

AWS User's Guide to Filler Metals



American Welding Society



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AWS User's Guide to Filler Metals

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The *AWS User's Guide to Filler Metals* is a collection of commentary information selected from the 30 technical standards written by the AWS Committee on Filler Metal. The User's Guide provides descriptions of specific filler metals and their intended usage, as well as methods for classification, welding procedures, and safety considerations. Although reasonable care has been taken in the compilation and publication of the User's Guide to insure authenticity of the contents, no representation is made as to the accuracy or reliability of this information. The User's Guide is intended solely as a supplement to the *AWS Filler Metal Comparison Charts*, and should not be regarded as a substitute for the various AWS specifications to which it refers. This publication is subject to revision at any time.

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AWS User's Guide to Filler Metals

1. Scope

This document contains information on the many different types of filler materials available to industry. Welding considerations and intended applications for the various materials are provided to assist the user. The information has been extracted directly from 32 AWS filler material standards, and it is recommended that the user reference these documents for additional information.

Part A:

General Information

2. Provisions

Each of the AWS filler material specifications contain sections that establish provisions for material acceptance and certification, as well as safety considerations. Because this information is necessary for the proper application of all filler materials, these sections are included in this guide.

2.1 Acceptance. Acceptance of all welding materials 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 the specification, shall be clearly stated in the purchase order according to the provisions of ANSI/AWS A5.01. In the absence of any such statement in the purchase order, the supplier may ship the material with whatever testing is normally conducted on material of the same classification, as specified in Schedule F, Table 1, of 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.

2.2 Certification. The act of placing the AWS specification and classification designations on the product packaging, or placing 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 tested 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 conducted. 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, *Filler Metal Procurement Guidelines*.

2.3 Standard Sizes, Packaging, and Physical Attributes. Requirements for standard sizes and packages of welding filler metals and their physical attributes, such as product appearance and identification are prescribed in AWS A5.02/A5.02M:2007, *Specification for Filler Metal Standard Sizes, Packaging, and Physical Attributes*. This specification applies to covered electrodes with both solid and tubular core wires; bare solid and tubular wires on spools, coils, and drums, or in straight lengths; and solid and sintered strip electrodes. It applies to all fusion welding processes, except brazing, braze welding, and thermal spraying, or granular metallic or mineral products, such as submerged arc fluxes, or other such products used in fusion welding processes.

The specification makes use of both U.S. Customary Units and the International System of Units (SI). The measurements are not exact equivalents; therefore, each system must be used independently of the other without combining in any way. The specification with the designation A5.02 uses U.S. Customary Units. The specification A5.02M uses SI Units.

2.4 General Safety Considerations. Safety and health issues and concerns are beyond the scope of these standards and, therefore, are not fully addressed herein. Some safety and health information can be found in the following paragraphs. Safety and health information is available from other sources.

2.4.1 Ventilation During Welding. Five major factors govern the quantity of fumes in the atmosphere to which welders and welding operators are exposed during welding; they are:

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

American National Standard Z49.1, *Safety in Welding, Cutting and Allied Processes* (published by the American Welding Society), discusses the ventilation that is required during welding and should be referred to for details. Attention is drawn particularly to the section of that document on health protection and ventilation. See also AWS F3.2 ventilation guide for weld fume, for more detailed descriptions of ventilation options.

The Safety and Health Fact Sheets listed below are published by the AWS. They may be downloaded and printed directly from the AWS website at <http://www.aws.org>. The Safety and Health Fact Sheets are revised and additional sheets added periodically.

2.4.6 AWS Safety and Health Fact Sheets Index (SHF)

No. Title

- 1 *Fumes and Gases*
- 2 *Radiation*
- 3 *Noise*
- 4 *Chromium and Nickel in Welding Fume*
- 5 *Electrical Hazards*
- 6 *Fire and Explosion Prevention*
- 7 *Burn Protection*
- 8 *Mechanical Hazards*
- 9 *Tripping and Falling*
- 10 *Falling Objects*
- 11 *Confined Spaces*
- 12 *Contact Lens Wear*
- 13 *Ergonomics in the Welding Environment*
- 14 *Graphic Symbols for Precautionary Labels*
- 15 *Style Guidelines for Safety and Health Documents*
- 16 *Pacemakers and Welding*
- 17 *Electric and Magnetic Fields (EMF)*
- 18 *Lockout/Tagout*

- 19 *Laser Welding and Cutting Safety*
- 20 *Thermal Spraying Safety*
- 21 *Resistance Spot Welding*
- 22 *Cadmium Exposure from Welding & Allied Processes*
- 23 *California Proposition 65*
- 24 *Fluxes for Arc Welding and Brazing: Safe Handling and Use*
- 25 *Metal Fume Fever*
- 26 *Arc Viewing Distance*
- 27 *Thoriated Tungsten Electrodes*
- 28 *Oxyfuel Safety: Check Valves and Flashback Arrestors*
- 29 *Grounding of Portable and Vehicle Mounted Welding Generators*
- 30 *Cylinders: Safe Storage, Handling, and Use*
- 31 *Eye and Face Protection for Welding and Cutting Operations*
- 33 *Personal Protective Equipment (PPE) for Welding & Cutting*
- 34 *Coated Steels: Welding and Cutting Safety Coneans*
- 36 *Ventilation for Welding & Cutting*
- 37 *Selecting Gloves for Welding & Cutting*

AWS documents are published by the American Welding Society, 550 N.W. LeJeune Road, Miami, FL 33126.

Part B:

Carbon and Low-Alloy Steels

3. Guide to Classification of Carbon and Low-Alloy Steel Rods for Oxyfuel Gas Welding

3.1 Provisions. Excerpts from AWS A5.2/A5.2M:2007, *Specification for Carbon and Low-Alloy Steel Rods for Oxyfuel Gas Welding*.

3.2 Introduction. The purpose of this guide is to correlate the rod classifications with their intended applications so that the specification can be used effectively. Appropriate base metal specifications are referred to whenever that can be done and when it would be helpful. Such correlations are intended only as examples rather than complete listings of the materials for which each filler metal is suitable.

