

ANSI/AWS A5.1-91
An American National Standard

**Specification
for
Carbon Steel Electrodes
for Shielded Metal Arc Welding**



American Welding Society

Keywords — Carbon steel electrodes, shielded metal arc welding welding electrodes, covered electrodes, arc welding, filler metal specification

ANSI/AWS A5.1-91
An American National Standard

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Specification for Carbon Steel Electrodes for Shielded Metal Arc Welding

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Prepared by
AWS Committee on Filler Metal

Under the direction of
AWS Technical Activities Committee

Approved by
AWS Board of Directors

Abstract

This specification establishes the requirements for classification of carbon steel electrodes for shielded metal arc welding. The requirements include mechanical properties of weld metal, weld metal soundness, and usability of electrode. Requirements for chemical composition of the weld metal, moisture content of low hydrogen electrode coverings, standard sizes and lengths, marking, manufacturing, and packaging are also included. A guide to the use of the standard is included in an Appendix.

Optional supplemental requirements include improved toughness and ductility, lower moisture contents, and diffusible hydrogen limits.



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Foreword

(This Foreword is not a part of ANSI/AWS A5.1-91 *Specification for Carbon Steel Electrodes for Shielded Metal Arc Welding*, but is included for information purposes only.)

This specification is the latest revision of the first filler metal specification issued over 50 years ago. The initial 1940 document and the three revisions within the next five years were prepared by a joint committee of the American Society for Testing and Materials and the American Welding Society. However, they were issued with only an ASTM specification designation. The 1948 revision was the first specification issued with the AWS designation appearing on the document. The 1969 revision was the first time that the document was issued without the ASTM designation.

The current document is the eleventh revision of this very popular specification and the fourth prepared exclusively by the AWS Filler Metal Committee. It contains a number of significant revisions from ANSI/AWS A5.1-81.

Document Development:

ASTM A233-40T	Tentative Specifications for Iron and Steel Arc-Welding Electrodes
ASTM A233-42T	Tentative Specifications for Iron and Steel Arc-Welding Electrodes
ASTM A233-43T	Tentative Specifications for Iron and Steel Arc-Welding Electrodes
ASTM A233-45T	Tentative Specifications for Iron and Steel Arc-Welding Electrodes
ASTM A233-48T	Tentative Specifications for Mild Steel Arc-Welding Electrodes
AWS A5.1-48T	
ASTM A233-55T	Tentative Specifications for Mild Steel
AWS A5.1-55T	Arc-Welding Electrodes
ASTM A233-58T	Tentative Specification for Mild Steel
AWS A5.1-58T	Arc-Welding Electrodes
AWS A5.1-64T	Tentative Specification for Mild Steel Covered
ASTM A233-64T	Arc-Welding Electrodes
AWS A5.1-69	Specification for Mild Steel Covered Arc-Welding
ANSI W3.1-1973	Electrodes
ANSI/AWS A5.1-78	Specification for Carbon Steel Covered Arc-Welding Electrodes
ANSI/AWS A5.1-81	Specification for Carbon Steel Covered Arc-Welding Electrodes

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

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

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Specification for Carbon Steel Electrodes for Shielded Metal Arc Welding

1. Scope

This specification prescribes requirements for the classification of carbon steel electrodes for shielded metal arc welding.

Part A *General Requirements*

2. Classification

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

- (1) Type of current (Table 1)
- (2) Type of covering (Table 1)
- (3) Welding position (Table 1)
- (4) Mechanical properties of the weld metal in the as-welded or aged condition (Tables 2 and 3)

2.2 Material classified under one classification shall not be classified under any other classification in this specification, except that E7018M may also be classified as E7018 provided the electrode meets all of the requirements of both classifications.

3. Acceptance

Acceptance¹ of the welding electrodes shall be in accordance with the provisions of the ANSI/AWS A5.01, *Filler Metal Procurement Guidelines*.²

1. See A3 (in the Appendix) for further information concerning acceptance, testing of the material shipped, and ANSI/AWS A5.01 *Filler Metal Procurement Guidelines*.
2. AWS standards can be obtained from the American

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.³

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" of the last right-hand place of figures used in expressing the limiting value in accordance with the round-off method of ASTM Practice E29 for *Using Significant Digits in Test Data to Determine Conformance with Specifications*.⁴

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3. See A4 (in the Appendix) for further information concerning certification and the testing called for to meet this requirement.

4. ASTM standards can be obtained from the American Society for Testing and Materials, 1916 Race Street, Philadelphia, Pennsylvania 19103.

Table 1
Electrode Classification

AWS Classification	Type of Covering	Welding Position ^a	Type of Current ^b
E6010	High cellulose sodium	F,V,OH,H	dcep
E6011	High cellulose potassium	F,V,OH,H	ac or dcep
E6012	High titania sodium	F,V,OH,H	ac or dcen
E6013	High titania potassium	F,V,OH,H	ac, dcep or dcen
E6019	Iron oxide titania potassium	F,V,OH,H,	ac, dcep or dcen
E6020	High iron oxide	{ H-fillets F	ac or dcen ac, dcep or dcen
E6022 ^c	High iron oxide	F,H	ac or dcen
E6027	High iron oxide, iron powder	{ H-fillets F	ac or dcen ac, dcep or dcen
E7014	Iron powder, titania	F,V,OH,H	ac, dcep or dcen
E7015 ^d	Low hydrogen sodium	F,V,OH,H	dcep
E7016 ^d	Low hydrogen potassium	F,V,OH,H	ac or dcep
E7018 ^d	Low hydrogen potassium, iron powder	F,V,OH,H	ac or dcep
E7018M	Low hydrogen iron powder	F,V,OH,H	dcep
E7024 ^d	Iron powder, titania	H-fillets,F	ac, dcep or dcen
E7027	High iron oxide, iron powder	{ H-fillets F	ac or dcen ac, dcep or dcen
E7028 ^d	Low hydrogen potassium, iron powder	H-fillets,F	ac or dcep
E7048 ^d	Low hydrogen potassium, iron powder	F,OH,H,V-down	ac or dcep

Notes:

- a. The abbreviations indicate the welding positions as follows:
 F = Flat
 H = Horizontal
 H-fillets = Horizontal fillets
 V-down = Vertical with downward progression
 V = Vertical } { For electrodes 3/16 in. (4.8mm) and under, except 5/32 in. (4.0mm)
 OH = Overhead } and under for classifications E7014, E7015, E7016, E7018, and E7018M.
- b. The term "dcep" refers to direct current electrode positive (dc, reverse polarity). The term "dcen" refers to direct current electrode negative (dc, straight polarity).
- c. Electrodes of the E6022 classification are intended for single-pass welds only.
- d. Electrodes with supplemental elongation, notch toughness, absorbed moisture, and diffusible hydrogen requirements may be further identified as shown in Tables 2, 3, 10, and 11.

Part B

Tests, Procedures, and Requirements

6. Summary of Tests

The tests required for each classification are specified in Table 4. The purpose of these tests is to determine the chemical composition, mechanical

properties, and soundness of the weld metal; moisture content of the low hydrogen electrode covering; and the usability of the electrode. 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 17.

The supplemental tests for absorbed moisture, in Section 16, Absorbed Moisture Test, and diffusible hydrogen, in Section 17, Diffusible Hydrogen Test, are not required for classification of the low hydrogen electrodes except for E7018M, where these are required. See Notes j and n of Table 4.

Table 2
Tension Test Requirements^{a,b,c}

AWS Classification	Tensile Strength		Yield Strength at 0.2% Offset		Elongation in 2 in. (50.8 mm) Percent
	ksi	MPa	ksi	MPa	
E6010	60	414	48	331	22
E6011	60	414	48	331	22
E6012	60	414	48	331	17
E6013	60	414	48	331	17
E6019	60	414	48	331	22
E6020	60	414	48	331	22
E6022 ^d	60	414	not specified		not specified
E6027	60	414	48	331	22
E7014	70	482	58	399	17
E7015	70	482	58	399	22
E7016	70	482	58	399	22
E7018	70	482	58	399	22
E7024	70	482	58	399	17 ^e
E7027	70	482	58	399	22
E7028	70	482	58	399	22
E7048	70	482	58	399	22
E7018M	note g	482	53-72 ^f	365-496 ^f	24

Notes:

- See Table 4 for sizes to be tested.
- Requirements are in the as-welded condition with aging as specified in 11.3.
- Single values are minimum.
- A transverse tension test, as specified in 11.2 and Figure 9 and a longitudinal guided bend test, as specified in Section 12, Bend Test, and Figure 10, are required.
- Weld metal from electrodes identified as E7024-1 shall have elongation of 22 % minimum.
- For 3/32 in. (2.4mm) electrodes, the maximum for the yield strength shall be 77 ksi (531 MPa).
- Tensile strength of this weld metal is a nominal 70 ksi (482 MPa).

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 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 five weld test assemblies are required.

- (1) The weld pad in Figure 1 for chemical analysis of the undiluted weld metal
- (2) The groove weld in Figure 2 for mechanical properties and soundness of the weld metal
- (3) The fillet weld in Figure 3 for the usability of the electrode

(4) The groove weld in Figure 4 for transverse tensile and longitudinal bend tests for welds made with the E6022 single pass electrode

(5) The groove weld in Figure 5 for mechanical properties and soundness of weld metal made with the E7018M electrode

The sample for chemical analysis may be taken from a low dilution area either in the groove weld in Figure 2 or 5 or in the fractured all-weld-metal tension test specimen, thereby avoiding the need to make a weld pad. In case of dispute, the weld pad shall be the referee method.

8.2 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 5 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 14.

Table 3
Charpy V-Notch Impact Requirements

AWS Classification	Limits for 3 out of 5 Specimens ^a	
	Average, Min.	Single Value, Min.
E6010, E6011, E6027, E7015, E7016 ^b , E7018 ^b , E7027, E7048	20 ft-lb at -20°F (27 J at -29°C)	15 ft-lb at -20°F (20 J at -29°C)
E6019 E7028	20 ft-lb at 0°F (27 J at -18°C)	15 ft-lb at 0°F (20 J at -18°C)
E6012, E6013, E6020, E6022, E7014, E7024 ^b	Not Specified	Not Specified
Limits for 5 out of 5 Specimens ^c		
	Average, Min.	Single Value, Min.
E7018M	50 ft-lb at -20°F (67 J at -29°C)	40 ft-lb at -20°F (54 J at -29°C)

Notes:

- a. Both the highest and lowest test values obtained shall be disregarded in computing the average. Two of these remaining three values shall equal or exceed 20 ft-lb (27 J).
 b. Electrodes with the following optional supplemental designations shall meet the lower temperature impact requirements specified below:

AWS Classification	Electrode Designation	Charpy V-Notch Impact Requirements, Limits for 3 out of 5 specimens (Refer to Note a above)	
		Average, Min.	Single Value, Min.
E7016 E7018	E7016-1 } E7018-1 }	20 ft-lb at -50°F (27 J at -46°C)	15 ft-lb at -50°F (20 J at -46°C)
E7024	E7024-1	20 ft-lb at 0°F (27 J at -18°C)	15 ft-lb at 0°F (20 J at -18°C)

- c. All five values obtained shall be used in computing the average. Four of the five values shall equal, or exceed, 50 ft-lb (67 J).

Electrodes other than low hydrogen electrodes shall be tested without "conditioning". Low hydrogen electrodes, if they have not been adequately protected against moisture pickup 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 Figure 1. Base metal of any convenient size of the type specified in Table 5 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). 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 Figure 1. Testing of this assembly shall be as specified in Section 9, Chemical Analysis.

Table 4
Required Tests^{a,b}

AWS Classification	Current and Polarity ^a	Electrode Size ^c		Chemical ^d Analysis	Radiographic Test ^e All-Weld-Metal Tension Test ^f	Impact Test ^g	Fillet Weld Test ^h	Moisture Test ⁱ
		in.	mm					
E6010	dcep	$\left\{ \begin{array}{l} 3/32, 1/8 \\ 5/32, 3/16 \\ 7/32 \\ 1/4 \\ 5/16 \end{array} \right\}$	$\left\{ \begin{array}{l} 2.4, 3.2 \\ 4.0, 4.8 \\ 5.6 \\ 6.4 \\ 8.0 \end{array} \right\}$	NR	NR ^b	NR ^b	NR ^b	NR
E6011	ac and dcep	$\left\{ \begin{array}{l} 3/32, 1/8 \\ 5/32, 3/16 \\ 7/32 \\ 1/4 \end{array} \right\}$	$\left\{ \begin{array}{l} 2.4, 3.2 \\ 4.0, 4.8 \\ 5.6 \\ 6.4 \end{array} \right\}$	NR	NR ^b	NR ^b	NR ^b	NR
E6012	ac and dcen	$\left\{ \begin{array}{l} 5/16 \\ 1/16 \text{ to } 1/8 \text{ inc.} \\ 5/32, 3/16 \\ 7/32 \\ 1/4, 5/16 \end{array} \right\}$	$\left\{ \begin{array}{l} 8.0 \\ 1.6 \text{ to } 3.2 \text{ inc.} \\ 4.0, 4.8 \\ 5.6 \\ 6.4, 8.0 \end{array} \right\}$	NR	NR ^b	NR ^b	NR ^b	NR
E6013	ac, dcep, and dcen	$\left\{ \begin{array}{l} 1/16 \text{ to } 1/8 \text{ inc.} \\ 5/32, 3/16 \\ 7/32 \\ 1/4, 5/16 \end{array} \right\}$	$\left\{ \begin{array}{l} 1.6 \text{ to } 3.2 \text{ inc.} \\ 4.0, 4.8 \\ 5.6 \\ 6.4, 8.0 \end{array} \right\}$	NR	NR ^b	NR ^b	NR ^b	NR
E6019	ac, dcep, and dcen	$\left\{ \begin{array}{l} 5/64 \text{ to } 1/8 \text{ inc.} \\ 5/32, 3/16 \\ 7/32 \\ 1/4, 5/16 \end{array} \right\}$	$\left\{ \begin{array}{l} 2.0 \text{ to } 3.2 \text{ inc.} \\ 4.0, 4.8 \\ 5.6 \\ 6.4, 8.0 \end{array} \right\}$	NR	NR ^b	NR ^b	NR ^b	NR
E6020	$\left\{ \begin{array}{l} \text{For H-fillets,} \\ \text{ac and dcen;} \\ \text{For flat} \\ \text{position} \\ \text{ac, dcep, and} \\ \text{dcen} \end{array} \right\}$	$\left\{ \begin{array}{l} 1/8 \\ 5/32, 3/16 \\ 7/32 \\ 1/4 \\ 5/16 \end{array} \right\}$	$\left\{ \begin{array}{l} 3.2 \\ 4.0, 4.8 \\ 5.6 \\ 6.4, 8.0 \end{array} \right\}$	NR	NR ^b	NR ^b	NR ^b	NR
E6022	ac and dcen	$\left\{ \begin{array}{l} 1/8 \\ 5/32 \text{ to } 7/32 \text{ inc.} \end{array} \right\}$	$\left\{ \begin{array}{l} 3.2 \\ 4.0, 4.8 \\ 5.6 \\ 6.4 \\ 8.0 \end{array} \right\}$	NR	NR ^b	NR ^b	NR ^b	NR
E6027	$\left\{ \begin{array}{l} \text{For H-fillets,} \\ \text{ac and dcen;} \\ \text{For flat} \\ \text{position} \\ \text{ac, dcep, and} \\ \text{dcen} \end{array} \right\}$	$\left\{ \begin{array}{l} 1/8 \\ 5/32, 3/16 \\ 7/32 \\ 1/4 \\ 5/16 \end{array} \right\}$	$\left\{ \begin{array}{l} 3.2 \\ 4.0, 4.8 \\ 5.6 \\ 6.4 \\ 8.0 \end{array} \right\}$	NR	NR ^b	NR ^b	NR ^b	NR

