping assemblies, respectively.

A7.1.9 EX018-WX (Weathering Steel) Electrodes. These low-hydrogen electrodes have been designed to produce weld metal that matches the corrosion resistance and the coloring of the ASTM weathering-type structural steels. These special properties are achieved by the addition of about $\frac{1}{2}\%$ copper to the weld metal. To meet strength, ductility, and notch toughness in the weld metal, some chromium and nickel additions are also made. These electrodes are used to weld the typical weathering steel, such as ASTM A242 and A588.

A8. Modification of Moisture Test Apparatus

A8.1 Some laboratories have modified test apparatus for determining the moisture content of electrode coverings. The following are some of the modifications which have been successfully used:

A8.1.1 This specification recommends that only nickel boats be used rather than clay boats because lower blank values can be obtained. Some laboratories use zirconium silicate combustion tubes in preference to fused silica or mullite because zirconium silicate will not devitrify or allow the escape of combustible gases at temperatures up to 2500°F (1370°C).

Some combustion tubes are reduced at the exit end, and a separate dust trap is used. This dust trap consists of a 200 mm drying tube filled with glass wool which is inserted between the Schwartz absorption U-tube and the combustion tube. A suitable 300°F (149°C) heater is mounted around the dust trap to keep evolved water from condensing in the trap. The dust trap is filled with glass wool which can be easily inspected to determine when the glass wool should be replaced. An extra spray trap may be installed downstream of the absorption U-tube to ensure that the concentrated sulfuric acid in the gas-sealing bottle is not accidentally drawn into the absorption U-tube.

A8.1.2 On the entrance end of the combustion tube, a pusher rod can be used consisting of a 1/8 in. (3.2 mm) stainless steel rod mounted in a 1/4 in. (6.4 mm) copper tee fitting. This is used at the entrance of the combustion tube and permits gradual introduction of the sample into the tube while oxygen is passing over the sample. In this way, any free moisture will not be lost, which can happen if the sample is introduced directly into the hot zone before closing the end of the tube.

A9. Special Tests

A9.1 It is recognized that supplementary tests may be necessary to determine the suitability of these welding electrodes for applications involving properties not considered in this specification. In such cases, additional tests to determine specific properties, such as hardness, corrosion resistance, mechanical properties at higher or lower service temperatures, wear resistance, and suitability for welding combinations of dissimilar metals, may need to be conducted.

A9.2 Diffusible Hydrogen Test. Hydrogen induced cracking of weld metal and the heat-affected zone can be encountered in low-alloy steels welded by the filler metals covered by this specification. Therefore, many of the electrode classifications in this specification are the low-hydrogen type. The diffusible hydrogen test is reintroduced into this specification as an optional supplemental test for low-hydrogen electrodes. However, the diffusible hydrogen test today is considerably improved over the former glycerin test, which appeared first in the original issue of AWS A5.5-48.

The covering moisture test has proved a satisfactory test over many years as a means of assessing the degree of care needed to avoid hydrogen induced cracking. This is, however, an indirect test. Moisture itself does not cause cracking, but the diffusible hydrogen that forms from the moisture and other hydrogen containing compounds (such as machining oil) in the arc causes cracking. Accordingly, the use of optional designators for diffusible hydrogen is introduced to indicate the maximum average value obtained under a clearly defined test condition in ANSI/AWS A4.3, *Standard Methods for Determination of the Diffusible Hydrogen Content of Martensitic, Bainitic, and Ferritic Steel Weld Metal Produced by Arc Welding*.

The user of this information is cautioned that actual welding conditions may result in different diffusible hydrogen values than those indicated by the designator.

The use of a reference atmospheric condition during welding is necessary because the arc always is imperfectly shielded. Moisture from the air, distinct from that in the covering, can enter the arc and subsequently the weld pool, contributing to the resulting observed diffusible hydrogen. This effect can be minimized by maintaining as short an arc length as possible consistent with a steady arc. Experience has shown that the effect of arc length is minor at the H16 level, but is very significant at the H4 level. An electrode meeting the H4 requirement under the reference atmospheric condition may not do so under conditions of higher humidity at the time of welding. This is especially true if a long arc is maintained.