3.3 Classification System

3.3.1 The system for identifying the rod classifications in this specification follows the standard pattern used in other AWS filler metal specifications. The prefix “R [RM]” designates a rod. For A5.2, the numbers (45, 60, 65, and 100) indicate the required minimum tensile strength, as a multiple of 1000 psi, of the weld metal in a test weld made in accordance with specification A5.2. Similarly, for A5.2M, the numbers [30, 40, 45, and 69] indicate the required minimum tensile strength, as a multiple of 10 MPa, of the weld metal in a test weld made in accordance with specification A5.2M.

3.3.2 “G” Classification. This specification includes filler metals classified as R(X)XX-G [RMXX-G]. The “G” indicates that the filler metal is of a *general* classification. It is general because not all of the particular requirements specified for each of the other classifications are specified for this classification. The intent in establishing this classification is to provide a means by which filler metals that differ in one respect or another (chemical composition, for example) from

all other classifications (meaning that the composition of the filler metal, in the case of the example, does not meet the composition specified for any of the classifications in the specification) can still be classified according to the specification. The purpose is to allow a useful filler metal—one that otherwise would have to await a revision of the specification—to be classified immediately under the existing specification. This means, then, that two filler metals, each bearing the same “G” classification, may be quite different in some certain respect (chemical composition, again, for example).

3.4 Welding Considerations

3.4.1 The oxyfuel gas supplied to the torch should be adjusted to give a neutral or slightly reducing flame. This assures the absence of the oxidizing flame that could adversely influence weld quality. The extent of the excess fuel gas is measured by the length of the streamer (the so-called feather) of unburned fuel gas visible at the extremity of the inner cone. This streamer should measure about 1/8 to 1/4 the length of the inner cone of the flame. Excessively long streamers should be avoided, since they may add carbon to the weld metal.

3.4.2 In forehand welding, the torch flame points ahead in the direction of welding, and the welding rod precedes the torch flame. To distribute the heat and molten weld metal, it is necessary to use opposing oscillating motions for the flame and welding rod. This may cause excessive melting of the base metal and mixing of base metal and weld metal. Weld-metal properties may be altered.

3.4.3 In backhand welding, the torch flame points back at the molten metal, and the welding rod is interposed between the flame and molten metal. There is significantly less manipulation of the flame, the welding rod, and the molten metal. Therefore, a backhand weld is more likely to approach the chemical composition of undiluted weld metal.

3.5 Description and Intended Use of Carbon and Low-Alloy Steel Rods

3.5.1 Oxyfuel gas welding rods have no coverings to influence usability of the rod. Thus, the ability to weld in the vertical or overhead position is essentially a matter of welder’s skill and can be affected to some degree by the chemical composition of the rod.

3.5.2 Class R45 [RM30] welding rods are used for the oxyfuel gas welding of steels, where the minimum tensile strength requirement of the steel does not exceed 45 ksi [300 MPa]. Class R45 [RM30] rods have a low carbon steel composition.

3.5.3 Class R60 [RM40] welding rods are used for the oxyfuel gas welding of carbon steels, where the minimum tensile strength requirement of the steel does not exceed 60 ksi [400 MPa]. Class R60 [RM40] rods have a carbon steel composition.

3.5.4 Class R65 [RM45] welding rods are used for the oxyfuel gas welding of carbon and low-alloy steels, where the minimum tensile strength requirement of the steel does not exceed 65 ksi [450 MPa]. Class R65 [RM45] welding rods may have either a low-alloy or an unalloyed carbon steel composition.

3.5.5 Class R100 [RM69] welding rods are used for the oxyfuel gas welding of low-alloy steels, where the minimum tensile strength requirement of the steel does not (AWS A5.2/A5.2M:2007) exceed 100 ksi [690 MPa] in the as-welded condition. Users are cautioned that response of the weld metal and base metal to postweld heat treatment may be different.

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

4.1 Provisions. Excerpts from ANSI/AWS A5.1/A5.1M:2004, *Specification for Carbon Steel Electrodes for Shielded Metal Arc Welding*.

4.2 Introduction. The purpose of this guide is to correlate the electrode classifications with their intended applications so that the specification can be used effectively. Appropriate base metal specifications are referred to whenever that can be done and when it would be most helpful. Such references are intended only as examples rather than complete listings of the base metals for which each electrode classification is suitable.

4.3 Classification System

4.3.1 The system for identifying the electrode classifications in this specification follows the standard pattern used in other AWS filler metal specifications. The prefix letter “E” at the beginning of each classification designation stands for

electrode. The first two digits, 60 [43], for example, designate tensile strength of at least 60 ksi [430 MPa] of the weld metal, produced in accordance with the test assembly preparation section of the specification. In this document, the classification in U.S. Customary Units is followed by the SI Unit classification in brackets. The third digit designates position usability that will allow satisfactory welds to be produced with the electrode. Thus, the “1,” as in E6010 [E4310], means that the electrode is usable in all positions (flat, horizontal, vertical, and overhead). The “2,” as in E6020 [E4320] designates that the electrode is suitable for use in the flat position and for making fillet welds in the horizontal position. The “4,” as in E7048 [E4948], designates that the electrode is suitable for use in vertical welding with downward progression and for other positions (see Table 4.1). 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 4.1.

4.3.2 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. An example of this is the E7024-1 [E4924-1] electrode which meets the classification requirements of E7024 [E4924] and also meets the optional supplemental requirements for toughness and improved elongation of the weld metal. Certain low-hydrogen electrodes may also have optional designators. An optional supplemental designator “HZ” following the four digit classification designators or following the “-1” optional supplemental