(Continued)

Table 4 (Continued)

AWS Classification	Current and Polarity ^a	Electrode Size ^c		Chemical ^d Analysis	Radiographic Test ^e All-Weld-Metal Tension Test ^f	Impact Test ^g	Fillet Weld Test ^h	Moisture Test ⁱ
		in.	mm					
E7014	ac, dcep, and dcen	3/32, 1/8	2.4, 3.2	NR ^b	NR ^b	NR	NR ^b	NR
		5/32	4.0	Fl	Fl	NR	V & OH	NR
		3/16	4.8	NR ^b	Fl	NR	H	NR
		7/32	5.6	NR ^b	NR ^b	NR	NR ^b	NR
		1/4	6.4	Fl	Fl	NR	H	NR
E7015	dcep	5/16	8.0	NR ^b	Fl	NR	H	NR
		3/32, 1/8	2.4, 3.2	NR ^b	NR ^b	NR ^b	NR ^b	NR ^b
		5/32	4.0	F	F	F	V & OH	Req'd.
		3/16	4.8	NR ^b	F	F	H	NR ^b
		7/32	5.6	NR ^b	NR ^b	NR ^b	NR ^b	NR ^b
E7016	ac and dcep	1/4	6.4	F	F	F	H	Req'd.
		5/16	8.0	NR ^b	F	NR ^b	NR ^b	NR ^b
		3/32, 1/8	2.4, 3.2	NR ^b	NR ^b	NR ^b	NR ^b	NR ^b
		5/32	4.0	F	F	F	V & OH	Req'd.
		3/16	4.8	NR ^b	F	F	H	NR ^b
E7018	ac and dcep	7/32	5.6	NR ^b	NR ^b	NR ^b	NR ^b	NR ^b
		1/4	6.4	F	F	F	H	Req'd.
		5/16	8.0	NR ^b	F	NR ^b	NR ^b	NR ^b
		3/32, 1/8	2.4, 3.2	NR ^b	NR ^b	NR ^b	NR ^b	NR ^b
		5/32	4.0	F	F	F	V & OH	Req'd.
E7018M ⁿ	dcep	3/16	4.8	NR ^b	F	F	H	NR ^b
		7/32	5.6	NR ^b	NR ^b	NR ^b	NR ^b	NR ^b
		1/4	6.4	F	F	F	H	Req'd.
		5/16	8.0	NR ^b	F	NR ^b	NR ^b	NR ^b
		3/32 to 5/32 inc. 3/16 to 5/16 inc.	2.4 to 4.0 inc. 4.8 to 8.0 inc.	F	V	V	NR	Req'd.
E7024	ac, dcep, and dcen	3/32, 1/8	2.4, 3.2	NR ^b	NR ^b	NR ^{b,o}	NR ^b	NR
		5/32	4.0	Fl	Fl ^m	F ^o	H	NR
		3/16	4.8	NR ^b	Fl ^m	F ^o	H	NR
		7/32	5.6	NR ^b	NR ^b	NR ^{b,o}	NR ^b	NR
		1/4	6.4	Fl	Fl ^m	F ^o	H	NR
E7027	For H-fillets ac and dcep For flat position ac, dcep, and dcen	5/16	8.0	NR ^b	FC ^{l,m}	NR ^{b,o}	NR ^b	NR
		1/8	3.2	NR ^b	NR ^b	NR ^b	NR ^b	NR
		5/32	4.0	Fl	Fl ^m	Fl	H	NR
		3/16	4.8	NR ^b	Fl ^m	Fl	H	NR
		7/32	5.6	NR ^b	NR ^b	NR ^b	NR ^b	NR

(Continued)

Table 4 (Continued)

AWS Classification	Current and Polarity ^a	Electrode Size ^c		Chemical ^d Analysis	Radiographic Test ^e All-Weld-Metal Tension Test ^f		Impact Test ^g	Fillet Weld Test ^h	Moisture Test ⁱ
		in.	mm						
E7028	ac and deep	1/8	3.2	NR ^b	NR ^b	NR ^b	NR ^b	NR ^b	NR ^b
		5/32	4.0	F	F ^m	F	F	Req'd.	Req'd.
		3/16	4.8	NR ^b	F ^m	F	H	NR ^b	NR ^b
		7/32	5.6	NR ^b	NR ^b	NR ^b	NR ^b	NR ^b	NR ^b
		1/4	6.4	F	F ^m	F	H	Req'd.	Req'd.
E7048	ac and deep	5/16	8.0	NR ^b	F ^m	NR ^b	NR ^b	NR ^b	NR ^b
		1/8	3.2	NR ^b	NR ^b	NR ^b	NR ^b	NR ^b	NR ^b
		5/32	4.0	F	F	F	V-down & OH	Req'd.	Req'd.
		3/16	4.8	NR ^b	F	F	V-down & H	NR ^b	NR ^b

a. NR means "not required". The abbreviations, F, H, H-fillets, V-down, V, and OH, are defined in Note a of Table 1. The terms "deep" and "dcen", are defined in Note b of Table 1.

b. 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 Figures 1, 2, and 3 and Table 6.

c. Electrodes manufactured in sizes not shown shall be tested to the requirements of the nearest standard size. 6.0 mm electrode shall be tested to the requirements of 1/4 in. (6.4 mm) electrode.

d. See Section 9, Chemical Analysis.

e. See Section 10, Radiographic Test.

f. See Section 11, Tension Test.

g. See Section 13, Impact Test.

h. See Section 14, Fillet Weld Test.

i. A radiographic test is not required for this classification.

j. The moisture test given in Sections 15 through 15.9 is the required test for measurement of moisture content of the covering. In Section 16, Absorbed Moisture Test, and Section 17, Diffusible Hydrogen Test, are supplemental tests required only when their corresponding optional supplemental designators are to be used with the classification designators.

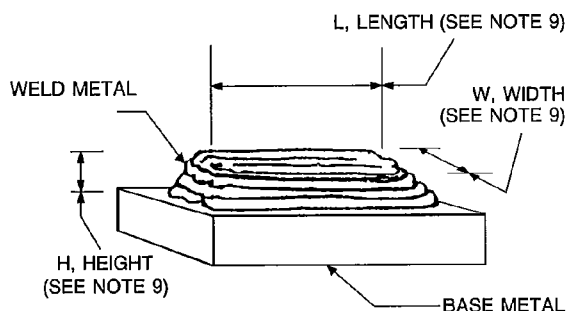
k. A transverse tension test (see 11.2 and Figure 9) and a longitudinal guided bend test (see Section 12, Bend Test, and Figure 10) are required for classification of 5/32, 3/16, and 7/32 in. (4.0, 4.8, and 5.6 mm) E6022 electrodes. Welding shall be in the flat position. See Note d of Table 2.

l. When deep and dcen are shown, only dcen need be tested.

m. 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.

n. Tests in Section 16 Absorbed Moisture Test, and in Section 17, Diffusible Hydrogen Test, are required tests for all sizes of E7018M.

o. Electrodes identified as E7024-1 shall be impact tested. See Note b of Table 3.



Notes:

1. Base metal of any convenient size, of any type specified in Table 5, 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 4 except for those classifications identified by note L in Table 4.
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.
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 at least 1/4 in. (6.4 mm) above the original base metal surface.

Figure 1 — Pad for Chemical Analysis of Undiluted Weld Metal

8.4 Groove Weld

8.4.1 Mechanical Properties and Soundness. A test assembly shall be prepared and welded as specified in Figures 2 or 5 using base metal of the appropriate type specified in Table 5. Testing of this assembly shall be as specified in Section 11, Tension Test, and Section 13, Impact Test. The assembly shall be tested in the as-welded or aged condition.

8.4.2 Transverse Tension and Bend Tests. A test assembly shall be prepared and welded as specified in Figure 4 using base metal of the appropriate type specified in Table 5. Testing of this assembly shall be as specified in 11.2 through 11.4 and Section 12,

Bend Test. The assembly shall be tested in the aged condition.

8.5 Fillet Weld. A test assembly shall be prepared and welded as specified in Table 4 and Figure 3 using base metal of the appropriate type specified in Table 5. The welding positions shall be as specified in Table 6 and Figures 3 and 6 according to the size and classification of electrode. Testing of the assembly shall be as specified in Section 14, Fillet Weld Test.

9. Chemical Analysis

9.1 The sample for analysis shall be taken from weld metal obtained with the electrode. The sample shall come from a weld pad or from a low dilution area in the fractured all-weld-metal tension specimen or the groove weld in Figures 2 or 5. Areas where arc starts or craters exist shall be avoided.

The top surface of the pad described in 8.3 and shown in Figure 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 at least 1/4 in. (6.4 mm) from the nearest surface of the base metal.

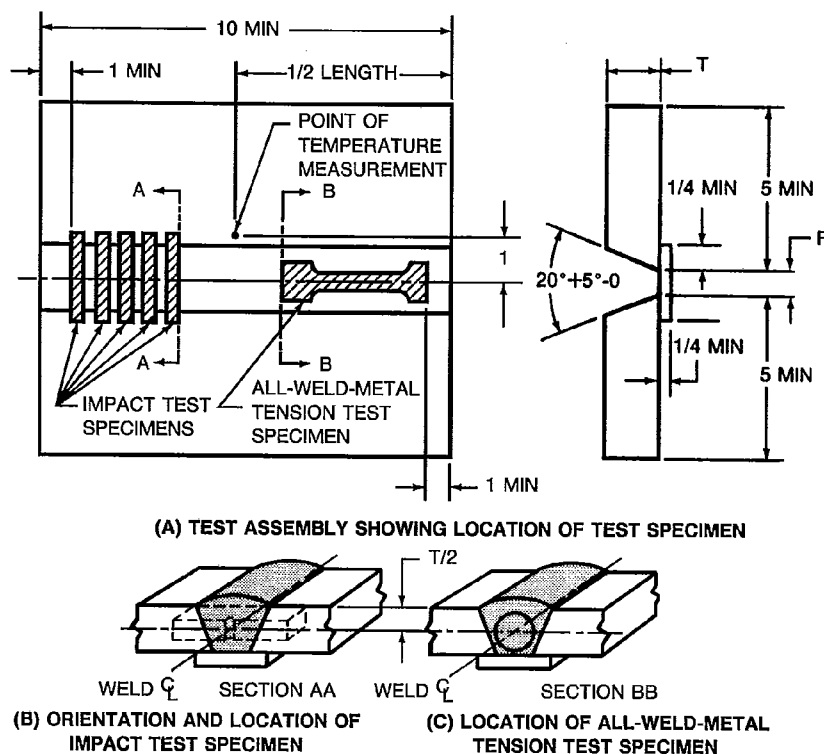
The low dilution area in the fractured tension test specimen or in the groove weld in Figures 2 or 5 shall be prepared for analysis by any suitable mechanical means.

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

9.3 The results of the analysis shall meet the requirements of Table 7 for the classification of the electrode under test.

10. Radiographic Test

10.1 When required in Table 4, the groove weld described in 8.4.1 and shown in Figure 2 or 5 shall be radiographed to evaluate the soundness of the weld metal. 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

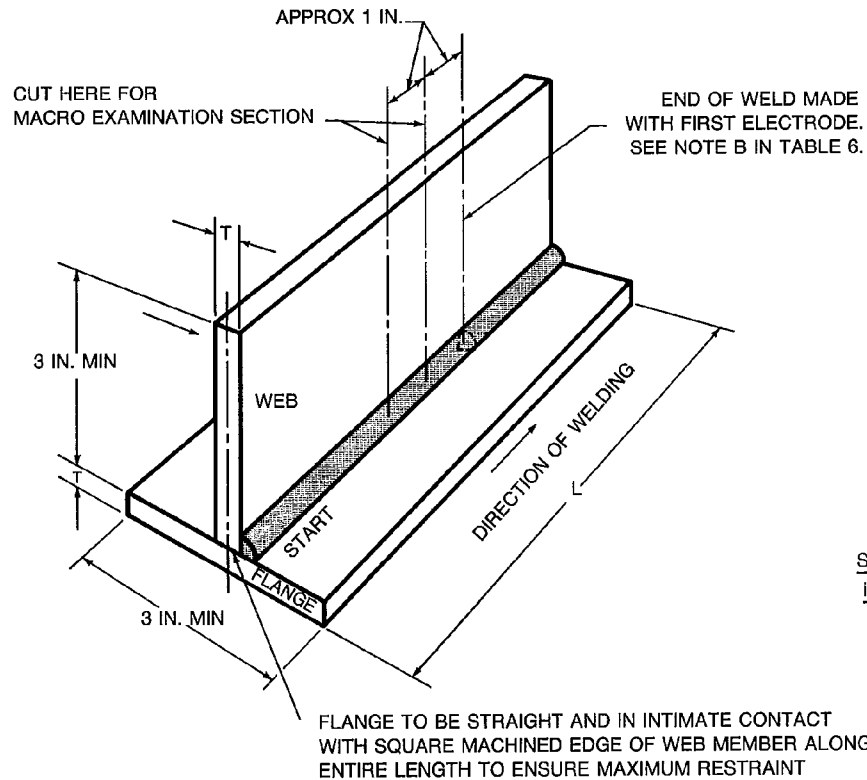


Electrode Size	(T)		(R)		Passes Per Layer	Total Layers
	in.	mm	in.	mm		
3/32	2.4	1/2 13	3/8 10	2	2	not specified
1/8	3.2	1/2 13	1/2 13	2	2	5 to 7
5/32	4.0	3/4 20	5/8 16	2	2	7 to 9
3/16	4.8	3/4 20	3/4 20	2	2	6 to 8
7/32	5.6	3/4 20	7/8 23	2	2	6 to 8
1/4	6.4	1 25	1 25	2	2	9 to 11
5/16	8.0	1-1/4 32	1-1/8 28	2	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) minimum length test assembly shall be welded.
3. Base metal shall be as specified in Table 5.
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 deg of plane. A welded test assembly that is more than 5 deg 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 4 except for classifications identified by Note L in Table 4.
7. The preheat temperature shall be 225°F (105°C) minimum. The interpass temperature shall not be less than 225°F (105°C) nor more than 350°F (175°C).
8. 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.