The reference atmospheric condition during welding of the test assembly is 10 grains of water vapor per pound (1.43 g/kg) of dry air. This corresponds to 70°F (21°C) and 10% R.H. on a standard psychometric chart at 29.92 in. Hg (760 mm) barometric pressure. Actual conditions, measured using a sling psychrometer or other suitable device, that equal or exceed this reference condition provide assurance that the conditions during welding will not diminish the final results of the test.

A9.3 Absorbed Moisture Test. The development of low-hydrogen electrode coverings that resist moisture absorption during exposure to humid air is a recent improvement in covered electrode technology. Not all commercial low-hydrogen electrodes possess this characteristic. To assess this characteristic, the absorbed moisture test described in Section 15 was devised. The exposure conditions selected for the test are arbitrary. Other conditions may yield quite different results.

A task group of the AWS A5A Subcommittee evaluated this test and concluded that it can successfully differentiate moisture-resistant electrodes from those

which are not. The task group also observed considerable variability of coating moisture results after exposure of electrodes in cooperative testing among several laboratories. The precision of the test is such that, with moisture-resistant electrodes from a single lot, the participating laboratories could observe exposed covering moisture values ranging, for example, from 0.15% or less to 0.35% or more. The cause of this variability is uncertain at present, but is considered by the task group to be related to variations in the exposure conditions. Because of this variability, the task group concluded that it is not realistic to set a limit for covering moisture of exposed moisture-resistant electrodes lower than 0.4% at this time.

A10. Discontinued Classifications

A number of electrode classifications have been discontinued during the numerous revisions of this specification, reflecting either changes in commercial practice, or changes in the classification system used in the specification. These discontinued electrode classifications are listed in Table A4, along with the year they were last published in this specification. Some discontinued electrode classifications continue to be applied to products even though they have been discontinued from the specification. In this case, the referenced specification year should be the last year that the classification was published in the specification unless the classification was transferred to another current AWS filler metal specification.

A11. Safety Considerations

A11.1 Burn Protection. Molten metal, sparks, slag, and hot-work surfaces are produced by welding, cutting, and allied processes. These can cause burns if precautionary measures are not used. Workers should wear protective clothing made of fire-resistant material. Pant cuffs, open pockets, or other places on clothing that can catch and retain molten metal or sparks should not be worn. High-top shoes or leather leggings and fire-resistant gloves should be worn. Pant legs should be worn over the outside of high-top shoes. Helmets or hand shields that provide protection for the face, neck, and ears, and a head covering to protect the head should be used. In addition, appropriate eye protection should be used.

When welding overhead or in confined spaces, ear plugs to prevent weld spatter from entering the ear canal should be worn in combination with goggles or equivalent to give added eye protection. Clothing should be kept free of grease and oil. Combustible materials

should not be carried in pockets. If any combustible substance has been spilled on clothing, a change to clean, fire resistant clothing should be made before working with open arcs or flame. Aprons, cape-sleeves, leggings, and shoulder covers with bibs designed for welding service should be used. Where welding or cutting of unusually thick base metal is involved, sheet-metal shields should be used for extra protection. Mechanization of highly hazardous processes or jobs should be considered.

Other personnel in the work area should be protected by the use of noncombustible screens or by the use of appropriate protection as described in the previous paragraph. Before leaving a work area, hot workpieces should be marked to alert other persons of this hazard. No attempt should be made to repair or disconnect electrical equipment when it is under load. Disconnection under load produces arcing of the contacts and may cause burns or shock, or both. (*Note: Burns can be caused by touching hot equipment such as electrode holders, tips, and nozzles. Therefore, insulated gloves should be worn when these items are handled, unless an adequate cooling period has been allowed before touching.*)

The following sources are for more detailed information on personal protection:

(1) American National Standards Institute. ANSI/ASC Z41.1, *Safety-Toe Footwear*. New York: American National Standards Institute.

(2) —. ANSI/ASC Z49.1, *Safety in Welding and Cutting*. Miami, FL: American Welding Society.