Table 4.1
Electrode Classification

AWS Classification		Type of Covering	Welding Position ^a	Type of Current ^b
A5.1	A5.1M			
E6010	E4310	High cellulose sodium	F, V, OH, H	dcep
E6011	E4311	High cellulose potassium	F, V, OH, H	ac or dcep
E6012	E4312	High titania sodium	F, V, OH, H	ac or dcen
E6013	E4313	High titania potassium	F, V, OH, H	ac, dcep, or dcen
E6018 ^c	E4318 ^c	Low-hydrogen potassium, iron powder	F, V, OH, H	ac or dcep
E6019	E4319	Iron oxide titania potassium	F, V, OH, H	ac, dcep, or dcen
E6020	E4320	High iron oxide	H-fillet	ac or dcen
			F	ac, dcep, or dcen
E6022 ^d	E4322 ^d	High iron oxide	F, H-fillet	ac or dcen
E6027	E4327	High iron oxide, iron powder	H-fillet	ac or dcen
			F	ac, dcep, or dcen
E7014	E4914	Iron powder, titania	F, V, OH, H	ac, dcep, or dcen
E7015	E4915	Low-hydrogen sodium	F, V, OH, H	dcep
E7016 ^c	E4916 ^c	Low-hydrogen potassium	F, V, OH, H	ac or dcep
E7018 ^c	E4918 ^c	Low-hydrogen potassium, iron powder	F, V, OH, H	ac or dcep
E7018M	E4918M	Low-hydrogen iron powder	F, V, OH, H	dcep
E7024 ^c	E4924 ^c	Iron powder, titania	H-fillet, F	ac, dcep, or dcen
E7027	E4927	High iron oxide, iron powder	H-fillet	ac or dcen
			F	ac, dcep, or dcen
E7028 ^c	E4928 ^c	Low-hydrogen potassium, iron powder	H-fillet, F	ac or dcep
E7048	E4948	Low-hydrogen potassium, iron powder	F, OH, H, V-down	ac or dcep

Notes:

^a The abbreviations, F, H, H-fillet, V, V-down, and OH indicate the welding positions as follows: F = Flat, H = Horizontal, H-fillet = Horizontal fillet, V = Vertical, progression upward (for electrodes 3/16 in [5.0 mm] and under, except 5/32 in [4.0 mm] and under for classifications E6018 [E4318], E7014 [E4914], E7015 [E4915], E7016 [E4916], E7018 [E4918], E7018M [E4918M], E7048 [E4948]). V-down = Vertical, progression downward (for electrodes 3/16 in [5.0 mm] and under, except 5/32 in [4.0 mm] and under for classifications E6018 [E4318], E7014 [E4914], E7015 [E4915], E7016 [E4916], E7018 [E4918], E7018M [E4918M], E7048 [E4948]), OH = Overhead (for electrodes 3/16 in [5.0 mm] and under, except 5/32 in [4.0 mm] and under for classifications E6018 [E4318], E7014 [E4914], E7015 [E4915], E7016 [E4916], E7018 [E4918], E7018M [E4918M], E7048 [E4948]).

^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 with supplemental elongation, notch toughness, absorbed moisture, and diffusible hydrogen requirements may be further identified as shown in Tables 2, 3, 10, and 11.

^d Electrodes of the E6022 [E4322] classification are intended for single-pass welds only.

designator, if used, indicates an average diffusible hydrogen content of not more than “Z” mL/100 g of deposited metal when tested in the “as-received” or conditioned state in accordance with AWS A4.3, *Standard Methods for Determination of the 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 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. A letter “R” is a designator used with the low-hydrogen electrode classifications. It 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.

4.4 Welding Considerations

4.4.1 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.

4.4.2 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.

4.4.3 Hydrogen is another factor to be considered in welding. Weld metals, other than those from low-hydrogen electrodes (E7015 [E4915], E7016 [E4916], E7018 [E4918], E7018M [E4918M], E7028 [E4928], and E7048 [E4948]), contain significant quantities of hydrogen for some period of time after they have been made. After two to four weeks at room temperature or 24 to 48 hours at 200°F to 220°F [90°C to 105°C], most of the hydrogen escapes. As a result of this change in hydrogen content, ductility of the weld metal increases toward its inherent value, while yield, tensile, and impact strengths remain relatively unchanged.

4.4.4 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.

4.4.5 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:

4.4.5.1 The tensile strength of the postweld heat-treated weld metal will be approximately 5 ksi [35 MPa] lower than that of the weld metal in the as-welded condition.

4.4.5.2 The yield strength of the postweld heat-treated weld metal will be approximately 10 ksi [70 MPa] lower than that of the weld metal in the as-welded condition.

4.4.6 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 212°F [100°C] and postweld heat-treated for 10 hours at 1150°F [620°C].

4.4.7 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 [E43XX and E49XX] classifications are the differences in chemical composition and mechanical properties of the weld metal. In many applications, electrodes of either E60XX or E70XX [E43XX or E49XX] classifications may be used.

4.4.8 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.

4.4.9 Electrode Covering Moisture Content and Conditioning

4.4.9.1 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.

4.4.9.2 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.

4.4.9.3 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 4.2.

4.4.9.4 Cellulosic coverings for E6010 [E4310] and E6011 [E4311] electrodes need moisture levels of approximately 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 4.2.)

4.4.10 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.

4.4.11 Coverings

4.4.11.1 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.

4.4.11.2 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 or 1/8 in [2.5 mm or 3.2 mm] electrodes are to be used in other than flat or horizontal fillet welding positions or for making groove welds.

4.4.11.3 The E70XX [E49XX] 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

Table 4.2
Typical Storage and Drying Conditions for Covered Arc Welding Electrodes

AWS Classification		Storage Conditions ^{a,b}		
A5.1	A5.1M	Ambient Air	Holding Ovens	Drying Conditions ^c
E6010, E6011	E4310, E4311	Ambient Temperature	Not recommended	Not recommended
E6012, E6013, E6019, E6020, E6022, E6027, E7014, E7024, E7027	E4312, E4313, E4319, E4320, E4322, E4327, E4914, E4924, E4927	80°F ± 20°F [30°C ± 10°C] 50 percent max relative humidity	20°F to 40°F [10°C to 20°C] above ambient temperature	275°F ± 25°F [135°C ± 15°C] 1 hour at temperature
E6018, E7015, E7016, E7018, E7028, E7018M, E7048	E4318, E4915 E4916, E4918, E4928, E4918M, E4948	Not recommended	50°F to 250°F [30°C to 140°C] above ambient temperature	500°F to 800°F [260°C to 425°C] 1 to 2 hours at temperature

^a After removal from manufacturer's packaging.

^b 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.

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

for electrodes with 70 ksi [490 MPa] minimum tensile strength. Unlike the E70XX-X [E 49XX-X] classification in AWS A5.5, *Specification for Low-Alloy Steel Electrodes for Shielded Metal Arc Welding*, these electrodes do not contain deliberate alloy additions, nor are they required to meet minimum tensile properties after postweld heat treatment.