Figure 2 — Groove Weld Test Assembly for Mechanical Properties and Soundness Except for E6022 and E7018M Electrodes

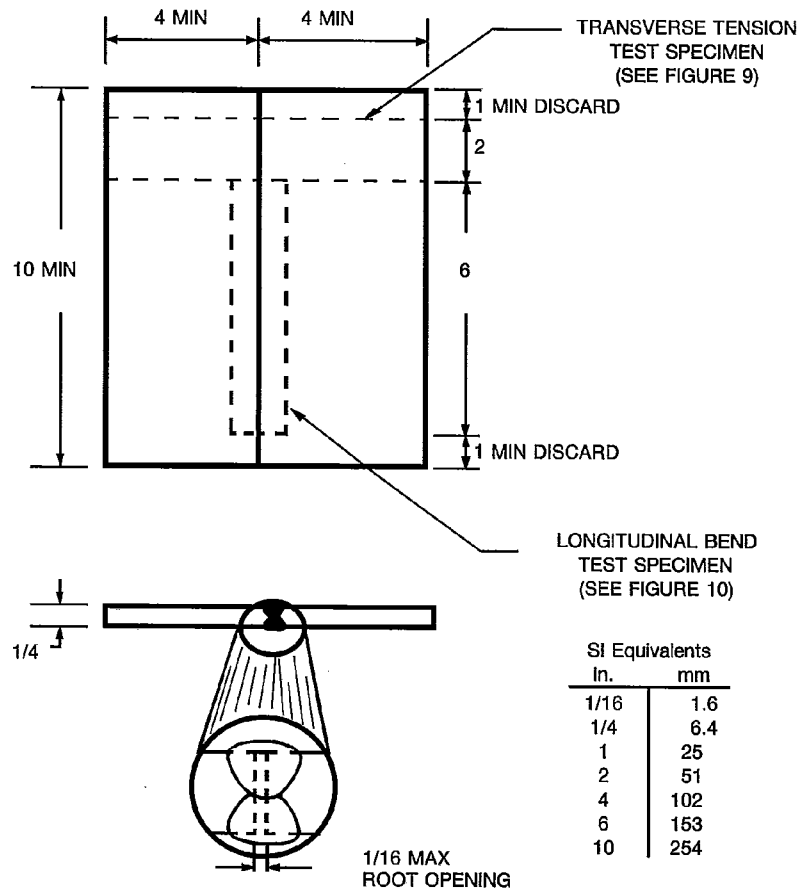


SI Equivalents	
in.	mm
1	25
3	76

Notes:

1. See Table 6 for values of T and L.
2. Base metal shall be as specified in Table 5.
3. The surfaces to be welded shall be clean.
4. An assembly shall be welded in each position specified in Table 6 and shown in Figure 6 using each type of current specified in Table 4.
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 no greater than 2 in. (50 mm).
7. Welding in the vertical position shall be with upward progression, except for the E7048 classification where progression shall be downward.
8. Weld cleaning shall be limited to slag chipping, brushing, and needle scaling. Grinding or filing of the weld face is prohibited.

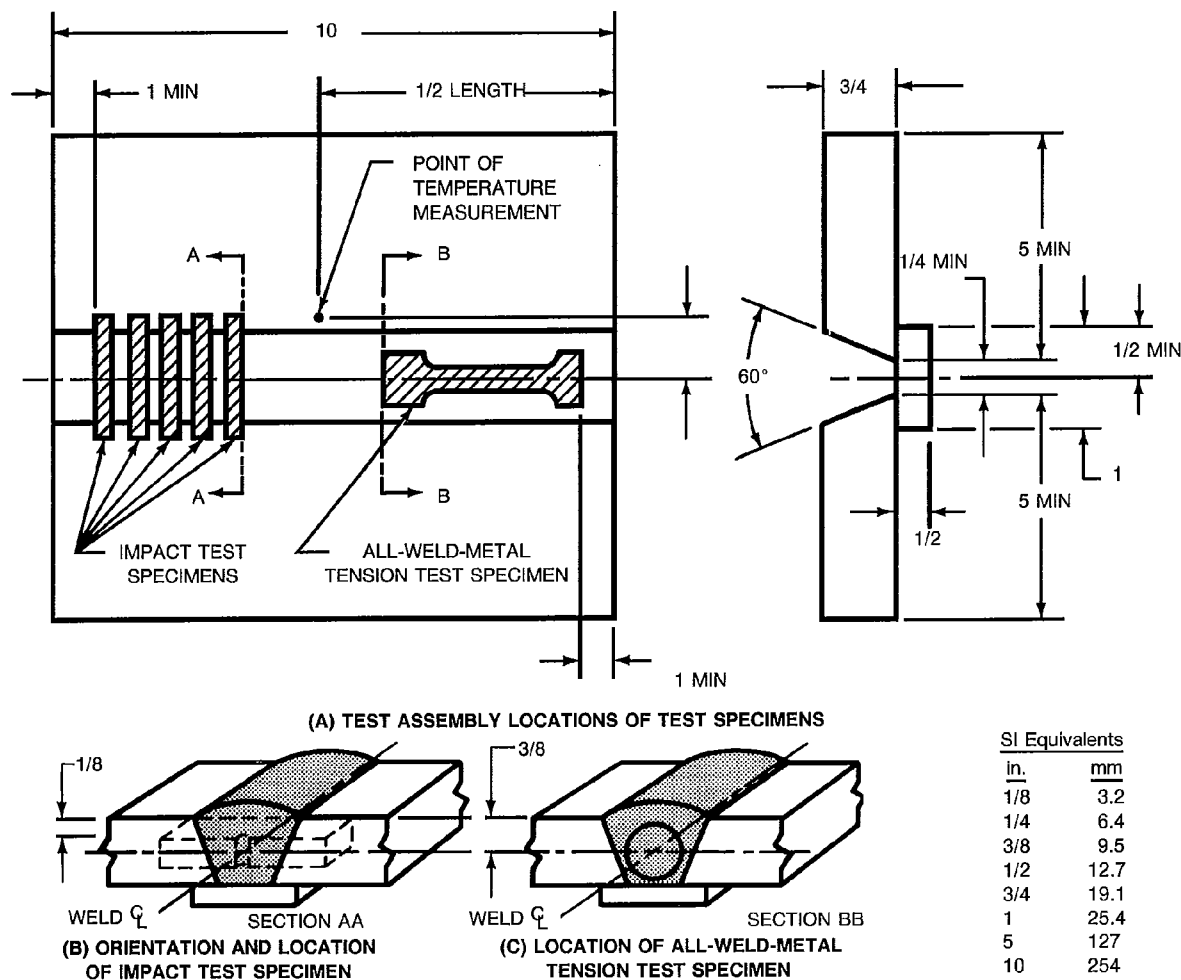
Figure 3 — Fillet Weld Test Assembly



Notes:

1. All dimensions are in inches.
2. Base metal shall be as specified in Table 5.
3. The surfaces to be welded shall be clean.
4. 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 deg of plane. A welded test assembly that is more than 5 deg out of plane shall be discarded. Straightening of the test assembly is prohibited.
5. The assembly shall be welded in the flat position, using the type of current specified in Table 4.
6. The preheat temperature shall be 60°F (16°C) min. The interpass temperature shall not exceed 350°F (180°C).
7. In addition to the stops and starts at the ends, each pass shall contain a stop and start in between the ends.
8. Back gouging may be done to ensure sound weld metal through the entire thickness of test assembly.
9. The completed weld shall be at least flush with the surface of the test plate.

Figure 4 — Test Assembly for Transverse Tension and Longitudinal Guided Bend Tests for Welds Made With E6022 Electrodes



Notes:

1. All dimensions except angles are in inches.
2. Base metal shall be as specified in Table 5.
3. The surfaces to be welded shall be clean.
4. 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 deg of plane. A welded test assembly that is more than 5 deg out of plane shall be discarded. Straightening of the test assembly is prohibited.
5. The assembly shall be welded in the vertical position with progression upward for electrodes 5/32 in. (4.0 mm) and less in size, and in the flat position for electrodes 3/16 in. (4.8 mm) and greater in size, using the type of current specified in Table 4 for the electrode and welding technique recommended by the electrode manufacturer.
6. The preheat temperature and the interpass temperature shall be 200-250°F (93-121°C).
7. The welding heat input shall be 30 to 40 kJ/in. (12 to 16 kJ/cm) for the 3/32 in. (2.4 mm) size electrodes and 50 to 60 kJ/in. (20 to 24 kJ/cm) for the 1/8 in. (3.2 mm) size and larger electrodes.
8. In addition to the stops and starts at the ends, each pass shall contain a stop and start in between the ends.
9. The completed weld shall be at least flush with the surface of the test plate. Maximum weld reinforcement shall be 3/16 in. (4.8 mm). Peening of weld beads is not permitted.

Figure 5 — Groove Weld Test Assembly for Mechanical Properties and Soundness of Weld Metal Made with E7018M Electrodes

Table 5
Base Metal for Test Assemblies

AWS Classification	Type	Base Metal	
		ASTM Specification ^a	UNS Number ^b
All	Carbon steel	A131 Grade B	K02102
		A285 Grade A	K01700
		A285 Grade B	K02200
All except E7018M	Carbon steel	A285 Grade C	K02801
		A283 Grade D	—
		A36	K02600
		A29 Grade 1015	G10150
		A29 Grade 1020	G10200

Notes:

a. Equivalent steel may be used.

b. SAE/ASTM Unified Numbering System for Metals and Alloys.

have a reasonably uniform reinforcement not exceeding 3/32 in. (2.4 mm). Both surfaces of the test assembly in the area of the weld shall be smooth enough to avoid difficulty in interpreting the radiograph.

10.2 The weld shall be radiographed in accordance with ASTM Method E142, *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 the following:

(1) No cracks, no incomplete fusion or incomplete joint penetration

(2) No slag inclusions longer than 1/4 in. (6.4 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 inclusions in the group

(3) No rounded indications in excess of those permitted by the radiographic standards in Figure 7 according to the grade specified in Table 8.

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

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 porosity indications larger than the largest rounded 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 as shown in Figure 2 or 5. The dimensions of the specimen shall be as shown in Figure 8.

11.2 For E6022 electrodes, one transverse tension test specimen shall be machined from the groove weld described in 8.4.2 and Figure 4. The dimensions of the specimen shall be as shown in Figure 9.

11.3 The tension specimens for all electrodes except the low hydrogen classifications shall be aged at 200 to 220°F (95 to 105°C) for 48 ± 2 hours, and cooled in air to room temperature. All specimens

Table 6
Requirements for Preparation of Fillet Weld Test Assemblies

AWS Classification	Electrode Size		Thickness (T)		Assembly Size ^a		Welding Position	Fillet Weld Size		
	mm		mm		mm			mm		
	in.	mm	in.	mm	in.	mm		in.	mm	
E6010 and E6011	{	3/32	2.4	1/8	3.2	10	250	V & OH	5/32 max.	4.0
		1/8	3.2	3/16	4.8	12	300	V & OH	3/16 max.	4.8
		5/32	4.0	3/8	9.5	12	300	V & OH	1/4 max.	6.4
		3/16	4.8	3/8	9.5	12	300	V & OH	5/16 max.	8.0
		7/32	5.6	1/2	12.7	12 or 16 ^c	300 or 400 ^c	H	1/4 min.	6.4
		1/4	6.4	1/2	12.7	16	400	H	1/4 min.	6.4
E6012, E6013 and E6019	{	5/16	8.0	1/2	12.7	16	400	H	1/4 min.	6.4
		1/16-5/64	1.6-2.0	1/8	3.2	6	150	V & OH	1/8 max.	3.2
		3/32	2.4	1/8	3.2	10	250	V & OH	1/8 max.	3.2
		1/8	3.2	3/16	4.8	12	300	V & OH	3/16 max.	4.8
		5/32	4.0	3/8	9.5	12	300	V & OH	1/4 max.	6.4
		3/16	4.8	1/2	12.7	12	300	V & OH	3/8 max.	9.5
E7014	{	7/32	5.6	1/2	12.7	12 or 16 ^c	300 or 400 ^c	H	1/4 min.	6.4
		1/4	6.4	1/2	12.7	16	400	H	5/16 min.	8.0
		5/16	8.0	1/2	12.7	16	400	H	5/16 min.	8.0
		3/32	2.4	1/8	3.2	12	300	V & OH	5/32 max.	4.0
		1/8	3.2	3/16	4.8	12	300	V & OH	3/16 max.	4.8
		5/32	4.0	3/8	9.5	12	300	V & OH	5/16 max.	8.0
E7015 and E7016	{	3/16	4.8	3/8	9.5	12	300	H	1/4 min.	6.4
		7/32	5.6	3/8	9.5	12 or 16 ^c	300 or 400 ^c	H	1/4 min.	6.4
		1/4	6.4	1/2	12.7	16	400	H	5/16 min.	8.0
		5/16	8.0	1/2	12.7	16	400	H	5/16 min.	8.0
		3/32	2.4	1/8	3.2	10	250	V & OH	5/32 max.	4.0
		1/8	3.2	1/4	6.4	12	300	V & OH	3/16 max.	4.8
E7015 and E7016	{	5/32	4.0	3/8	9.5	12	300	V & OH	5/16 max.	8.0
		3/16	4.8	3/8	9.5	12	300	V & OH	3/16 min.	4.8
		7/32	5.6	1/2	12.7	12 or 16 ^c	300 or 400 ^c	H	1/4 min.	6.4
		1/4	6.4	1/2	12.7	16	400	H	5/16 min.	8.0
		5/16	8.0	1/2	12.7	16	400	H	5/16 min.	8.0

(Continued)

Table 6 (Continued)

AWS Classification	Electrode Size		Thickness (T)		Assembly Size ^a		Welding Position	Fillet Weld Size		
	in.	mm	in.	mm	Length ^b (L), Min.			in.	mm	
					in.	mm				
E7018	}	3/32	2.4	1/8	3.2	10 or 12 ^d	250 or 300 ^d	V & OH	3/16 max.	4.8
		1/8	3.2	1/4	6.4	12	300	V & OH	1/4 max.	6.4
		5/32	4.0	3/8	9.5	12	300	V & OH	5/16 max.	8.0
		3/16	4.8	3/8	9.5	12	300	H	1/4 min.	6.4
		7/32	5.6	1/2	12.7	12 or 16 ^c	300 or 400 ^c	H	1/4 min.	6.4
		1/4	6.4	1/2	12.7	16	400	H	5/16 min.	8.0
E6020	}	5/16	8.0	1/2	12.7	16	400	H	5/16 min.	8.0
		1/8	3.2	1/4	6.4	12	300	H	1/8 min.	3.2
		5/32	4.0	3/8	9.5	12	300	H	5/32 min.	4.0
		3/16	4.8	3/8	9.5	12 or 16 ^c	300 or 400 ^c	H	3/16 min.	4.8
		7/32	5.6	1/2	12.7	16	400	H	1/4 min.	6.4
		1/4	6.4	1/2	12.7	16	400	H	5/16 min.	8.0
E6027, E7024, E7027 and E7028	}	5/16	8.0	1/2	12.7	16	400	H	5/16 min.	8.0
		3/32 ^e	2.4 ^e	1/4	6.4	10	250	H	5/32 min.	4.0
		1/8	3.2	1/4	6.4	12	300	H	5/32 min.	4.0
		5/32	4.0	3/8	9.5	12	300	H	3/16 min.	4.8
		3/16	4.8	3/8	9.5	12 or 16 ^c	300 or 400 ^c	H	1/4 min.	6.4
		7/32	5.6	1/2	12.7	16 or 26 ^f	400 or 650 ^f	H	1/4 min.	6.4
E7048	}	1/4	6.4	1/2	12.7	16 or 26 ^f	400 or 650 ^f	H	5/16 min.	8.0
		5/16	8.0	1/2	12.7	16 or 26 ^f	400 or 650 ^f	H	5/16 min.	8.0
		1/8	3.2	1/4	6.4	12	300	V-down & OH	1/4 max.	6.4
		5/32	4.0	3/8	9.5	12	300	V-down & OH	5/16 max.	8.0
		3/16	4.8	3/8	9.5	12 or 16 ^c	300 or 400 ^c	H & V-down	1/4 min.	6.4

Notes:

- a. See Figure 3.
- b. When the end of the bead with the first electrode will be less than 4 in. (100 mm) from the end of the test assembly, a starting tab or a longer test assembly shall be used.
- c. For 14 in. (350 mm) electrodes, the minimum length of the test assembly shall be 12 in. (300 mm); for 18 in. (460 mm) electrodes, the minimum length of the test assembly shall be 16 in. (400 mm).
- d. For 12 in. (300 mm) electrodes, the minimum length of the test assembly shall be 10 in. (250 mm); for 14 in. (350 mm) electrodes, the minimum length of the test assembly shall be 12 in. (300 mm).
- e. E7024 only.
- f. For 18 in. (460 mm) electrodes, the minimum length of the test assembly shall be 16 in. (400 mm); for 28 in. (700 mm) electrodes, the minimum length of the test assembly shall be 26 in. (650 mm).