(3) —. ANSI/ASC Z87.1, *Practice for Occupational and Educational Eye and Face Protection*. New York: American National Standards Institute.

(4) Occupational Safety and Health Administration. *Code of Federal Regulations*, Title 29 Labor, Chapter XVII, Part 1910. Washington, D.C.: U. S. Government Printing Office.⁵

A11.2 Electrical Hazards. Electric shock can kill; however, it can be avoided. Live electrical parts should not be touched. The manufacturer's instructions and recommended safe practices should be read and understood. Faulty installation, improper grounding, and incorrect operation and maintenance of electrical equipment are all sources of danger.

All electrical equipment and the workpieces should be grounded. The workpiece lead is not a ground lead. It is used only to complete the welding circuit. A separate connection is required to ground the workpiece.

⁵ OSHA documents are available from U. S. Government Printing Office, Washington, D.C. 20402

PART C — SPECIFICATIONS FOR WELDING RODS,
ELECTRODES, AND FILLER METALS

SFA-5.5



TABLE A4
DISCONTINUED ELECTRODE CLASSIFICATIONS^a

AWS Classification	Last A5.5 (ASTM A316) Publication Date	Classification	Last A5.5 (ASTM A316) Publication Date
E7010 ^b	1954	E10026	1948
E7011 ^b	1954	E10030	1948
E7013	1948	E12015 ^b	1954
E7015 ^c	1954	E12016 ^b	1954
E7016 ^c	1954	E7015-C1	1954
E7020 ^b	1954	E7016-C1	1954
E7025	1948	E7015-C2	1954
E7026	1948	E7016-C2	1954
E7030	1948	E9010-B3	1954
E8010 ^b	1954	E9011-B3	1954
E8011 ^b	1954	E9013-B3	1954
E8013 ^b	1954	E8010-B1	1958
E8015 ^b	1954	E8011-B1	1958
E8016 ^b	1954	E8013-B1	1958
E8020	1948	E8015-B1	1958
E8025	1948	E8010-B2	1958
E8026	1948	E8011-B2	1958
E8030	1948	E8013-B2	1958
E9010 ^b	1954	E8015-B2	1958
E9011 ^b	1954	E8015-B4	1958
E9013 ^b	1954	E8016-B4	1958
E9015 ^b	1954	E8018-B4	1958
E9016 ^b	1954	E8015-C1	1958
E9020	1948	E8015-C2	1958
E9025	1948	E8015-C3	1958
E9026	1948	E9016-D1	1958
E9030	1948	E7018-W ^d	1981
E10010 ^b	1954	E8015-B2L ^e	1981
E10011 ^b	1954	E8018-B2L ^e	1981
E10013 ^b	1954	E8018-NM ^f	1981
E10015 ^b	1954	E8018-W ^d	1981
E10016 ^b	1954	E9015-B3L ^e	1981
E10020	1948	E9018-B3L ^e	1981
E10025	1948		

NOTES:

- See Section A10, Discontinued Classifications (in the Annex), for information on discontinued classifications and how they may be used.
- The higher tensile strength electrode classifications without chemistry requirements for classifications were discontinued in 1958 and replaced with the "G" classifications in order to permit a single classification system with chemistry requirements.
- Both E7015 and E7016 classifications were transferred to AWS A5.1-88T and continue to be included in the current revision of that specification.
- Both E7018-W and E8018-W classification designations have been changed to E7018-W1 and E8018-W2 in order to permit the suffix designator to differentiate between the two chemical compositions of undiluted weld metal.
- These Cr-Mo electrode classifications were down graded to reflect a more realistic minimum tensile strength for low-carbon chromium-molybdenum steel weld metal. This change may or may not show a corresponding reduction in creep strength of the weld metal depending on how the chemical composition of the weld metal is controlled.
- The E8018-NM classification has been changed to E8018-NM1 to allow for other possible Ni-Mo steel electrode classifications in future revisions.

The workpiece should not be mistaken for a ground connection.

The correct cable size should be used, since sustained overloading will cause cable failure and result in possible electrical shock or fire hazard. All electrical connections should be tight, clean, and dry. Poor connections can overheat and even melt. Further, they can produce dangerous arcs and sparks. Water, grease, or dirt should not be allowed to accumulate on plugs, sockets, or electrical units. Moisture can conduct electricity.