4.4.11.4 E70XX [E49XX] low-hydrogen electrodes have mineral coverings which are high in limestone and other ingredients that are low in moisture and hence produce weld deposits “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 under bead cracks occur in the base metal, usually just below the weld bead. Weld-metal cracks may also occur. Low-hydrogen electrodes should be used when welding high-sulfur or enameling steels. Other electrodes are likely to cause porosity and/or cracks in high-sulfur steels. With enameling steels, the hydrogen that escapes after welding with other than low-hydrogen electrodes produces holes in the enamel.

4.4.12 Amperage Ranges. Table 4.3 gives amperage ranges which are satisfactory for most classifications.

4.5 Description and Intended Use of Electrodes

4.5.1 E6010 [E4310] Classification

4.5.1.1 E6010 [E4310] 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.

4.5.1.2 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.

4.5.1.3 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 [5.0 mm] generally have limited use in other than flat or horizontal-fillet welding positions.

4.5.1.4 These electrodes have been designed for use with dcep (direct current, 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.

4.5.2 E6011 [E4311] Classification

4.5.2.1 E6011 [E4311] electrodes are designed to be used with ac current and to duplicate the usability characteristics and mechanical properties of the E6010 [E4310] classification. Although also usable with dcep, a decrease in joint penetration will be noted when compared to the E6010 [E4310] electrodes. Arc action, slag, and fillet weld appearance are similar to those of the E6010 [E4310] electrodes.

4.5.2.2 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 [E4310] coverings, small quantities of calcium and potassium compounds usually are present.

4.5.2.3 Sizes larger than 3/16 in [5.0 mm] generally have limited use in other than flat or horizontal-fillet welding positions.

4.5.3 E6012 [E4312] Classification

4.5.3.1 E6012 [E4312] 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 (direct current, electrode negative).

Table 4.3
Typical Amperage Ranges

Electrode Diameter	A5.1	E6010, E6011	E6012	E6013	E6019	E6020	E6022	E6027, E7027	E7014	E6018, E7015, E7016	E7018M, E7018	E7024, E7028	E7048
A5.1 (in)	A5.1M (mm)	E4310, E4311	E4312	E4313	E4319	E4320	E4322	E4327, E4927	E4914	E4915, E4916	E4918M, E4918	E4924, E4928	E4948
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 ^a	2.4 ^a , 2.5 ^a	40 to 80	35 to 85	45 to 90	50 to 90	—	—	—	80 to 125	65 to 110	70 to 110	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	105 to 155	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	130 to 200	180 to 250	150 to 220
3/16	5.0	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	6.0	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	—

^a This diameter is not manufactured in the E7028 [E4828] classification.

4.5.3.2 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 [E4312] electrodes compared to welds with E6010 [E4310] and E6011 [E4311] electrodes of the same diameter.

4.5.3.3 The E6012 [E4312] 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 [E4310] or E6011 [E4311] electrode.

4.5.3.4 Weld metal from these electrodes is generally lower in ductility and may be higher in yield strength (1 ksi to 2 ksi [0.7 MPa to 1.4 MPa]) than weld metal from the same size of either the E6010 [E4310] or E6011 [E4311] electrodes.

4.5.4 E6013 [E4313] Classification

4.5.4.1 E6013 [E4313] electrodes, although very similar to the E6012 [E4312] electrodes, have distinct differences. Their flux covering makes slag removal easier and gives a smoother arc transfer than E6012 [E4312] electrodes. This is particularly the case for the small diameters 1/16, 5/64, and 3/32 in [1.6 mm, 2.0 mm, and 2.5 mm]. This permits satisfactory operation with lower open-circuit ac voltage. E6013 [E4313] electrodes were designed specifically for light sheet metal work. However, the larger diameters are used on many of the same applications as E6012 [E4312] electrodes and provide low penetrating arc. The smaller diameters provide a less penetrating arc than is obtained with E6012 [E4312] electrodes. This may result in incomplete penetration in fillet welded joints.

4.5.4.2 Coverings of E6013 [E4313] 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.

4.5.4.3 E6013 [E4313] electrodes are similar to the E6012 [E4312] 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 [E4313] 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 [E4312] 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 freer of slag and oxide inclusions than E6012 [E4312] weld metal and exhibits better soundness. Welds with the smaller diameter E6013 [E4313] electrodes often meet the Grade 1 radiographic requirements of this specification.

4.5.4.4 E6013 [E4313] electrodes usually cannot withstand the high amperages that can be used with E6012 [E4312] electrodes in the flat and horizontal welding positions. Amperages in the vertical and overhead positions, however, are similar to those used with E6012 [E4312] electrodes.

4.5.5 E7014 [E4914] Classification

4.5.5.1 E7014 [E4914] electrode coverings are similar to those of E6012 [E4312] and E6013 [E4313] electrodes, but with the addition of iron powder for obtaining higher deposition efficiency. The covering thickness and the amount of iron powder in E7014 [E4914] are less than in E7024 [E4924] electrodes (see 4.5.10).

4.5.5.2 The iron powder also permits the use of higher amperages than are used for E6012 [E4312] and E6013 [E4313] electrodes. The amount and character of the slag permit E7014 [E4914] electrodes to be used in all positions.

4.5.5.3 The E7014 [E4914] 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 [E4312] electrodes (see 4.5.3.1), 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.

4.5.6 Low-Hydrogen Electrodes

4.5.6.1 Electrodes of the low-hydrogen classifications E6018 [E4318], E7015 [E4915], E7016 [E4916], E7018 [E4918], E7018M [E4918M], E7028 [E4928], and E7048 [E4948] are made with inorganic coverings that contain minimal moisture. The covering moisture test such as that specified in AWS A4.4M, *Standard Procedure for Determination of Moisture Content of Welding Fluxes and Welding Electrode Flux Coverings*, converts hydrogen-bearing compounds in any form in the covering into water vapor that is collected and measured. The test thus assesses the potential hydrogen available from an electrode covering. All low-hydrogen electrodes, in the as-manufactured condition or after conditioning, are expected to meet a maximum covering moisture limit of 0.6% or less, as required in Table 4.4.

4.5.6.2 The relative potential of an electrode to contribute to diffusible hydrogen in the weld metal can be assessed more directly, but less conveniently, by the 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.

4.5.6.3 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.

4.5.6.4 Low-hydrogen electrode coverings can be designed to resist moisture absorption for a considerable time in a humid environment. The absorbed moisture test see assesses this characteristic by determining the covering moisture after nine hours of exposure at 80°F [27°C] and 80% relative humidity in 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.