Table 7
Chemical Composition Requirements for Weld Metal

AWS Classification	UNSA Number	Weight, Percent ^b							Combined Limit for Mn + Ni + Cr + Mo + V		
		C	Mn	Si	P	S	Ni	Cr		Mo	V
E6010	W06010	Not Specified									
E6011	W06011										
E6012	W06012										
E6013	W06013										
E6019	W06019										
E6020	W06020										
E6022	W06022										
E6027	W06027										
E7016	W07016										
E7018	W07018	Not Specified	1.60	0.75	Not Specified	0.30	0.20	0.30	1.75		
E7027	W07027										
E7014	W07014										
E7015	W07015	Not Specified	1.25	0.90	Not Specified	0.30	0.20	0.30	1.50		
E7024	W07024										
E7028	W07028	Not Specified	1.60	0.90	Not Specified	0.30	0.20	0.30	1.75		
E7048	W07048										
E7018M	W07018	0.12	0.40 to 1.60	0.80	0.030	0.020	0.25	0.15	0.35	0.05	Not Specified

Notes:

a. SAE/ASTM Unified Numbering System for Metals and Alloys.

b. Single values are maximum.

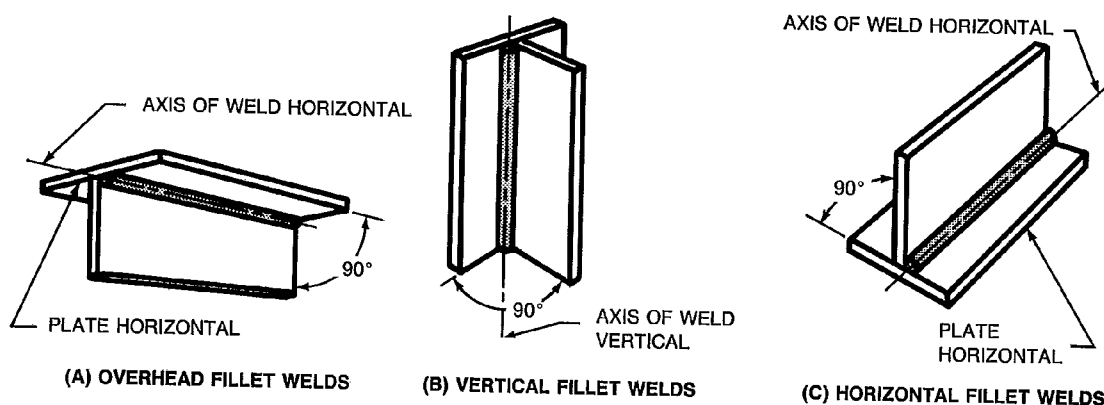


Figure 6 — Welding Positions for Fillet Weld Test Assemblies

shall be tested in the manner described in the tension testing section of AWS B4.0, *Standard Methods for Mechanical Testing of Welds*.

11.4 The results of the tension test shall meet the requirements specified in Table 2.

12. Bend Test (For E6022 Electrodes Only)

12.1 One longitudinal face bend specimen, as required in Table 4, shall be machined from the groove weld test assembly described in 8.4.2 and shown in Figure 4. Dimensions of the specimen shall be as shown in Figure 10.

12.2 The bend specimen shall be aged at 200 to 220°F (95 to 105 °C) for 48 ±2 hours then air cooled to room temperature and tested as required in 12.3.

12.3 The specimen shall be tested in the manner described in the bend testing section of AWS B4.0, *Standard Methods for Mechanical Testing of Welds*. The specimen shall be bent uniformly through 180 degrees over a 3/4 in. (19 mm) radius in any suitable jig. Three standard jigs are shown in Figure 11. Positioning of the face bend specimen shall be such that the weld face of the last side welded is in tension.

12.4 Each specimen, after bending, shall conform to the 3/4 in. (19 mm) radius, with an appropriate allowance for springback and the weld metal shall

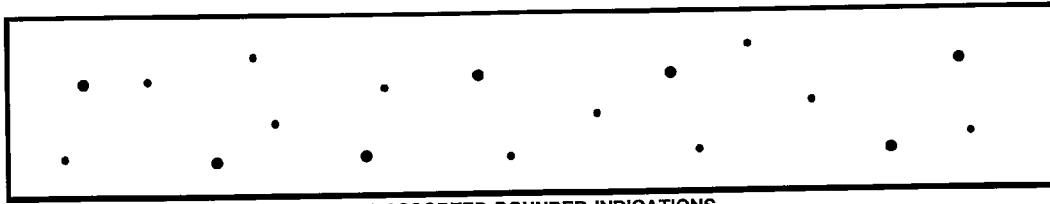
Table 8
Radiographic Soundness Requirements

AWS Classification	Radiographic Standard ^{a,b}
E6019	Grade 1
E6020	
E7015	
E7016	
E7018	
E7018M	
E7048	Grade 2
E6010	
E6011	
E6013	
E7014	
E7024	
E6027	
E7027	
E7028	Not specified
E6012	
E6022	

Notes:

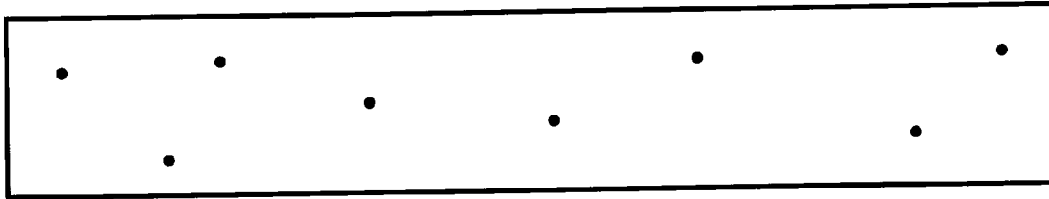
a. See Figure 7.

b. The radiographic soundness obtainable under actual industrial conditions employed for the various electrode classifications is discussed in A6.10.1 in the Appendix.

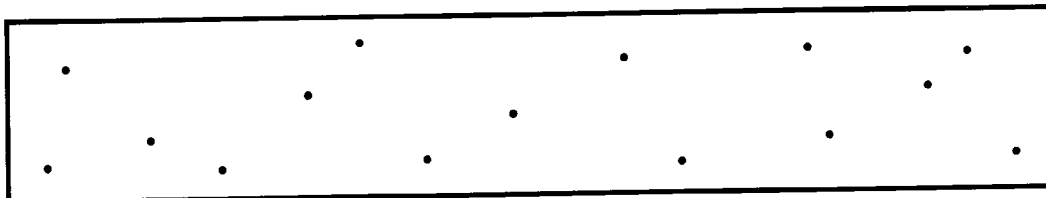
**(A) ASSORTED ROUNDED INDICATIONS**

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:

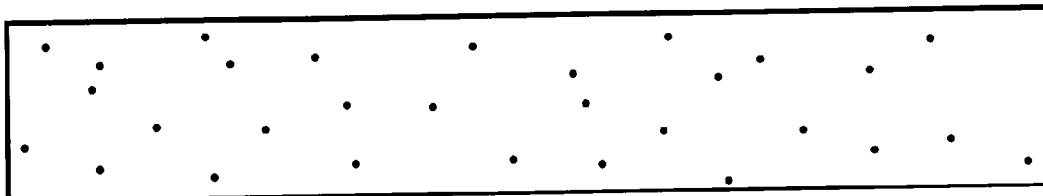
MAXIMUM NUMBER OF LARGE 3/64 in. (1.2 mm) TO 1/16 in. (1.6 mm) IN DIAMETER OR IN LENGTH INDICATIONS = 3.
 MAXIMUM NUMBER OF MEDIUM 1/32 in. (0.8 mm) TO 3/64 in. (1.2 mm) IN DIAMETER OR IN LENGTH INDICATIONS = 5.
 MAXIMUM NUMBER OF SMALL 1/64 in. (0.4 mm) TO 1/32 in. (0.8 mm) IN DIAMETER OR IN LENGTH 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.

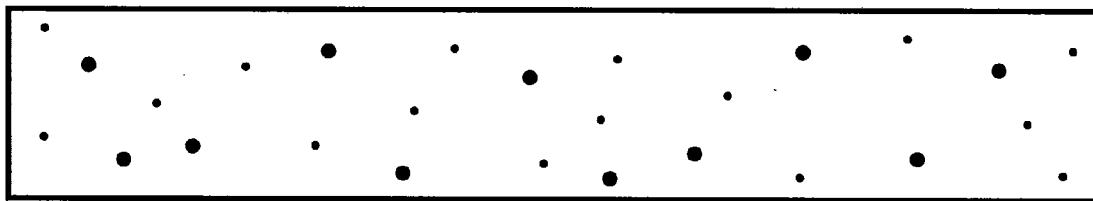
**(D) SMALL ROUNDED INDICATIONS**

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.

**Figure 7 — Radiographic Acceptance Standards for Rounded Indications
 (Grade 1)**

**(E) ASSORTED ROUNDED INDICATIONS**

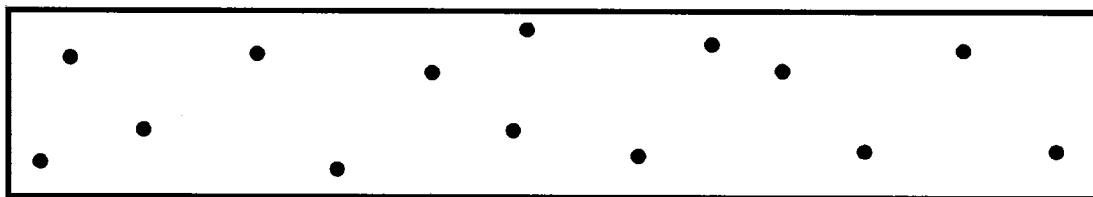
SIZE 1/64 in. (0.4 mm) TO 5/64 in. (2.0 mm) IN DIAMETER OR IN LENGTH.

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.

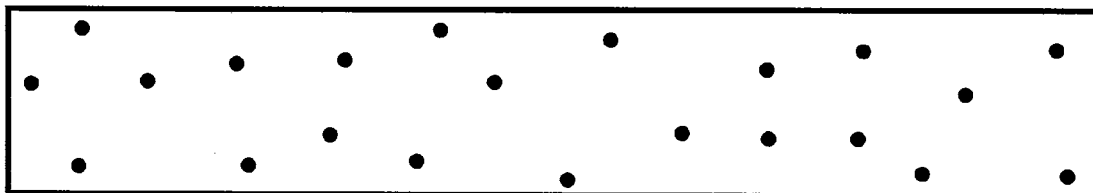
MAXIMUM NUMBER OF MEDIUM 3/64 in. (1.2 mm) TO 1/16 in. (1.6 mm) IN DIAMETER OR IN LENGTH INDICATIONS = 8.

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**

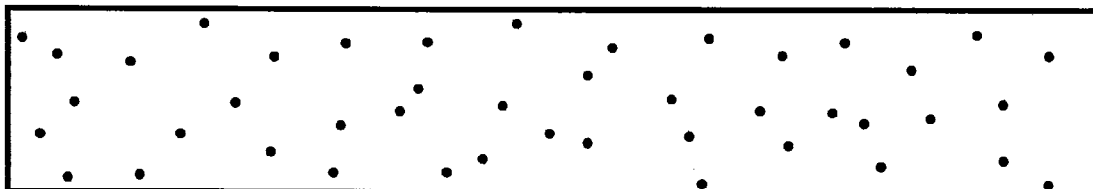
SIZE 1/16 in. (1.6 mm) TO 5/64 in. (2.0 mm) IN DIAMETER OR IN LENGTH.

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.

Figure 7 (Continued) — Radiographic Acceptances Standards for Rounded Indications (Grade 2)

not contain openings in excess of 1/8 in. (3.2 mm) on the convex surface.

13. Impact Test

13.1 Five Charpy V-notch impact test specimens, Figure 12, shall be machined from the test assembly shown in Figure 2 or 5, for those classifications for which impact testing is required in Table 4.

13.2 The five specimens shall be tested in accordance with the fracture toughness testing section of AWS B4.0, *Standard Methods for Mechanical Testing of Welds*. The test temperature shall be that specified in Table 3 for the classification under test.

13.3 In evaluating the test results for all the classifications that require impact testing, except E7018M, the lowest and the highest values obtained shall be disregarded. Two of the three remaining values shall equal, or exceed, the specified 20 ft-lb (27J) energy level. One of the three may be lower, but not lower than 15 ft-lb (20J). The average of the three shall not be less than the required 20 ft-lb (27J) energy level.

13.4 In evaluating the results for E7018M, all five values shall be used. Four of the five values shall equal, or exceed, the specified 50 ft-lb (67J) energy level. One of the five may be lower, but not lower than 40 ft-lb (54J). The average of the five shall not be less than the required 50 ft-lb (67J) energy level.

14. Fillet Weld Test

14.1 The fillet weld test, when required in Table 4, shall be made in accordance with 8.5 and Figure 3. The entire face of the completed fillet weld shall be examined visually. It shall be free of cracks, overlap, slag, and porosity, and shall be substantially free of undercut. An infrequent short undercut up to 1/32 in. (0.8 mm) depth shall be allowed. After the visual examination, a specimen, approximately 1 in. (25 mm) in length, shall be removed as shown in Figure 3. One cross-sectional surface of the specimen shall be polished, etched, and then examined as required in 14.2.

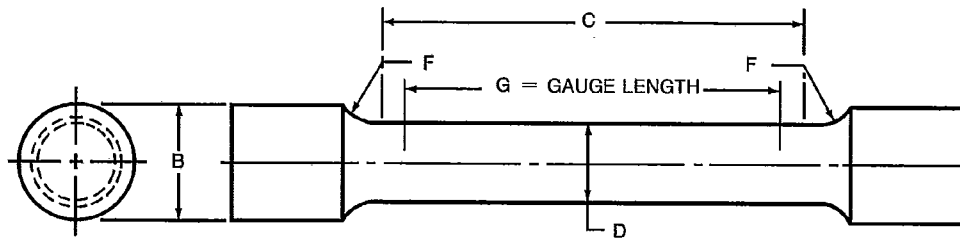
14.2 Scribe lines shall be placed on the prepared surface, as shown in Figure 13, and the fillet weld size, fillet weld leg, and convexity shall be determined to the nearest 1/64 in. (0.4 mm) by actual measurement (see Figure 13). These measurements shall meet the requirements of Table 6 with respect to minimum or maximum fillet weld size and the requirements of Table 9 with respect to maximum convexity and maximum difference between fillet weld legs according to the fillet weld size measured.

14.3 The remaining two sections of the test assembly shall be broken through the fillet weld by a force exerted as shown in Figure 14. When necessary to facilitate fracture through the fillet, one or more of the following procedures may be used:

(1) A reinforcing bead, as shown in Figure 14, may be added to each leg of the weld.

Table 9
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	3.2	3/64	1.2	1/32	0.8
5/32	4.0	3/64	1.2	3/64	1.2
3/16	4.8	1/16	1.6	1/16	1.6
7/32	5.6	1/16	1.6	5/64	2.0
1/4	6.4	1/16	1.6	3/32	2.4
9/32	7.1	1/16	1.6	7/64	2.8
5/16	8.0	5/64	2.0	1/8	3.2
11/32	8.7	5/64	2.0	9/64	3.6
3/8	9.5	5/64	2.0	5/32	4.0



Dimensions of Specimen, in.