To prevent shock, the work area, equipment, and clothing should be kept dry at all times. Welders should wear dry gloves and rubber-soled shoes, or stand on a dry board or insulated platform. Cables and connections should be kept in good condition. Improper or worn electrical connections may create conditions that could cause electrical shock or short circuits. Worn, damaged, or bare cables should not be used. Open-circuit voltage should be avoided. When several welders are working with arcs of different polarities, or when a number of alternating current machines are being used, the open-circuit voltages can be additive. The added voltages increase the severity of the shock hazard.

In case of electric shock, the power should be turned off. If the rescuer must resort to pulling the victim from the live contact, nonconducting materials should be used. If the victim is not breathing, cardiopulmonary resuscitation (CPR) should be administered as soon as contact with the electrical source is broken. A physician should be called and CPR continued until breathing has been restored, or until a physician has arrived. Electrical burns are treated as thermal burns; that is, clean, cold (iced) compresses should be applied. Contamination should be avoided; the area should be covered with a clean, dry dressing; and the patient should be transported to medical assistance.

Recognized safety standards such as ANSI/ASC Z49.1, *Safety in Welding and Cutting*, and NFPA No. 70, *National Electrical Code*, available from National Fire Protection Association, Batterymarch Park, Quincy, MA 02269, should be followed.

A11.3 Fumes and Gases. Many welding, cutting, and allied processes produce fumes and gases which may be harmful to health. Fumes are solid particles which originate from welding filler metals and fluxes, the base metal, and any coatings present on the base metal. Gases are produced during the welding process or may be produced by the effects of process radiation on the surrounding environment. Management personnel and welders alike should be aware of the effects of these fumes and gases. The amount and composition of these fumes and gases depend upon the composition

of the filler metal and base metal, welding process, current level, arc length, and other factors.

The possible effects of over-exposure range from irritation of eyes, skin, and respiratory system to more severe complications. Effects may occur immediately or at some later time. Fumes can cause symptoms such as nausea, headaches, dizziness, and metal fume fever. The possibility of more serious health effects exists when especially toxic materials are involved. In confined spaces, the shielding gases and fumes might displace breathing air and cause asphyxiation. One's head should always be kept out of the fumes. Sufficient ventilation, exhaust at the arc, or both, should be used to keep fumes and gases from your breathing zone and the general area.

In some cases, natural air movement will provide enough ventilation. Where ventilation may be questionable, air sampling should be used to determine if corrective measures should be applied.

Special precautions should be used when welding with the electrodes of the B3, B4, B6, B7, B8, and B9 series. As a group, the fumes from the normal use of these electrodes contain significant amounts of hexavalent chromium (Cr VI) compounds. The permissible exposure limit (PEL) and the threshold limit value (TLV) for Cr VI of 0.05 mg/m³ as chromium will be exceeded before reaching the 5.0 mg/m³ threshold limit value for general welding fume. Therefore, for these products, monitoring for hexavalent chromium will be more conservative than monitoring for general welding fume. Short-term effects of excessive overexposure to chromium VI present in fumes may be irritation of the breathing system. Some people may have allergic reactions. Chromium VI is considered a carcinogen by the International Agency for Research on Cancer (IARC) and the National Toxicology Program (NTP). However, evidence from studies involving welding fumes and gases containing chromium compounds do not confirm any carcinogenic risk when exposures are held within OSHA mandated limits.

More detailed information on fumes and gases produced by the various welding processes may be found in the following:

(1) The permissible exposure limits required by OSHA can be found in *Code of Federal Regulations*, Title 29, Chapter XVII, Part 1910.

(2) The recommended threshold limit values for fumes and gases may be found in *Threshold Limit Values for Chemical Substances and Physical Agents in the Workroom Environment*, published by the American Conference of Governmental Industrial Hygienists (ACGIH), 6550 Glenway Avenue, Building D-5, Cincinnati, OH 45211.