4.5.6.5 E7015 [E4915] Classification

4.5.6.5.1 E7015 [E4915] electrodes are low-hydrogen electrodes to be used with dcep. The slag is chemically basic.

4.5.6.5.2 E7015 [E4915] electrodes are commonly used for making small welds on thick base metal, since the welds are less susceptible to cracking. They are also used for welding high-sulfur and enameling steels. Welds made with E7015 [E4915] electrodes on high-sulfur 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 sulfur content.

Table 4.4
Moisture Content Limits in Electrode Coverings

AWS Classification		Electrode Designation		Limit of Moisture Content, % by Wt, Max	
A5.1	A5.1M	A5.1	A5.1M	As-Received or Conditioned ^a	As-Exposed ^b
E6018	E4318	E6018	E4318	0.6	Not Specified
E7015	E4915	E7015	E4915		
E7016	E4916	E7016	E4916		
E7018	E4918	E7016-1	E4916-1		
		E7018	E4918		
		E7018-1	E4918-1		
E7028	E4928	E7028	E4928	0.3	0.4
E7048	E4948	E7048	E4948		
E6018	E4318	E6018R	E4318R		
E7015	E4915	E7015R	E4915R		
E7016	E4916	E7016R	E4916R		
E7018	E4918	E7016-1R	E4916-1R		
		E7018R	E4918R		
		E7018-1R	E4918-1R		
E7028	E4928	E7028R	E4928R	0.1	0.4
E7048	E4948	E7048R	E4948R		
E7018M	E4918M	E7018M	E4918M		

^a As-received or conditioned electrode coverings shall be tested as specified in Section 16, Moisture Test.

^b As-exposed electrode coverings shall have been exposed to a moist environment as specified in Section 17 before being tested as specified in Section 16.

4.5.6.5.3 The arc of E7015 [E4915] 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.

4.5.6.5.4 E7015 [E4915] 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.

4.5.6.5.5 Amperages for E7015 [E4915] electrodes are higher than those used with E6010 [E4310] electrodes of the same diameter. The shortest possible arc length should be maintained for best results with E7015 [E4915] electrodes. This reduces the risk of porosity. The necessity for preheating is reduced; therefore, better welding conditions are provided.

4.5.6.6 E7016 [E4916] Classification

4.5.6.6.1 E7016 [E4916] electrodes have all the characteristics of E7015 [E4915] electrodes, plus the ability to operate on ac. The core wire and coverings are very similar to those of E7015 [E4915], 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 [E4915] electrodes applies equally well to the E7016 [E4916] electrodes. The discussion in 4.4.11.4 also applies.

4.5.6.6.2 Electrodes designated as E7016-1 [E4916-1] have the same usability and weld-metal composition as E7016 [E4916] 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 [E4916] electrodes.

4.5.6.7 E6018 [E4318] and E7018 [E4918] Classifications

4.5.6.7.1 E7018 [E4918] electrode coverings are similar to E7015 [E4915] 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 [E4916] electrodes.

4.5.6.7.2 E7018 [E4918] low-hydrogen electrodes can be used with either ac or dcep. They are designed for the same applications as the E7016 [E4916] electrodes. As is common with all low-hydrogen electrodes, a short arc length should be maintained at all times.

4.5.6.7.3 In addition to their use on carbon steel, the E7018 [E4918] electrodes are also used for joints involving high-strength, high-carbon, or low-alloy steels (see also 4.4.11). 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 [E4918] electrodes can be used at high travel speeds.

4.5.6.7.4 Electrodes designated as E7018-1 [E4918-1] have the same usability and weld-metal composition as E7018 [E4918] 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 [E4918] electrodes.

4.5.6.7.5 E6018 [E4318] electrodes possess operating and mechanical property characteristics similar to E7018 [E4918] except at a lower strength level. The electrode coating and low hydrogen characteristics are also similar. This electrode is desirable where matching or under matching weld deposit is required. Electrodes that meet this classification may also be suitable for buffer layer application in cladding operations.

4.5.6.8 E7018M [E4918M] Classification

4.5.6.8.1 E7018M [E4918M] electrodes are similar to E7018-1H4R [E4918-1H4R] 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 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 [-30°C]. The maximum allowable moisture-in-coating values in the “as-received” or reconditioned state are more restrictive than that required for E7018R [E4918R]. This classification closely corresponds to MIL-7018-M in the United States military standard 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.

4.5.6.8.2 E7018M [E4918M] 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 [E4918] provided all the requirements of E7018 [E4918] are met.

4.5.6.8.3 In addition to their use on carbon steel, the E7018M [E4918M] 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.

4.5.6.9 E7028 [E4928] Classification

4.5.6.9.1 E7028 [E4928] electrodes are very much like the E7018 [E4918] electrodes. However, E7028 [E4928] electrodes are suitable for fillet welds in the horizontal welding position and groove welds in the flat welding position only, whereas E7018 [E4918] electrodes are suitable for all positions.

4.5.6.9.2 The E7028 [E4928] electrode coverings are much thicker. They make up approximately 50% of the weight of the electrodes. The iron content of E7028 [E4928] 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 [E4928] electrodes give a higher deposition rate than the E7018 [E4918] electrodes for a given size of electrode.

4.5.6.10 E7048 [E4948] Classification. Electrodes of the E7048 [E4948] classification have the same usability, composition, and design characteristics as E7018 [E4918] electrodes, except that E7048 [E4948] electrodes are specifically designed for exceptionally good vertical welding with downward progression (see Table 4.1).

4.5.7 E6019 [E4319] Classification

4.5.7.1 E6019 [E4319] electrodes, although very similar to E6013 and E6020 [E4313 and E4320] electrodes in their coverings, have distinct differences. E6019 [E4319] electrodes, with a rather fluid slag system, provide deeper arc penetration and produce weld metal that meets a 22-percent minimum elongation requirement, meets the Grade 1 radiographic standards, and has an average impact strength of 20 ft-lbf (27J) when tested at 0°F [−20°C].

4.5.7.2 E6019 [E4319] 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 [5.0 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.

4.5.8 E6020 [E4320] Classification

4.5.8.1 E6020 [E4320] 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.

4.5.8.2 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 [E4320] electrodes are best suited for thicker base metal.