Test Plate Thickness	D	G	C	B	F, Min.
1/2	0.250 ± 0.005	1.000 ± 0.005	1-1/4	3/8	3/16
3/4 and larger	0.500 ± 0.010	2.000 ± 0.005	2-1/4	3/4	3/8

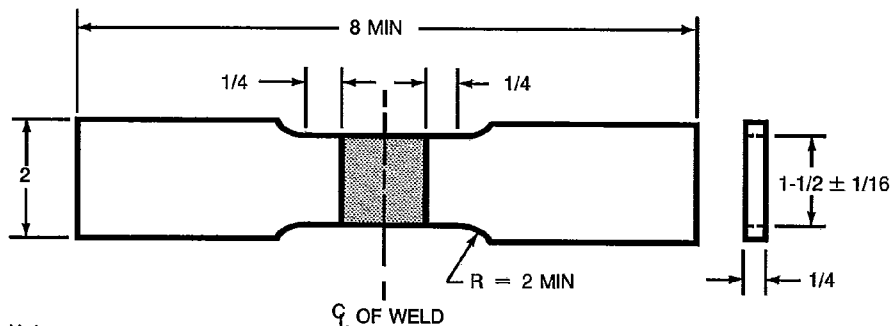
Dimensions of Specimen, mm

Test Plate Thickness	D	G	C	B	F, Min.
12.7	6.40 ± 0.13	25.40 ± 0.13	32	9.5	4.8
19 and larger	12.70 ± 0.25	50.80 ± 0.13	57	19	9.5

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 $63 \mu\text{ in.}$ ($1.6 \mu\text{ m.}$).

Figure 8 — All-Weld-Metal Tension Test Specimen Dimensions

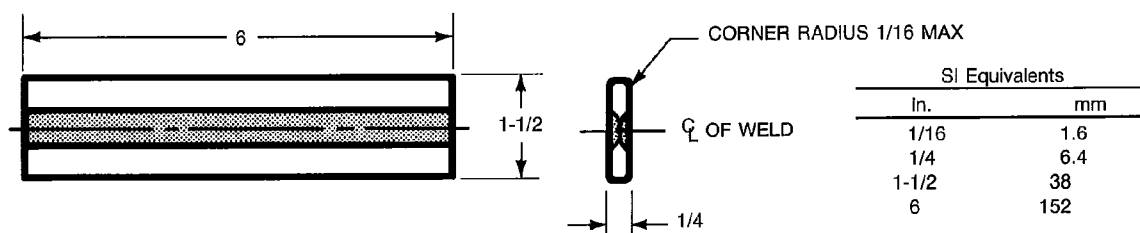


SI Equivalents	
in.	mm
1/4	6.4
1-1/2 $\pm$ 1/16	38.1 $\pm$ 1.6
2	51
8	203

Notes:

1. All dimensions are in inches.
2. Weld reinforcement shall be ground or machined smooth and flush with the surfaces of the specimen. Grinding or machining marks shall be parallel of the longest dimension of the specimen.

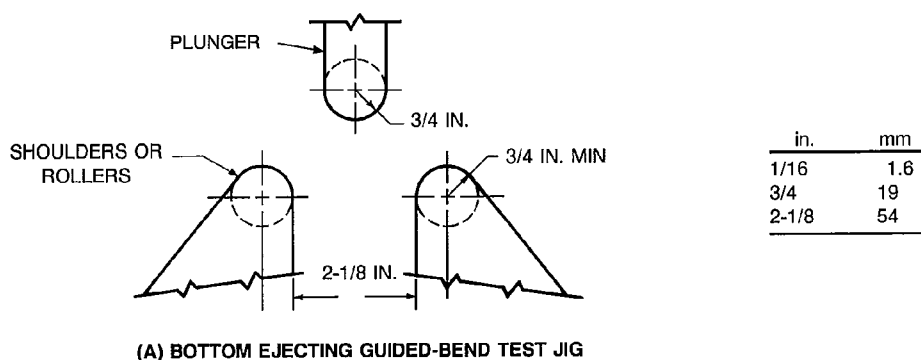
Figure 9 — Transverse Tension Test Specimen (E6022)



Notes:

1. All dimensions are in inches.
2. Weld reinforcement shall be ground or machined smooth and flush with the surfaces of the specimen. Grinding or machining marks shall be parallel to the length of the weld.

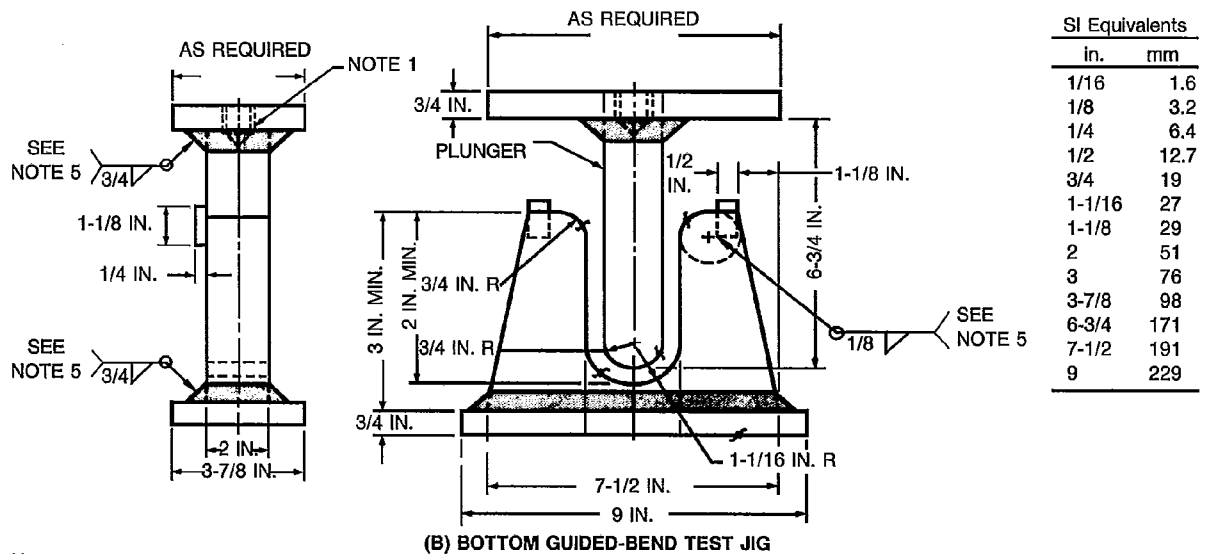
Figure 10 — Longitudinal Guided-Bend Test Specimen (E6022)



Notes:

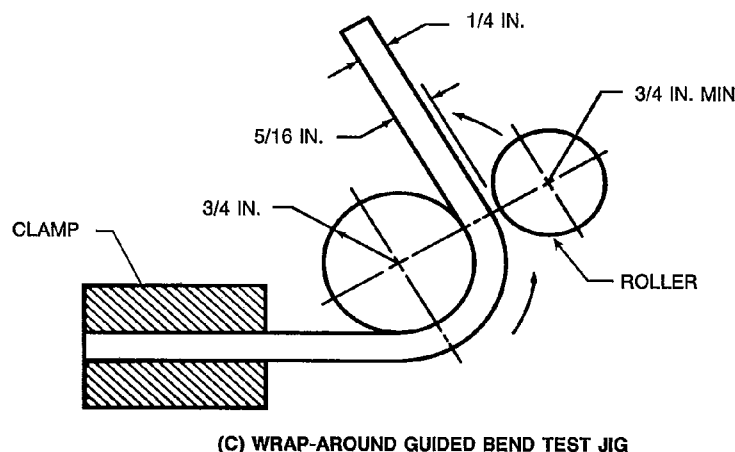
1. Either hardened and greased shoulders or hardened rollers free to rotate shall be used.
2. The shoulders or rollers shall have a minimum bearing length of 2 in. (51 mm) for placement of the specimen.
3. The shoulders or rollers shall be high enough above the bottom of the testing jig so that the specimen will clear the shoulders or rollers when the plunger is in the low position.
4. The plunger shall be fitted with an appropriate base and provision for attachment to the testing machine and shall be designed to minimize deflection or misalignment.
5. The shoulder or roller supports may be made adjustable in the horizontal direction so that specimens of various thickness may be tested in the same jig.
6. The shoulder or roller supports shall be fitted to a base designed to maintain the shoulders or rollers centered and aligned with respect to the plunger, and to minimize deflection or misalignment.

Figure 11 — Bend Test Jigs



Notes:

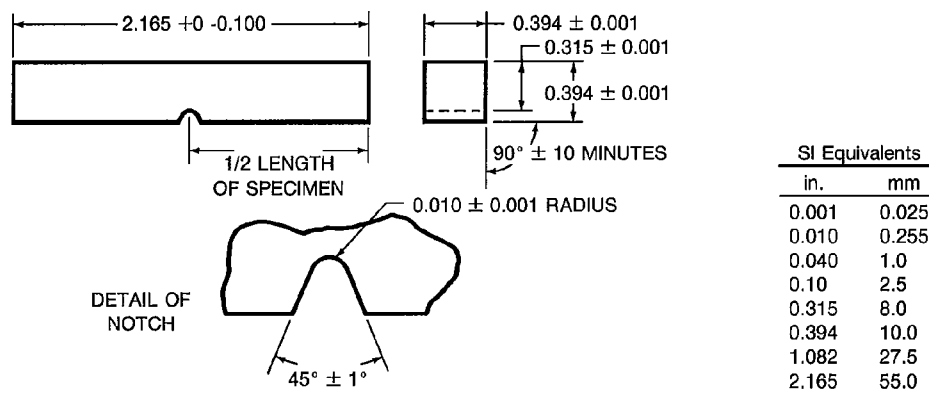
1. A tapped hole of appropriate size, or other suitable means for attaching plunger to testing machine shall be made.
2. Either hardened and greased shoulders or hardened rollers free to rotate shall be used in the die.
3. The plunger and base shall be designed to minimize deflection and misalignment.
4. The specimen shall be forced into the die by applying the load on the plunger until the curvature of the specimen is such that a 1/8 in. (3.0 mm) diameter wire cannot be placed between the specimen and all points in the curvature of the die member of the jig.
5. Weld size indicated is a recommendation. The actual size is the responsibility of the user to ensure rigidity and design adequacy.



Notes:

1. Dimensions not shown are the option of the designer, except that the minimum width of the components shall be 2 in. (51 mm).
2. It is essential to have adequate rigidity so that the jig will not deflect during testing. The specimen shall be firmly clamped on one end so that it does not slide during the bending operation.
3. Test specimens shall be removed from the jig when the outer roll has traversed 180° from the starting point.

Figure 11 (Continued) — Bend Test Jigs

**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 in. (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 in. (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 (+).

Figure 12 — Charpy V-Notch Impact Test Specimen

(2) The position of the web on the flange may be changed, as shown in Figure 14.

(3) The face of the fillet may be notched, as shown in Figure 14.

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 as required for retest in Section 7, Retest, does not apply.

14.4 The fractured surfaces shall be visually examined without magnification. The fracture surface shall be free of cracks. Incomplete fusion at the weld root shall not be greater than 20 % of the total length of the weld. There shall be no continuous length of incomplete fusion greater than 1 in. (25 mm) as measured along the weld axis except for electrodes of the E6012, E6013, and E7014 classifications. Fillet welds made with electrodes of these classifications may exhibit incomplete fusion through the entire length of the fillet weld, provided that at no

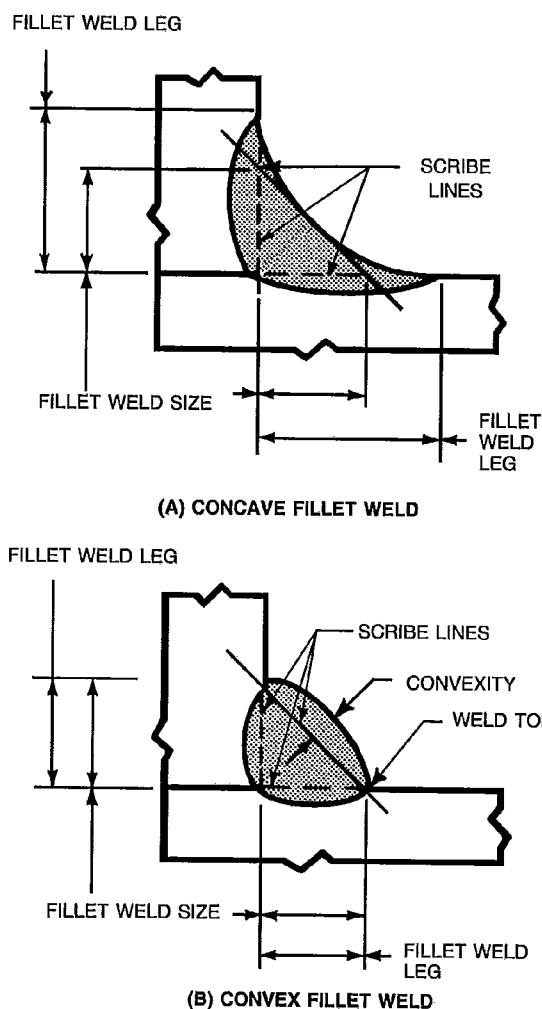
point this incomplete fusion exceeds 25 percent of the smaller leg of the fillet weld.

15. Moisture Test

15.1 The moisture content of the covering on the low hydrogen electrodes, when required in Table 4, shall be determined by any suitable method. In case of dispute, the method described in 15.3 through 15.9 shall be the referee method.

15.2 The electrodes 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 10.

15.3 This method (the referee method) consists of heating a sample of the covering in a nickel or clay boat placed inside a combustion tube in order to



Note:

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.

Figure 13 — Dimensions of Fillet Welds

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 ex-

pressed as a percentage of the original weight of the sample of covering.

15.4 The apparatus shall be as shown in Figure 15⁵ 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% 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).

(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.

15.5 In conducting this 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.

15.6 The furnace shall be operated at 1800°F ± 25°F (982°C ± 14°C) with an oxygen flow of 200 to 250 ml per minute. The empty boat (see 15.3) 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

5. Modifications of the type described in Appendix A8, which give equivalent results, also meet the requirements of this specification.

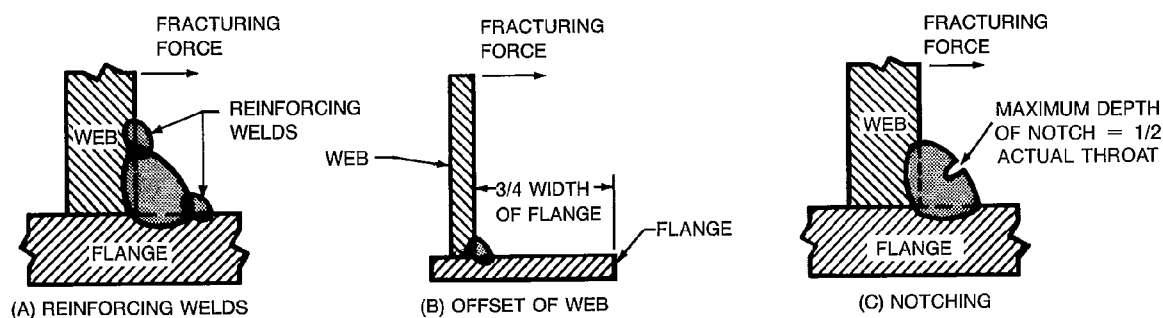


Figure 14 — Alternative Methods for Facilitating Fracture of the Fillet Weld

a desiccant. After a cooling period of 20 minutes, the absorption U-tube shall be weighed.