(3) The results of an AWS-funded study are available in a report entitled, *Fumes and Gases in the Welding Environment*, available from the American Welding Society.

(4) Manufacturer's Material Safety Data Sheet for the product.

A11.4 Radiation. Welding, cutting, and allied operations may produce radiant energy (radiation) harmful to health. One should become acquainted with the effects of this radiant energy.

Radiant energy may be ionizing (such as x-rays), or nonionizing (such as ultraviolet, visible light, or infrared). Radiation can produce a variety of effects such as skin burns and eye damage, depending on the radiant energy's wavelength and intensity, if excessive exposure occurs.

A11.4.1 Ionizing Radiation. Ionizing radiation is produced by the electron beam welding process. It is ordinarily controlled within acceptance limits by use of suitable shielding enclosing the welding area.

A11.4.2 Nonionizing Radiation. The intensity and wavelengths of nonionizing radiant energy produced depend on many factors, such as the process, welding parameters, electrode and base-metal composition, fluxes, and any coating or plating on the base metal. Some processes such as resistance welding and cold pressure welding ordinarily produce negligible quantities of radiant energy. However, most arc welding and cutting processes (except submerged arc when used properly), laser welding and torch welding, cutting, brazing, or soldering can produce quantities of nonionizing radiation such that precautionary measures are necessary.

Protection from possible harmful effects caused by nonionizing radiant energy from welding include the following measures:

(1) One should not look at welding arcs except through welding filter plates which meet the requirements of ANSI/ASC Z87.1, *Practice for Occupational and Educational Eye and Face Protection*, published by American National Standards Institute. It should be noted that transparent welding curtains are not intended as welding filter plates, but rather are intended to protect a passerby from incidental exposure.

(2) Exposed skin should be protected with adequate gloves and clothing, as specified in ANSI/ASC Z49.1, *Safety in Welding, Cutting, and Allied Processes*, published by American Welding Society.

(3) Reflections from welding arcs should be avoided, and all personnel should be protected from intense

reflections. (Note: Paints using pigments of substantially zinc oxide or titanium dioxide have a lower reflectance for ultraviolet radiation.)

(4) Screens, curtains, or adequate distance from aisles, walkways, etc., should be used to avoid exposing passersby to welding operations.

(5) Safety glasses with UV protective side shields have been shown to provide some beneficial protection from ultraviolet radiation produced by welding arcs.

A11.4.3 Ionizing radiation information sources include the following:

(1) ANSI/AWS F2.1-78, *Recommended Safe Practices for Electron Beam Welding and Cutting*, available from the American Welding Society.

(2) Manufacturer's product information literature.

A11.4.4 The following include nonionizing radiation information sources:

(1) American National Standards Institute. ANSI/ASC Z136.1, *Safe Use of Lasers*, New York, NY: American National Standards Institute.

(2) —. ANSI/ASC Z87.1, *Practice for Occupational and Educational Eye and Face Protection*. New York, NY: American National Standards Institute.

(3) —. ANSI/ASC Z49.1, *Safety in Welding, Cutting, and Allied Processes*. (published by AWS) Miami, FL: American Welding Society.

(4) Hinrichs, J. F. "Project committee on radiation-summary report." *Welding Journal*, January, 1978.

(5) Moss, C. E. "Optical radiation transmission levels through transparent welding curtains." *Welding Journal*, March 1979.

(6) Moss, C. E. and Murray, W. E. "Optical radiation levels produced in gas welding, torch brazing, and oxygen cutting." *Welding Journal*, September 1979.

(7) Marshall, W. J., Sliney, D. H. and others. "Optical radiation levels produced by air-carbon arc cutting processes." *Welding Journal*, March 1980.

(8) National Technical Information Service. Non-ionizing radiation protection special study no. 42-0053-77, "Evaluation of the potential hazards from actinic ultraviolet radiation generated by electric welding and cutting arcs." Springfield, VA: National Technical Information Service. ADA-033768.

(9) —. Non-ionizing radiation protection special study no. 42-0312-77, "Evaluation of the potential retina hazards from optical radiation generated by electrical welding and cutting arcs." Springfield, VA: National Technical Information Service, ADA-043023.