4.5.9 E6022 [E4322] Classification. Electrodes of the E6022 [E4322] 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.

4.5.10 E7024 [E4924] Classification

4.5.10.1 E7024 [E4924] electrode coverings contain large amounts of iron powder in combination with ingredients similar to those used in E6012 and E6013 [E4312 and E4313] electrodes. The coverings on E7024 [E4924] electrodes are very thick and usually amount to about 50% of the weight of the electrode, resulting in higher deposition efficiency.

4.5.10.2 The E7024 [E4924] 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.

4.5.10.3 Electrodes designated as E7024-1 [E4924-1] have the same general usability characteristics as E7024 [E4924] electrodes. They are intended for use in situations requiring greater ductility and a lower transition temperature than normally is available from E7024 [E4924] electrodes.

4.5.11 E6027 [E4327] Classification

4.5.11.1 E6027 [E4327] electrode coverings contain large amounts of iron powder in combination with ingredients similar to those found in E6020 [E4320] electrodes. The coverings on E6027 [E4327] electrodes are also very thick and usually amount to about 50% of the weight of the electrode.

4.5.11.2 The E6027 [E4327] 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.

4.5.11.3 E6027 [E4327] electrodes have a spray-type arc. They will operate at high travel speeds. Arc penetration is medium. Spatter loss is very low. These electrodes produce a heavy slag, which is honeycombed on the underside. The slag is friable and easily removed.

4.5.11.4 Welds produced with E6027 [E4327] 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 [E4320] 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.

4.5.12 E7027 [E4927] Classification. E7027 [E4927] electrodes have the same usability and design characteristics as E6027 [E4327] electrodes, except they are intended for use in situations requiring slightly higher tensile and yield strengths than are obtained with E6027 [E4327] electrodes. They must also meet chemical composition requirements. In other respects, all previous discussions for E6027 [E4327] electrodes also apply to E7027 [E4927] electrodes.

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

5.1 Provisions. Excerpts from AWS A5.5/A5.5M:2006, *Specification for Low-Alloy Steel Electrodes for Shielded Metal Arc Welding*.

5.2 Introduction. The purpose of this guide is to correlate the electrode classifications with their intended applications so that the specification can be used effectively. Appropriate base metal specifications are referred to whenever that can be done and when it would be helpful. Such references are intended as examples rather than complete listings of the base metals for which each filler metal is suitable.

5.3 Classification System

5.3.1 The system for identifying the electrode classification in this specification follows the standard pattern used in other AWS filler metal specifications. The prefix letter “E” at the beginning of each classification stands for electrode. The first two (or three) digits, 70 (or 110) [49 (or 76)], for example, designate tensile strength of at least 70 (or 110) ksi [490 (or 760) MPa] of the weld metal, welded and postweld heat-treated (if required) in accordance with the test assembly preparation section of this specification. The third (or fourth) digit designates position usability that will allow satisfactory welds to be produced with the electrode. Thus, the “1,” as in E7018-C2L (or E11018M) [E4918-C2L (or E7618M)], means that the electrode is usable in all positions (flat, horizontal, vertical, and overhead). The “2,” as in E7020-A1 [E4920-A1], designates that the electrode is suitable for use in the flat position and for making fillet welds in the horizontal position. The “4,” as in E8045-P2 [E5545-P2], designates that the electrode is usable in the flat, horizontal, and overhead positions, and is especially suitable for vertical welding with downward progression. 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. With the exception of the military similar electrodes [e.g., E(X)XX18M(1)], the classifications in this specification also include a suffix designator, separated by a hyphen from the tensile strength and usability designators.

This composition designator, such as A1, B3, or W1, immediately identifies the classification as different from those in AWS A5.1/A5.1M, *Specification for Carbon Steel Electrodes for Shielded Metal Arc Welding*. This composition designator identifies the chemical composition of the weld metal. For example, an “A1” composition designator identifies the electrode as one that produces carbon-molybdenum steel weld metal, when the electrode is deposited using shielded metal arc welding.

5.3.2 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 purchaser. Certain low-hydrogen electrodes may have optional designators. An optional supplemental designator “HZ” following the composition designator indicates an average diffusible hydrogen content of not more than “Z” mL/100 g of deposited metal when tested in the “as-received” or conditioned state in accordance with AWS A4.3. Electrodes that are designated as meeting the lower or lowest hydrogen limits 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. The letter “R” is a designator used with the low-hydrogen electrode classifications. It 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.

5.3.3 “G” Classification

5.3.3.1 This specification includes filler metals classified as E(X)XXXX-G. The “G” indicates that the filler metal is of a *general* classification. It is *general* because not all of the particular requirements specified for each of the other classifications are specified for this classification. The intent, in establishing this classification, is to provide a means by which filler metals that differ in one respect or another (chemical composition, for example) from all other classifications (meaning that the composition of the filler metal—in the case of the example—does not meet the composition specified for any of the classifications in the specification) can still be classified according to the specification. The purpose is to allow a useful filler metal, one that otherwise would have to await a revision of the specification, to be classified immediately, under the existing specification. This means, then, that two filler metals, each bearing the same “G” classification, may be quite different in some certain respect (chemical composition, again, for example).

5.4 Welding Considerations

5.4.1 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 that would represent good welding practice and minimize variation of the most potent of these variables.

5.4.2 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.

5.4.3 Hydrogen is another factor to be considered in welding. Weld metals, other than those from low-hydrogen electrodes [E(X)XX15-X, E(X)XX16-X, E(X)XX18-X, E(X)XX18M(1), and E(X)XX45-P2], contain significant quantities of hydrogen for some period of time after they have been made. After two to four weeks at room temperature or in 24 to 48 hours at 200°F to 220°F [95°C to 105°C], most of the hydrogen escapes. As a result of this change in hydrogen content, ductility of the weld metal increases toward its inherent value, while yield, tensile, and impact strengths remain relatively unchanged. This specification permits aging of the test specimens of cellulosic electrodes at 200°F to 220°F [95°C to 105°C] for 48 hours before subjecting them to tension testing. This is done to minimize discrepancies in testing. Aging treatments are sometimes used for low-hydrogen electrodes, especially when testing high-strength deposits. Note that aging may involve holding test specimens at room temperature for several days or holding at a higher temperature for a shorter period of time. Consequently, users are cautioned to employ adequate preheat and interpass temperatures to avoid the deleterious effects of hydrogen in production welds.