15.7 In the blank determination, 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

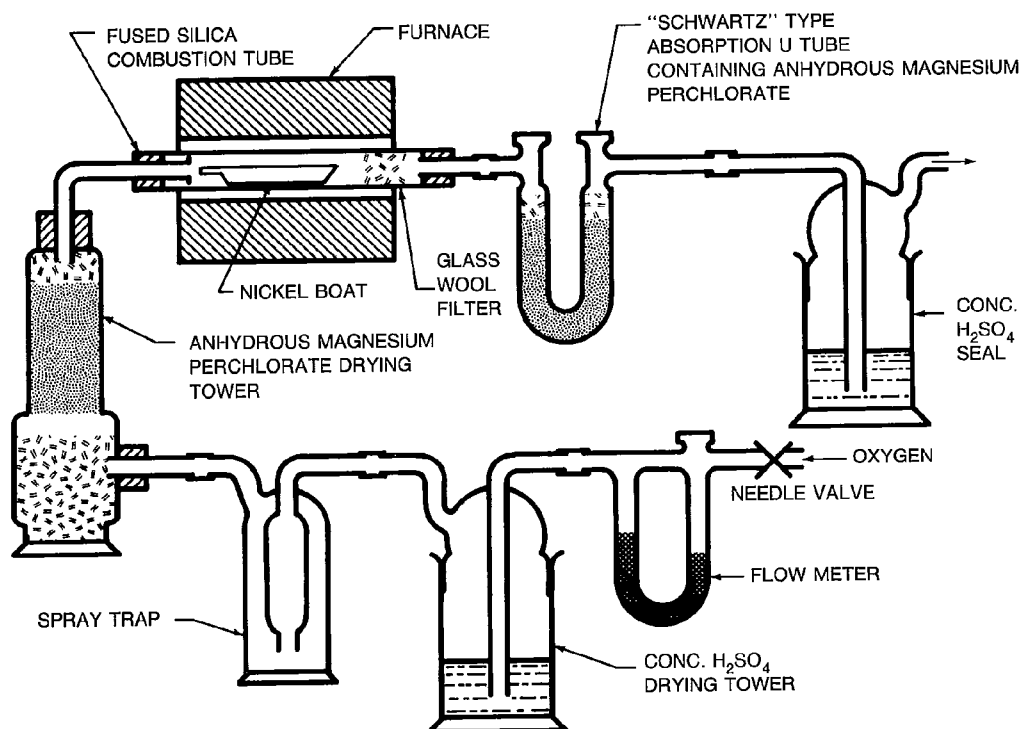


Figure 15 — Schematic of Train for Moisture Determinations

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.

15.8 Immediately after weighing the absorption U-tube above, 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 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.

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

$$\text{Percent Moisture} = \frac{A - B}{\text{Weight of Sample}} \times 100$$

where:

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

16. Absorbed Moisture Test

16.1 In order for a low hydrogen electrode to be designated as low-moisture-absorbing with the "R" suffix designator or classified as E7018M, sufficient electrodes shall be exposed to an environment of 80°F (26.7°C)/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 16.2 through 16.6 shall be the referee method. The moisture content of the electrode covering on the low-moisture-absorbing, low hydrogen electrodes (E7015R, E7016R, E7016-1R, E7018R, E7018-1R, E7018M, E7028R, E7048R) shall be determined by any suitable method. In case of dispute, the method described in 15.3 to 15.9 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 designated electrode and classification in Table 10.

16.2 An electrode sample of each size of E7018M or the smallest and the largest sizes of "R" designated electrode shall be exposed. 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.

16.3 The electrode sample shall be exposed in a suitably calibrated and controlled environmental chamber for nine hours minimum at 80°F, minus 0, plus 5°F (26.7°C, minus 0, plus 2.8°C) and 80% RH, minus 0, plus 5%.

16.4 The environmental chamber 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 electrode of 100 to 325 fpm (0.5 to 1.7 m/sec.).
- (3) The apparatus shall have a drip-free area where the covered electrode 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 temperature and either the wet bulb temperature or the differential between the dry bulb and 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/s) 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.

16.5 The exposure procedure 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 (6°C) above the dew point of the chamber at the time of loading.
- (2) The electrode sample shall be loaded into the

Table 10
Moisture Content Limits in Electrode Coverings

AWS Classification	Electrode Designation	Limit of Moisture Content, % by Wt., Max.	
		As-Received or Conditioned ^a	As-Exposed ^b
E7015	E7015	0.6	Not specified
E7016	{ E7016		
	{ E7016-1		
E7018	{ E7018		
	{ E7018-1		
E7028	E7028	0.3	0.4
E7048	E7048		
E7015	E7015R		
E7016	{ E7016R		
	{ E7016-1R		
E7018	{ E7018R		
	{ E7018-1R		
E7028	E7028R	0.1	0.4
E7048	E7048R		
E7018M	E7018M		

Notes:

a. As-received or conditioned electrode coverings shall be tested as specified in Section 15, Moisture Test.

b. As-exposed electrode coverings shall have been exposed to a moist environment as specified in 16.2 through 16.6 before being tested as specified in 16.1.

chamber without delay after the packages are opened.

(3) The electrodes shall be placed in the chamber in a vertical or horizontal position on 1 in. (25 mm) centers, with the length of the electrode 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 electrodes shall be removed from the chamber and a sample of the electrode covering taken for moisture determination, as specified in Section 15, Moisture Test.

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

17. Diffusible Hydrogen Test

The smallest and largest sizes of the electrode of each classification to be designated by an optional

supplemental diffusible hydrogen designator and all sizes of E7018M, 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 Steel 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 11.

For purposes of certifying compliance with diffusible hydrogen requirements, the reference atmospheric condition 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. (See Appendix, A9.2)

When the absolute humidity equals or exceeds the reference condition at the time of preparation of

Table 11
Diffusible Hydrogen Limits for Weld Metal

AWS Classification	Diffusible Hydrogen Designator	Diffusible Hydrogen Content, Average mL(H ₂)/100g Deposited Metal, Max. ^{a,b}
E7018M	None	4.0
E7015	$\left\{ \begin{array}{l} \text{H16} \\ \text{H8} \\ \text{H4} \end{array} \right.$	16.0
E7016		
E7018		8.0
E7028		
E7048		4.0

Notes:

- a. Diffusible hydrogen testing in Section 17, Diffusible Hydrogen Test, is required for E7018M. Diffusible hydrogen testing of other low hydrogen electrodes is only required when diffusible hydrogen designator is added as specified in Figure 16.
- b. Some low hydrogen classifications may not meet the H4 and H8 requirements.

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 11, the electrode also meets the requirements for all higher hydrogen designators in Table 11 without the need to retest.

Part C

Manufacture, Identification, and Packaging

18. 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.

19. Standard Sizes and Lengths

19.1 Standard sizes (diameter of the core wire) and lengths of electrodes are shown in Table 12.

19.2 The diameter of the core wire shall not vary more than ± 0.002 in. (0.05 mm) from the diameter

specified. The length shall not vary more than $\pm 1/4$ in. (10 mm) from that specified.

20. Core Wire and Covering

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

20.2 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) 7% of the mean dimension in sizes 3/32 in. (2.4 mm) and smaller;
 - (2) 5% of the mean dimension in sizes 1/8 in. (3.2 mm) and 5/32 in. (4.0 mm)
 - (3) 4% of the mean dimension in sizes 3/16 in. (4.8 mm) and larger.
- Concentricity may be measured by any suitable means.

21. Exposed Core

21.1 The grip end of each electrode shall be bare (free of covering) for a distance of not less than 1/2 in. (12 mm), nor more than 1-1/4 in. (30 mm) for 5/32 in. (4.0 mm) and smaller sizes, and not less than 3/4 in. (19 mm) nor more than 1-1/2 in. (40 mm) for 3/16 in.

Table 12
Standard Sizes and Lengths

Standard Sizes, ^a (Core Wire Diameter)		Standard Lengths ^{a,b}							
		E6010, E6011, E6012, E6013, E6022, E7014, E7015, E7016, E7018 E7018M				E6020, E6027, E7024 E7027, E7028, E7048		E6019	
		in.	mm	in.	mm	in.	mm	in.	mm
1/16 ^c	(0.063)	1.6 ^c	9	230	—	—	—	—	—
5/64 ^c	(0.072)	2.0 ^c	9 or 12	230 or 300	—	—	—	9 or 12	230 or 300
3/32 ^c	(0.094)	2.4 ^c	12 or 14	300 or 350	12 or 14	300 or 350	12 or 14	12 or 14	300 or 350
1/8	(0.125)	3.2	14	350	14	350	14	14	350
5/32	(0.156)	4.0	14	350	14	350	14	14 or 18	350 or 450
3/16	(0.188)	4.8	14	350	14 or 18	350 or 460	14 or 18	14 or 18	350 or 450
7/32 ^c	(0.219)	5.6 ^c	14 or 18	350 or 460	18 or 28	460 or 700	18	18	450
1/4 ^c	(0.250)	6.4 ^c	18	460	18 or 28	460 or 700	18	18	450
5/16 ^c	(0.313)	8.0 ^c	18	460	18 or 28	460 or 700	18	18	450

Notes:

- a. Lengths and sizes other than these shall be as agreed to by purchaser and supplier.
 b. In all cases, end-gripped electrodes are standard.
 c. These diameters are not standard sizes for all classifications (see Table 4).

(4.8 mm) and larger sizes, to provide for electrical contact with the electrode holder.

21.2 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 1/8 in. (3 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 1/4 in. (6 mm) or twice the diameter of the core wire, meet the requirements of this specification, provided no chip uncovers more than 50% of the circumference of the core.

22. Electrode Identification

All electrodes shall be identified as follows:

22.1 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 Figure 16 within 2-1/2 in. (65 mm) of the grip end of the electrode.

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

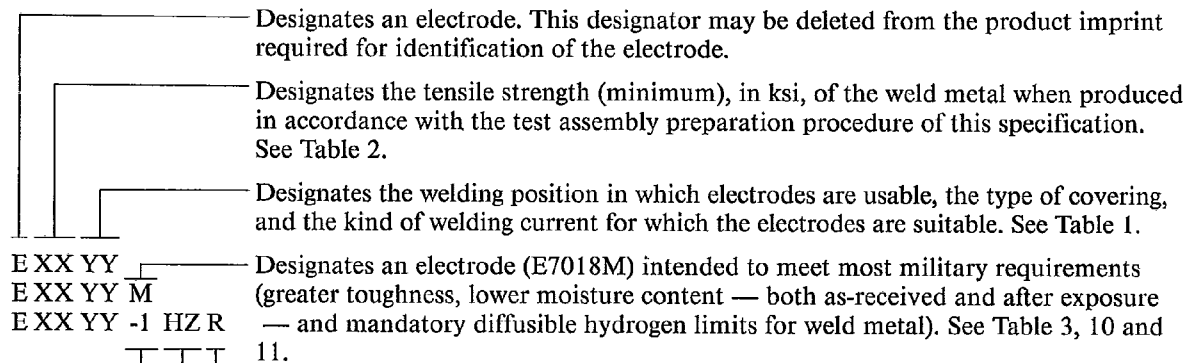
22.3 The ink used for imprinting shall provide sufficient contrast with the electrode covering so that, in normal use, the numbers and letters are legible both before and after welding.

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

23. Packaging

23.1 Electrodes shall be suitably packaged to protect them from damage during shipment and storage under normal conditions. In addition, E7018M electrodes shall be packaged in hermetically sealed containers. Hermetically sealed containers shall be capable of passing the test specified in 23.2.

23.2 For the test, a representative container shall be immersed in water that is at a temperature of at least 50°F (27°C) above that of the packaged material (room temperature). The container shall be immersed so that the surface under observation is approximately 1 in. (25 mm) below the water level.

Mandatory Classification Designators:***Optional Supplemental Designators:**

- Designates that the electrode meets the requirements of the absorbed moisture test (an optional supplemental test for all low hydrogen electrodes except the E7018M classification, for which the test is required). See Table 10.
- Designates that the electrode meets the requirements of the diffusible hydrogen test (an optional supplemental test of the weld metal from low hydrogen electrodes, as-received or conditioned — with an average value not exceeding “Z” mL of H₂ per 100g of deposited metal, where “Z” is 4, 8, or 16). See Table 11.
- Designates that the electrode (E7016, E7018, or E7024) meets the requirements for improved toughness — and ductility in the case of E7024 — (optional supplemental test requirements shown in Tables 2 and 3). See notes to Tables 2 and 3.

Note:

* The combination of these designators constitutes the electrode classification.

Figure 16 — Order of Electrode Mandatory and Optional Supplemental Designators

and the greatest dimension is parallel to the water surface. A container with a stream of bubbles that lasts for 30 seconds or more does not meet the requirements of this specification.

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

24. Marking of Packages

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

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

24.2 The following precautionary information (as a minimum) shall be prominently displayed in legible print on all packages of electrodes, 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.

(continued)

- 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, P. O. Box 351040, Miami, Florida 33135; *OSHA Safety*

and Health Standards, 29CFR 1910, available from the U.S. Government Printing Office, Washington, DC 20402.

DO NOT REMOVE THIS INFORMATION

Appendix

Guide to AWS Specification for Carbon Steel Electrodes for Shielded Metal Arc Welding

(This appendix is not a part of ANSI/AWS A5.1-91, *Specification for Carbon Steel Electrodes for Shielded Metal Arc Welding*, but is included for information purposes only.)

A1. Introduction

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 digits, 60, for example, designate tensile strength of at least 60 ksi of the weld metal, produced in accordance with the test assembly preparation section of the specification. The third digit designates position usability that will allow satisfactory welds to be produced with the electrode. Thus, the "1", as in E6010, means that the electrode is usable in all positions (flat, horizontal, vertical, and overhead). The "2", as in E6020 designates that the electrode is suitable for use in flat position and for making fillet welds in the horizontal position. The "4", as in E7048, designates that the electrode is suitable for use in vertical welding with downward progression and for other positions (see Table 1). 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.

A2.2 Optional designators are also used in this specification in order to identify electrodes that have met the mandatory classification requirements and certain supplementary requirements as agreed to between the supplier and the purchaser. A "-1" designator following classification identifies an electrode which meets optional supplemental impact requirements at a lower temperature than required for the classification (see Note b to Table 3). An example of this is the E7024-1 electrode which meets the classification requirements of E7024 and also meets the optional supplemental requirements for fracture toughness and improved elongation of the weld metal (see Note c to Table 2). Certain low hydrogen electrodes also may have optional designators.

A letter "R" is a designator used with the low hydrogen electrode classifications. The letter "R" is used to identify electrodes that have been exposed to a humid environment for a given length of time and tested for moisture absorption in addition to the standard moisture test required for classification of low hydrogen electrodes. See Section 16, Absorbed Moisture Test, and Table 10.

An optional supplemental designator "HZ" following the four digit classification designators or following the "-1" optional supplemental designator, if used, indicates an average diffusible hydrogen content of not more than "Z" ml/100g of deposited metal when tested in the "as-received" or condi-

tioned state in accordance with ANSI/AWS A4.3, *Standard Methods for Determination of Diffusible Hydrogen Content of Martensitic, Bainitic, and Ferritic Steel Weld Metal Produced by Arc Welding*. Electrodes that are designated as meeting the lower or lowest hydrogen limits, as specified in Table 11, are also understood to be able to meet any higher hydrogen limits even though these are not necessarily designated along with the electrode classification. Therefore, as an example, an electrode designated as "H4" also meets "H8" and "H16" requirements without being designated as such. See Section 17, Diffusible Hydrogen Test, and Table 11.

A2.3 Table A1 shows the classification for similar electrodes from Canadian Standards Association Specification W48.1-M1980, *Mild Steel Covered Arc Welding Electrodes*.