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

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

5.4.6 Preheat and interpass minimum temperatures also have a significant effect on the strength levels attained with certain low-alloy steel weld metals. These weld metals are affected by rapid cooling rates, which tend to produce more martensitic or bainitic microstructures. These microstructures will often exhibit higher yield and tensile strengths with a decrease in ductility. The cooling rate can be retarded by utilizing a higher preheat and interpass temperature. The preheat and interpass temperature ranges of this specification are adequate for the preparation of the test assemblies. However, in actual production, users are encouraged to test their own procedures to verify that they have selected preheat and interpass temperatures which will produce desirable results in production.

5.4.7 Heat input usually is measured as Joules per linear inch, J/in [kJ/mm]. Heat input will have a significant effect on the strength levels attained in many of the higher strength weld metals produced from the electrode classifications in this specification. For instance, weld metal produced with E11018M [E7618M] electrode at a 35 000 J/in [1.38 kJ/mm] heat input rate may exceed 110 ksi [760 MPa] yield strength in the as-welded condition and 95 ksi [655 MPa] yield strength after postweld heat treatment. On the other hand, if the heat input is raised to 55 000 J/in [2.17 kJ/mm], this same electrode will produce weld metal that does not exceed 110 ksi [760 MPa] yield strength in the as-welded condition and may be below 95 ksi [655 MPa] yield strength after postweld heat treatment. It is, therefore, recommended that, if the user is going to use either lower or higher heat inputs than normally used for classification testing of electrodes, the user should test the welding procedure to be used to determine that the strength levels expected will be attained in production. This is especially true if out-of-position welding is to be performed.

5.4.8 Electrodes that meet all the requirements of any given classification may be expected to have similar characteristics (the “G” classifications notwithstanding). Certain minor differences continue to exist from one brand to another due to differences in preferences that exist regarding specific operating characteristics.

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

5.4.10 Core Wire. The core wire for all the electrodes in this specification is usually (but not always) a mild steel having a typical composition which may differ significantly from that of the weld metal produced by the covered electrode.

5.4.11 Coverings

5.4.11.1 Electrodes of some classifications have substantial quantities of iron and other metal powders added to their coverings. (Use of the term “iron powder” herein is intended to include metal powders added to the coating for alloying of the weld metal. For example, quite large quantities of chromium and ferrochromium powders can be added in such alloy designations as B7, B8, and B9.)

The iron powder fuses with the core wire as the electrode melts, and is deposited as part of the weld metal, just as is the core wire and other metals in the covering. 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.

5.4.11.2 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 [2.5 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.

5.4.11.3 The E70XX-X [E49XX-X] electrodes were included in this specification to recognize the lowest strength levels obtained with low-alloy steel electrodes, as well as to recognize the industry demand for low-alloy electrodes with 70 ksi [490 MPa] minimum tensile strength. Unlike the E70XX [E49XX] classifications in AWS

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

5.4.11.4 Low-hydrogen electrodes have mineral coverings, which are high in calcium carbonate and other ingredients that are low in moisture and organic materials and hence “low in hydrogen content.” Low-hydrogen electrodes were developed for welding low-alloy, high-strength steels, some of which were high in carbon content. Electrodes with other than low-hydrogen coverings may produce “hydrogen-induced cracking” in those steels. These under bead cracks occur in the base metal, usually just below the weld bead. Weld cracks also may occur. These cracks are caused by the hydrogen absorbed from the arc atmosphere. Although these cracks do not generally occur in carbon steels which have low carbon content, they may occur when welding higher carbon or low-alloy steels with other than low-hydrogen electrodes and without precautions, such as increased preheat temperatures and postweld heating. Some extra-low hydrogen (H4) electrode coverings may be prone to reduced operability and producing unacceptable porosity. The unacceptable condition is usually associated with varying or excessive arc length and highly dependent on operator skill level.

5.4.12 Amperage Ranges. Table 5.1 gives amperage ranges which are satisfactory for most electrode classifications. When welding in the vertical position with upward progression, currents near the lower limit of the range are generally used.

5.5 Description and Intended Use of Electrodes

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

(In the specification, detailed weld metal chemical composition requirements for each electrode classification are provided. This specification lists the mechanical properties of the weld metal when the electrode is used in the flat downhand position, and the weldment is subjected to the postweld heat treatment (PWHT) requirements. It should be noted that changes in welding position, welding variables, or heat treatment can be expected to affect the mechanical properties. However, except for the effects of dilution, the chemical composition can be expected to remain reasonably unchanged. The suffixes, which are part of each alloy electrode classification, identify the chemical composition of the weld metal produced by the electrode.)

The following paragraphs highlight the differences between these electrodes and electrode groups and indicate typical applications.

5.5.1.1 E70XX-A1 [E49XX-A1] (C-Mo Steel) Electrodes. These electrodes are similar to the E70XX [E49XX] carbon steel electrodes classified in AWS A5.1/A5.1M, except that 1/2% molybdenum has been added. This addition increases the strength of the weld metal, especially at elevated temperatures, and provides some increase in corrosion

Table 5.1
Typical Amperage Ranges

Electrode Diameter		E(X)XX10-X and E(X)XX11-X		E7020-X [E4920-X]		E(X)XX15-X and E(X)XX16-X		E(X)XX18M(1) and E(X)XX18-X		E(X)XX45-P2	
in.	mm		E(X)XX13-G		E7027-X [E4927-X]						
3/32	2.5	40 to 80	45 to 90	—	—	65 to 110	70 to 100	80 to 110			
1/8	3.2	75 to 125	80 to 130	100 to 150	125 to 185	100 to 150	115 to 155	125 to 160			
5/32	4.0	110 to 170	105 to 180	130 to 190	160 to 240	140 to 200	135 to 185	170 to 215			
—	4.5	—	—	—	—	—	—	180 to 240			
3/16	5.0	140 to 215	150 to 230	175 to 250	210 to 300	180 to 255	200 to 275	—			
7/32	—	170 to 250	—	225 to 310	250 to 350	240 to 320	260 to 340	—			
1/4	6.0	210 to 320	—	275 to 375	300 to 420	300 to 390	315 to 400	—			
5/16	8.0	—	—	—	375 to 475	—	—	—			

resistance; however, it may reduce the notch toughness of the weld metal. Typical applications include the welding of C-Mo steel base metals such as ASTM A 204 plate and A 335-P1 pipe.