Table A1
Canadian Electrode Classifications Similar to
AWS Classifications (For Information Only)

Canadian Electrode Classification ^a	AWS Classification
E41000	—
E41010	E6010
E41011	E6011
E41012	E6012
E41013	E6013
E41022	E6022
E41027	E6027
E48000	—
E48010	—
E48011	—
E48012	—
E48013	—
E48014	E7014
E48015	E7015
E48016	E7016
E48018 ^b	E7018
E48022	—
E48024	E7024
E48027	E7027
E48028	E7028
E48048	E7048

Notes:

- From CSA Standard W48.1-M1980, *Mild Steel Covered Arc Welding Electrodes*, published by Canadian Standards Association, 178 Rexdale Boulevard, Rexdale, Ontario, Canada M9W 1R3.
- Also includes E48018-1 designated electrode.

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 the supplier normally conducts on material of that classification, as specified in Schedule F, Table 1, of the ANSI/AWS A5.01. Testing in accordance with any other schedule in that table shall be specifically required by the purchase order. In such cases, acceptance of the material shipped shall 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 Program" in ANSI/AWS A5.01.

A5. Ventilation During Welding

A5.1 The following 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 Z49.1, *Safety in Welding and Cutting* (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, "Health Protection and 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 subfreezing to several hundred degrees. No single temperature or reasonable range of temperatures can be chosen for classification tests which will 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 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 standard. 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. Weld metals, other than those from low hydrogen electrodes (E7015, E7016, E7018, E7018M, E7028, and E7048), contain significant quantities of hydrogen for some period of time after they have been made. 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, the ductility of the weld metal increases towards its inherent value, while the yield, tensile, and impact strengths remain relatively unchanged. This specification requires aging of the test specimens at 200 to 220°F (95 to 105°C) for 48 hours before subjecting them to the tension test or bend test. This is done to minimize discrepancies in testing.

A6.4 When weldments are given a postweld heat treatment, the temperature and time at temperature are very important. The tensile and yield strengths generally are decreased as postweld heat treatment temperature and time at temperature are increased.

A6.5 Welds made with electrodes of the same classification and the same welding procedure will have significantly different tensile and yield strengths in the as-welded and postweld heat-treated conditions. Comparison of the values for as-welded and postweld heat-treated [1150°F (620°C) for one hour] weld metal will show the following:

A6.5.1 The tensile strength of the postweld heat-treated weld metal will be approximately 5 ksi (34.5 MPa) lower than that of the weld metal in the as-welded condition.

A6.5.2 The yield strength of the postweld heat-treated weld metal will be approximately 10 ksi (69 MPa) lower than that of the weld metal in the as-welded condition.

A6.6 Conversely, postweld heat-treated welds made with the same electrodes and using the same welding procedure except for variation in interpass temperature and postweld heat treatment time can have almost identical tensile and yield strengths. As

an example, almost identical tensile and yield strengths may be obtained in two welds, one using an interpass temperature of 300°F (150°C) and postweld heat-treated for 1 hour at 1150°F (620°C), and the other using an interpass temperature of 200°F (93°C) and postweld heat-treated for 10 hours at 1150°F (620°C).

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. Furthermore, the only differences between the present E60XX and E70XX classifications are the differences in chemical composition and mechanical properties of the weld metal, as shown in Tables 2, 3, and 7. In many applications, electrodes of either E60XX or E70XX classifications may be used.

A6.8 Since the electrodes within a given classification have similar operating characteristics and mechanical properties, the user can limit the study of available electrodes to those within a single classification after determining which classification best suits the 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, a particular characteristic is common to a number of classifications and testing for it is not necessary. In other 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 is included in Appendix A7 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 carbon 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 8 are not necessarily indicative of the average radiographic soundness to be expected in production use. Electrodes of the E6010, E6011, E6019, and E6020 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 E7015, E7016, E7018, and E7018M 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. E6013 electrodes usually produce the best radiographic soundness in welding small, thin parts.

E6027, E7024 and E7028 electrodes produce welds which may be either quite good or rather inferior in radiographic soundness. The tendency seems to be in the latter direction. Of all types, the E6022 and E6012 electrodes generally produce welds with the least favorable radiographic soundness.

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).

A6.10.3 Toughness. Charpy V-notch impact requirements are included in the specification. All classes 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 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 are 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 electrodes may have absorbed excessive moisture, they may be restored 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 A2.

A6.11.4 Cellulosic coverings for E6010 and E6011 electrodes need moisture levels of 3% to 7% for proper operation; therefore, storage or conditioning above ambient temperature may dry them too much and adversely affect their operation (see Table A2).

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

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 the 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 currents 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 diameter without iron powder.

Table A2
Typical Storage and Drying Conditions for Covered Arc Welding Electrodes

AWS Classifications	Storage Conditions ^a		Drying Conditions ^b
	Ambient Air	Holding Ovens	
E6010, E6011	Ambient temperature	Not recommended	Not recommended
E6012, E6013, E6019, E6020, E6022, E6027, E7014, E7024, E7027	80 ± 20°F (30 ± 10°C) 50 percent max relative humidity	20°F (12°C) to 40°F (24°C) above ambient temperature	1 hour at temperature 275 ± 25°F (135 ± 15°C)
E7015, E7016, E7018, E7028, E7018M, E7048	Not Recommended ^c	50°F (30°C) to 250°F (140°C) above ambient temperature	500 to 800°F (260 to 427°C) 1 to 2 hours at temperature

Notes:

a. After removal from manufacturer's packaging.

b. Because of inherent differences in covering composition, the manufacturers should be consulted for the exact drying conditions.

c. 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.

A6.13.2 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 3/32 in. (2.4 mm) or 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 E70XX electrodes were included in this specification to acknowledge the higher strength levels obtained with many of the iron powder and low hydrogen electrodes, as well as to recognize the industry demand for electrodes with 70 ksi (482 MPa) minimum tensile strength. Unlike the E70XX-X classification in ANSI/AWS A5.5, *Specification for Low Alloy Steel Covered Arc Welding Electrodes*, these electrodes do not contain deliberate alloy additions, nor are they required to meet minimum tensile properties after postweld heat treatment.

A6.13.4 E70XX low hydrogen electrodes have mineral coverings which are high in limestone and other ingredients that are low in moisture 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. These underhead cracks occur in the base metal, usually just below the weld bead.

Weld metal cracks also may occur. These usually 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 whenever other electrodes are used on higher carbon or alloy steels. Low hydrogen electrodes are also used to weld high-sulphur and enameling steels. Electrodes with other than low hydrogen coverings give porous welds on high-sulphur steels. With enameling steels, the hydrogen that escapes after welding with other than low hydrogen electrodes produces holes in the enamel.

A6.14 Amperage Ranges Table A3 gives amperage ranges which are satisfactory for most classifications. When welding vertically upward, currents near the lower limit of the range are generally used.

A7. Description and Intended Use of Electrodes

A7.1 E6010 Classification

A7.1.1 E6010 electrodes are characterized by a deeply penetrating, forceful, spray type arc and readily removable, thin, friable slag which may not seem to completely cover the weld bead. Fillet welds usually have a relatively flat weld face and have a rather coarse, unevenly spaced ripple. The coverings are high in cellulose, usually exceeding 30% by weight. The other materials generally used in the covering include titanium dioxide, metallic deoxidizers such as ferromanganese, various types of magnesium or aluminum silicates, and liquid sodium silicate as a binder. Because of their covering composition, these electrodes are generally described as the high-cellulose sodium type.

A7.1.2 These electrodes are recommended for all welding positions, particularly on multiple pass applications in the vertical and overhead welding positions and where welds of good soundness are required. They frequently are selected for joining pipe and generally are capable of welding in the vertical position with either uphill or downhill progression.

A7.1.3 The majority of applications for these electrodes is in joining carbon steel. However, they have been used to advantage on galvanized steel and on some low alloy steels. Typical applications include shipbuilding, buildings, bridges, storage tanks, piping, and pressure vessel fittings. Since the applications are so widespread, a discussion of each is impractical. Sizes larger than 3/16 in. (4.8 mm) generally have limited use in other than flat or horizontal-fillet welding positions.

A7.1.4 These electrodes have been designed for use with dcep (electrode positive). The maximum amperage that can generally be used with the larger sizes of these electrodes is limited in comparison to that for other classifications due to the high spatter loss that occurs with high amperage.

A7.2 E6011 Classification

A7.2.1 E6011 electrodes are designed to be used with ac current and to duplicate the usability characteristics and mechanical properties of the

Table A3
Typical Amperage Ranges

Electrode Diameter	E6010 and E6011		E6012	E6013	E6019	E6020	E6022	E6027 and E7027	E7014	E7015 and E7016	E7018M and E7018	E7024 and E7028	E7048
	in.	mm											
1/16	1.6	—	20 to 40	20 to 40	—	—	—	—	—	—	—	—	—
5/64	2.0	—	25 to 60	25 to 60	35 to 55	—	—	—	—	—	—	—	—
3/32*	2.4*	40 to 80	35 to 85	45 to 90	50 to 90	—	—	—	80 to 125	65 to 110	70 to 100	100 to 145	—
1/8	3.2	75 to 125	80 to 140	80 to 130	80 to 140	100 to 150	110 to 160	125 to 185	110 to 160	100 to 150	115 to 165	140 to 190	80 to 140
5/32	4.0	110 to 170	110 to 190	105 to 180	130 to 190	130 to 190	140 to 190	160 to 240	150 to 210	140 to 200	150 to 220	180 to 250	150 to 220
3/16	4.8	140 to 215	140 to 240	150 to 230	190 to 250	175 to 250	170 to 400	210 to 300	200 to 275	180 to 255	200 to 275	230 to 305	210 to 270
7/32	5.6	170 to 250	200 to 320	210 to 300	240 to 310	225 to 310	370 to 520	250 to 350	260 to 340	240 to 320	260 to 340	275 to 365	—
1/4	6.4	210 to 320	250 to 400	250 to 350	310 to 360	275 to 375	—	300 to 420	330 to 415	300 to 390	315 to 400	335 to 430	—
5/16	8.0	275 to 425	300 to 500	320 to 430	360 to 410	340 to 450	—	375 to 475	390 to 500	375 to 475	375 to 470	400 to 525	—

* This diameter is not manufactured in the E7028 classification.

E6010 classification. Although also usable with dcep (electrode positive), a decrease in joint penetration will be noted when compared to the E6010 electrodes. Arc action, slag, and fillet weld appearance are similar to those of the E6010 electrodes.

A7.2.2 The coverings are also high in cellulose and are described as the high-cellulose potassium type. In addition to the other ingredients normally found in E6010 coverings, small quantities of calcium and potassium compounds usually are present.

A7.2.3 Sizes larger than 3/16 in. (4.8 mm) generally have limited use in other than flat or horizontal-fillet welding positions.

A7.3 E6012 Classification

A7.3.1 E6012 electrodes are characterized by low penetrating arc and dense slag, which completely covers the bead. This may result in incomplete root penetration in fillet welded joints. The coverings are high in titania, usually exceeding 35% by weight, and usually are referred to as the "titania" or "rutile" type. The coverings generally also contain small amounts of cellulose and ferromanganese, and various siliceous materials such as feldspar and clay with sodium silicate as a binder. Also, small amounts of certain calcium compounds may be used to produce satisfactory arc characteristics on dcen (electrode negative).

A7.3.2 Fillet welds tend to have a convex weld face with smooth even ripples in the horizontal welding position, and widely spaced rougher ripples in the vertical welding position which become smoother and more uniform as the size of the weld is increased. Ordinarily, a larger size fillet must be made in the vertical and overhead welding positions using E6012 electrodes compared to welds with E6010 and E6011 electrodes of the same diameter.

A7.3.3 The E6012 electrodes are all-position electrodes and usually are suitable for welding in the vertical welding position with either the upward or downward progression. However, more often the larger sizes are used in the flat and horizontal welding positions rather than in the vertical and overhead welding positions. The larger sizes are often used for single pass, high-speed, high current fillet welds in the horizontal welding position. Their ease

of handling, good fillet weld face, and ability to bridge wide root openings under conditions of poor fit, and to withstand high amperages make them very well suited to this type of work. The electrode size used for vertical and overhead position welding is frequently one size smaller than would be used with an E6010 or E6011 electrode.

A7.3.4 Weld metal from these electrodes is generally lower in ductility and may be higher in yield strength [1 to 2 ksi (690 to 1380 kPa)] than weld metal from the same size of either the E6010 or E6011 electrodes.

A7.4 E6013 Classification

A7.4.1 E6013 electrodes, although very similar to the E6012 electrodes, have distinct differences. Their flux covering makes slag removal easier and gives a smoother arc transfer than E6012 electrodes. This is particularly the case for the small diameters [1/16, 5/64, and 3/32 in. (1.6, 2.0, and 2.4 mm)]. This permits satisfactory operation with lower open-circuit ac voltage. E6013 electrodes were designed specifically for light sheet metal work. However, the larger diameters are used on many of the same applications as E6012 electrodes and provide low penetrating arc. The smaller diameters provide a less penetrating arc than is obtained with E6012 electrodes. This may result in incomplete penetration in fillet welded joints.

A7.4.2 Coverings of E6013 electrodes contain rutile, cellulose, ferromanganese, potassium silicate as a binder, and other siliceous materials. The potassium compounds permit the electrodes to operate with ac at low amperages and low open-circuit voltages.

A7.4.3 E6013 electrodes are similar to the E6012 electrodes in usability characteristics and bead appearance. The arc action tends to be quieter and the bead surface smoother with a finer ripple. The usability characteristics of E6013 electrodes vary slightly from brand to brand. Some are recommended for sheet metal applications where their ability to weld satisfactorily in the vertical welding position with downward progression is an advantage.

Others, with a more fluid slag, are used for horizontal fillet welds and other general purpose welding. These electrodes produce a flat fillet weld face rather than the convex weld face characteristic of

E6012 electrodes. They are also suitable for making groove welds because of their concave weld face and easily removable slag. In addition, the weld metal is definitely free of slag and oxide inclusions than E6012 weld metal and exhibits better soundness. Welds with the smaller diameter E6013 electrodes often meet the Grade 1 radiographic requirements of this specification.

A7.4.4 E6013 electrodes usually cannot withstand the high amperages that can be used with E6012 electrodes in the flat and horizontal welding positions. Amperages in the vertical and overhead positions, however, are similar to those used with E6012 electrodes.

A7.5 E7014 Classification

A7.5.1 E7014 electrode coverings are similar to those of E6012 and E6013 electrodes, but with the addition of iron powder for obtaining higher deposition efficiency. The covering thickness and the amount of iron powder in E7014 are less than in E7024 electrodes (see A7.10).

A7.5.2 The iron powder also permits the use of higher amperages than are used for E6012 and E6013 electrodes. The amount and character of the slag permit E7014 electrodes to be used in all positions.

A7.5.3 The E7014 electrodes are suitable for welding carbon and low alloy steels. Typical weld beads are smooth with fine ripples. Joint penetration is approximately the same as that obtained with E6012 electrodes (see 7.3.1), which is advantageous when welding over a wide root opening due to poor fit. The face of fillet welds tends to be flat to slightly convex. The slag is easy to remove. In many cases, it removes itself.

A7.6 Low Hydrogen Electrodes

A7.6.1 Electrodes of the low hydrogen classifications (E7015, E7016, E7018, E7018M, E7028, and E7048) are made with inorganic coverings that contain minimal moisture. The covering moisture test, as specified in Section 15, Moisture Test, converts hydrogen-bearing compounds in any form in the covering into water vapor that is collected and weighed. The test thus assesses the potential hydrogen available from an electrode covering. All low hydrogen electrodes, in the as-manufactured condi-

tion or after conditioning, are expected to meet a maximum covering moisture limit of 0.6% or less, as required in Table 10.

A7.6.2 The potential for diffusible hydrogen in the weld metal can be assessed more directly, but less conveniently, by the diffusible hydrogen test, as specified in Section 17, Diffusible Hydrogen Test. The results of this test, using electrodes in the as-manufactured condition or after conditioning, permit the addition of an optional supplemental diffusible hydrogen designator to the classification designation according to Table 11. See also A9.2 in this Appendix.

A7.6.3 In order to maintain low hydrogen electrodes with minimal moisture in their coverings, these electrodes should be stored and handled with considerable care. Electrodes which have been exposed to humidity may absorb considerable moisture and their low hydrogen character may be lost. Then conditioning can restore their low hydrogen character. See Table A2.

A7.6.4 Low hydrogen electrode coverings can be designed to resist moisture absorption for a considerable time in a humid environment. The absorbed moisture test (see Section 16, Absorbed Moisture Test), assesses this characteristic by determining the covering moisture after nine hours exposure to 80°F (27°C), 80% relative humidity air. If, after this exposure, the covering moisture does not exceed 0.4%, then the optional supplemental designator, "R", may be added to the electrode classification designation, as specified in Table 10. See also A9.3 in this Appendix.

A7.6.5 E7015 Classification

A7.6.5.1 E7015 electrodes are low hydrogen electrodes to be used with deep (electrode positive). The slag is chemically basic.

A7.6.5.2 E7015 electrodes are commonly used for making small welds on thick base metal, since the welds are less susceptible to cracking (see A6.13.4). They are also used for welding high sulphur and enameling steels. Welds made with E7015 electrodes on high sulphur steels may produce a very tight slag and a very rough or irregular bead appearance in comparison to welds with the same electrodes in steels of normal sulphur content.

A7.6.5.3 The arc of E7015 electrodes is moderately penetrating. The slag is heavy, friable, and easy to remove. The weld face is convex, although a fillet weld face may be flat.

A7.6.5.4 E7015 electrodes up to and including the 5/32 in. (4.0 mm) size are used in all welding positions. Larger electrodes are used for groove welds in the flat welding position and fillet welds in the horizontal and flat welding positions.

A7.6.5.5 Amperages for E7015 electrodes are higher than those used with E6010 electrodes of the same diameter. The shortest possible arc length should be maintained for best results with E7015 electrodes. This reduces the risk of porosity. The necessity for preheating is reduced; therefore, better welding conditions are provided.

A7.6.6 E7016 Classification

A7.6.6.1 E7016 electrodes have all the characteristics of E7015 electrodes, plus the ability to operate on ac. The core wire and coverings are very similar to those of E7015, except for the use of a potassium silicate binder or other potassium salts in the coverings to facilitate their use with ac. Most of the preceding discussion on E7015 electrodes applies equally well to the E7016 electrodes. The discussion in A6.13.4 also applies.

A7.6.6.2 Electrodes designated as E7016-1 have the same usability and weld metal composition as E7016 electrodes except that the manganese content is set at the high end of the range. They are intended for welds requiring a lower transition temperature than is normally available from E7016 electrodes.

A7.6.7 E7018 Classification

A7.6.7.1 E7018 electrode coverings are similar to E7015 coverings, except for the addition of a relatively high percentage of iron powder. The coverings on these electrodes are slightly thicker than those of the E7016 electrodes.

A7.6.7.2 E7018 low hydrogen electrodes can be used with either ac or dcep. They are designed for the same applications as the E7016 electrodes. As is common with all low hydrogen electrodes, a short arc length should be maintained at all times.

A7.6.7.3 In addition to their use on carbon steel, the E7018 electrodes are also used for joints involving high-strength, high carbon, or low alloy steels (see also A6.13). The fillet welds made in the horizontal and flat welding positions have a slightly convex weld face, with a smooth and finely rippled surface. The electrodes are characterized by a smooth, quiet arc, very low spatter, and medium arc penetration. E7018 electrodes can be used at high travel speeds.

A7.6.7.4 Electrodes designated as E7018-1 have the same usability and weld metal composition as E7018 electrodes, except that the manganese content is set at the high end of the range. They are intended for welds requiring a lower transition temperature than is normally available from E7018 electrodes.

A7.6.8 E7018M Electrodes

A7.6.8.1 E7018M electrodes are similar to E7018-1H4R electrodes, except that the testing for mechanical properties and for classification is done on a groove weld that has a 60 degree included angle and, for electrodes up to 5/32 in. (4.0 mm), welded in the vertical position with upward progression. The impact test results are evaluated using all five test values and higher values are required at -20°F (-29°C). The maximum allowable moisture-in-coating values in the "as-received" or reconditioned state are more restrictive than that required for E7018R. This classification closely corresponds to MIL-7018-M in MIL-E-22200/10 specification, with the exception that the absorbed moisture limits on the electrode covering and the diffusible hydrogen limits on the weld metal are not as restrictive as those in MIL-E-22200/10.

A7.6.8.2 E7018M is intended to be used with dcep type current in order to produce the optimum mechanical properties. However, if the manufacturer desires, the electrode may also be classified as E7018 provided all the requirements of E7018 are met.

A7.6.8.3 In addition to their use on carbon steel, the E7018M electrodes are used for joining carbon steel to high strength low alloy steels and higher carbon steels. Fillet welds made in the horizontal and flat welding positions have a slightly convex weld face, with a smooth and finely rippled surface. The electrodes are characterized by a

smooth, quiet arc, very low spatter, and medium arc penetration.

A7.6.9 E7028 Classification

A7.6.9.1 E7028 electrodes are very much like the E7018 electrodes. However, E7028 electrodes are suitable for fillet welds in the horizontal welding position and groove welds in the flat welding position only, whereas E7018 electrodes are suitable for all positions.

A7.6.9.2 The E7028 electrode coverings are much thicker. They make up approximately 50% of the weight of the electrodes. The iron content of E7028 electrodes is higher (approximately 50% of the weight of the coverings). Consequently, on fillet welds in the horizontal position and groove welds in the flat welding position, E7028 electrodes give a higher deposition rate than the E7018 electrodes for a given size of electrode.

A7.6.10 E7048 Classification. Electrodes of the E7048 classification have the same usability, composition, and design characteristics as E7018 electrodes, except that E7048 electrodes are specifically designed for exceptionally good vertical welding with downward progression (see Table 1).

A7.7 E6019 Classification

A7.7.1 E6019 electrodes, although very similar to E6013 and E6020 electrodes in their coverings, have distinct differences. E6019 electrodes, with a rather fluid slag system, provide deeper arc penetration and produce weld metal that meets a 22% minimum elongation requirement, meets the Grade 1 radiographic standards, and has an average impact strength of 20 ft-lb (27J) when tested at 0°F (-18°C).

A7.7.2 E6019 electrodes are suitable for multipass welding of up to 1 in. (25 mm) thick steel. They are designed for use with ac, dcen, or dcep. While 3/16 in. (4.8 mm) and smaller diameter electrodes can be used for all welding positions (except vertical welding position with downward progression), the use of larger diameter electrodes should be limited to the flat or horizontal fillet welding position. When welding in the vertical welding position with upward progression, weaving should be limited to minimize undercut.

A7.8 E6020 Classification

A7.8.1 E6020 electrodes have a high iron oxide covering. They are characterized by a spray type arc, produce a smooth and flat, or slightly concave weld face and have an easily removable slag.

A7.8.2 A low viscosity slag limits their usability to horizontal fillets and flat welding positions. With arc penetration ranging from medium to deep (depending upon welding current), E6020 electrodes are best suited for thicker base metal.

A7.9 E6022 Classification. Electrodes of the E6022 classification are recommended for single pass, high-speed, high current welding of groove welds in the flat welding position, lap joints in the horizontal welding position, and fillet welds on sheet metal. The weld face tends to be more convex and less uniform, especially since the welding speeds are higher.

A7.10 E7024 Classification

A7.10.1 E7024 electrode coverings contain large amounts of iron powder in combination with ingredients similar to those used in E6012 and E6013 electrodes. The coverings on E7024 electrodes are very thick and usually amount to about 50% of the weight of the electrode, resulting in higher deposition efficiency.

A7.10.2 The E7024 electrodes are well suited for making fillet welds in the flat or horizontal position. The weld face is slightly convex to flat, with a very smooth surface and a very fine ripple. These electrodes are characterized by a smooth, quiet arc, very low spatter, and low arc penetration. They can be used with high travel speeds. Electrodes of these classifications can be operated on ac, dcep, or dcen.

A7.10.3 Electrodes designated as E7024-1 have the same general usability characteristics as E7024 electrodes. They are intended for use in situations requiring greater ductility and a lower transition temperature than normally is available from E7024 electrodes.

A7.11 E6027 Classification

A7.11.1 E6027 electrode coverings contain large amounts of iron powder in combination with ingredients similar to those found in E6020 elec-

trodes. The coverings on E6027 electrodes are also very thick and usually amount to about 50% of the weight of the electrode.

A7.11.2 The E6027 electrodes are designed for fillet or groove welds in the flat welding position with ac, dcep, or dcen, and will produce a flat or slightly concave weld face on fillet welds in the horizontal position with either ac or dcen.

A7.11.3 E6027 electrodes have a spray-type arc. They will operate at high travel speeds. Arc penetration is medium. Spatter loss is very low. E6027 electrodes produce a heavy slag which is honeycombed on the underside. The slag is friable and easily removed.

A7.11.4 Welds produced with E6027 electrodes have a flat to slightly concave weld face with a smooth, fine, even ripple, and good wetting along the sides of the joint. The weld metal may be slightly inferior in radiographic soundness to that from E6020 electrodes. High amperages can be used, since a considerable portion of the electrical energy passing through the electrode is used to melt the covering and the iron powder it contains. These electrodes are well suited for thicker base metal.

A7.12 E7027 Classification. E7027 electrodes have the same usability and design characteristics as E6027 electrodes, except they are intended for use in situations requiring slightly higher tensile and yield strengths than are obtained with E6027 electrodes. They must also meet chemical composition requirements (see Table 7). In other respects, all previous discussions for E6027 electrodes also apply to E7027 electrodes.

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 the 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 different carbon and low alloy steels, may need to be conducted.

A9.2 Diffusible Hydrogen Test Hydrogen induced cracking of weld metal and the heat-affected zone generally are not problems with carbon steels containing 0.30%, or less, carbon. Nevertheless, the welding electrodes of the specification are sometimes used to join higher carbon steels or low alloy steels, where hydrogen induced cracking may be a serious problem.

The coating moisture test has proven to be a satis-

factory 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 in the arc can cause cracking.

Since entry of diffusible hydrogen into the weld pool can be affected by the form of the moisture in the coating (for example, chemically bonded versus surface absorbed), there is a fundamental utility for considering diffusible hydrogen for low hydrogen electrodes. 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 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 necessitated 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 conditions 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 (1.43g/kg) of dry air. This corresponds to 70°F (21°C) and 10% RH on a standard psychrometric chart at 29.92 in. Hg (760 mm) barometric pressure. Actual conditions, measured using a sling psychrometer, that equal or exceed this reference condition provide assurance that the condi-

tions 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 16, Absorbed Moisture Test, 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 covering 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 scope of filler metals classified in the specification. These discontinued electrode classifications are listed in Table A4, along with the year they were last published in this specification.

Table A4
Discontinued Electrode Classifications^a

AWS Classification	Last A5.1 (ASTM A-233) Publication Date	AWS Classification	Last A5.1 (ASTM A-233) Publication Date
E4511	1943	E9020	1945
E4521	1943	E9030	1945
E7010 ^b	1945	E10010 ^b	1945
E7011 ^b	1945	E10011 ^b	1945
E7012	1945	E10012	1945
E7020 ^b	1945	E10020	1945
E7030	1945	E10030	1945
E8010 ^b	1945	E4510	1958
E8011 ^b	1945	E4520	1958
E8012	1945	E6014	1958
E8020 ^b	1945	E6015	1958
E8030	1945	E6016	1958
E9010 ^b	1945	E6018	1958
E9011 ^b	1945	E6024	1958
E9012	1945	E6028	1958
		E6030	1958

Notes:

a. See A10 (in the Appendix) for information on discontinued classifications.

b. These electrode classifications were transferred from the ASTM A233-45T to the new AWS A5.5-48T. They were later discontinued from that specification and replaced with the new "G" classifications in order to permit a single classification system with weld metal chemistry requirements in AWS A5.5-58T.

AWS Filler Metal Related Documents

AWS Designation	Title
FMC	Filler Metal Comparison Charts
A4.2	Standard Procedures for Calibrating Magnetic Instruments to Measure the Delta Ferrite Content of Austenitic Stainless Steel Weld Metal
A4.3	Standard Methods for Determination of the Diffusible Hydrogen Content of Martensitic, Bainitic, and Ferritic Steel Weld Metal Produced by Arc Welding
A5.01	Filler Metal Procurement Guidelines
A5.1	Specification for Carbon Steel Electrodes for Shielded Metal Arc Welding
A5.2	Specification for Carbon and Low Alloy Steel Rods for Oxyfuel Gas Welding
A5.3	Specification for Aluminum and Aluminum Alloy Electrodes for Shielded Metal Arc Welding
A5.4	Specification for Covered Corrosion-Resisting Chromium and Chromium-Nickel Steel Welding Electrodes
A5.5	Specification for Low Alloy Steel Covered Arc Welding Electrodes
A5.6	Specification for Covered Copper and Copper Alloy Arc Welding Electrodes
A5.7	Specification for Copper and Copper Alloy Bare Welding Rods and Electrodes
A5.8	Specification for Filler Metals for Brazing
A5.9	Specification for Corrosion-Resisting Chromium and Chromium-Nickel Steel Bare and Composite Metal Cored and Stranded Welding Electrodes and Welding Rods
A5.10	Specification for Bare Aluminum and Aluminum Alloy Welding Electrodes and Rods
A5.11	Specification for Nickel and Nickel Alloy Welding Electrodes for Shielded Metal Arc Welding
A5.12	Specification for Tungsten Arc Welding Electrodes
A5.13	Specification for Solid Surfacing Welding Rods and Electrodes
A5.14	Specification for Nickel and Nickel Alloy Bare Welding Electrodes and Rods
A5.15	Specification for Welding Electrodes and Rods for Cast Iron
A5.16	Specification for Titanium and Titanium Alloy Welding Electrodes and Rods
A5.17	Specification for Carbon Steel Electrodes and Fluxes for Submerged Arc Welding
A5.18	Specification for Carbon Steel Filler Metals for Gas Shielded Arc Welding
A5.19	Specification for Magnesium Alloy Welding Rods and Bare Electrodes
A5.20	Specification for Carbon Steel Electrodes for Flux Cored Arc Welding
A5.21	Specification for Composite Surfacing Welding Rods and Electrodes
A5.22	Specification for Flux Cored Corrosion-Resisting Chromium and Chromium-Nickel Steel Electrodes
A5.23	Specification for Low Alloy Steel Electrodes and Fluxes for Submerged Arc Welding
A5.24	Specification for Zirconium and Zirconium Alloy Welding Electrodes and Rods
A5.25	Specification for Carbon and Low Alloy Steel Electrodes and Fluxes for Electroslag Welding
A5.26	Specification for Carbon and Low Alloy Steel Electrodes for Electrogas Welding
A5.27	Specification for Copper and Copper Alloy Rods for Oxyfuel Gas Welding
A5.28	Specification for Low Alloy Steel Filler Metals for Gas Shielded Arc Welding
A5.29	Specification for Low Alloy Steel Electrodes for Flux Cored Arc Welding
A5.30	Specification for Consumable Inserts

For additional information, contact the Order Department, American Welding Society, 550 N.W. LeJeune Road, P.O. Box 351040, Miami, Florida 33135.