5.5.1.2 EXXXX-BX and EXXXX-BXL (Cr-Mo Steel) Electrodes. These low-hydrogen electrodes produce weld metal that contains between 1/2% and 9% chromium and between 1/2% and 1% molybdenum. They are designed to produce weld metal for high-temperature service and for matching the properties of the typical Cr-Mo base metals. For many of these Cr-Mo electrode classifications, low carbon EXXXX-BXL classifications have been established. While regular Cr-Mo electrodes produce weld metal with about 0.08% carbon, the “L-Grades” are limited to a maximum of 0.05% carbon. While the lower percent carbon in the weld metal will improve ductility and lower hardness, it will also reduce the high-temperature strength and creep resistance of the weld metal. Since all Cr-Mo electrodes produce weld metal which will harden in still air, both preheat and PWHT are required for most applications. No minimum notch toughness requirements have been established for any of the Cr-Mo electrode classifications. While it is possible to obtain Cr-Mo electrodes with minimum toughness values at ambient temperatures down to 32°F [0°C], specific values and testing must be agreed to by the supplier and the purchaser.

5.5.1.2.1 E70XX-B2L [E49XX-B2L] and E80XX-B3L [E55XX-B3L] Electrodes. In AWS A5.5-81, and previous revisions, electrodes classified as E70XX-B2L [E49XX-B2L] were classified as E80XX-B2L [E55XX-B2L]. Likewise, electrodes herein classified as E80XX-B3L [E55XX-B3L] were classified as E90XX-B3L [E62XX-B3L]. The composition ranges in AWS A5.5-96, or the present edition, have not been changed from A5.5-81 for the corresponding classifications. The strength designations and room-temperature strength requirements after postweld heat treatment have been reduced to reflect the fact that commercial products have been producing marginal tensile strength results in classification tests over many years. The base metals with which these classifications are generally used have lower strength requirements than were reflected by the former electrode classifications. Therefore, unless the higher strength indicated by the former classifications of these electrodes is specifically necessary for a particular welding procedure, the E70XX-B2L [E49XX-B2L] classifications in this standard should be considered as identical to the corresponding E80XX-B2L [E55XX-B2L] classifications of A5.5-81. Likewise, the E80XX-B3L [E55XX-B3L] classifications in this standard should be considered as identical to the E90XX-B3L [E62XX-B3L] classifications of A5.5-81.

5.5.1.2.2 E90XX-B9 [E62XX-B9] Electrodes. E90XX-B9 [E62XX-B9] is a 9% Cr to 1% Mo, low-hydrogen electrode modified with niobium (columbium) and vanadium, designed to provide improved creep strength, toughness, fatigue life, and oxidation and corrosion resistance at elevated temperatures. Due to the higher elevated temperature properties of this alloy, components that are now fabricated from stainless and ferritic steels may be fabricated from a single alloy, eliminating problems associated with dissimilar welds. In addition to the classification requirements in this specification, impact toughness or high temperature creep strength properties may be determined. Due to the influence of various levels of carbon and niobium (columbium), testing must be agreed to by the supplier and purchaser.

Thermal treatment of this alloy is critical and must be closely controlled. The temperature at which the microstructure has complete transformation to martensite (Mf) is relatively low. For applications requiring optimal ductility and creep resistance, consideration should be given to allowing the weldment to cool sufficiently to maximize transformation to martensite. The maximum allowable temperature for postweld heat treatment is also critical in that the lower transformation temperature (Ac1) is also comparably low. To aid in allowing for an adequate postweld heat treatment, the restriction on Mn + Ni has been imposed. The combination of Mn and Ni tends to lower the Ac1 temperature to the point where the PWHT temperature approaches the Ac1, possibly causing partial transformation of the microstructure. By restricting the Mn + Ni, the PWHT temperature will be sufficiently below the Ac1 to avoid this partial transformation.

5.5.1.3 EXXXX-CX and EXXXX-CXL (Ni Steel) Electrodes. These low-hydrogen electrodes have been designed to produce weld metal with increased strength without being air-hardenable or with increased notch toughness at temperatures as low as -175°F [-115°C]. They have been specified with nickel contents which fall into five nominal levels of 1% Ni, 1½% Ni, 2½% Ni, 3½% Ni, and 6½% Ni in steel. With carbon levels of up to 0.12%, strength increases and permits these Ni steel electrodes to be classified as E80XX-CX [E55XX-CX]. However, with lower levels of carbon, low-temperature toughness improves to match the base-metal properties of nickel steels, such as ASTM A 203 Gr. E, ASTM A 352 LC3 and LC4 classifications. Thus, the intended application and the needed mechanical properties determine whether or not “L-Grades” should be selected. Many low-alloy steels require postweld heat treatment to stress relieve the weld or temper the weld metal and heat-affected zone to achieve increased ductility. It is often acceptable to exceed the PWHT holding temperatures shown in the specification. However, for many applications, nickel steel weld metal can be used without postweld heat treatment. If PWHT is to be specified for a nickel steel weldment, the holding

temperature should not exceed the maximum temperature given in the specification for the classification considered since nickel steels can be embrittled at higher temperatures.

5.5.1.4 E8018-NM1 [E5518-NM1] (Ni-Mo-Steel) Electrodes. This low-hydrogen electrode, which contains about 1% nickel and 1/2% molybdenum, is similar to the Mn–Mo steel electrodes discussed in 5.5.1.5. However, this electrode can often be welded without PWHT, but the resulting strength and notch toughness are lower than the values obtained with Mn–Mo electrodes. Some typical applications include the welding of high-strength, low-alloy or microalloyed structural steels.

5.5.1.5 E(X)XX1X-DX [EXX1X-DX] (Mn-Mo-Steel) Electrodes. These low-hydrogen electrodes produce weld metal that contains about 1½% manganese and between 1/3% and 2/3% molybdenum. This weld metal provides higher strength and better notch toughness than the C–1/2% Mo and 1% Ni–1/2% Mo steel weld metal discussed in 5.5.1.1 and 5.5.1.4. However, the weld metal from these Mn–Mo steel electrodes is quite air-hardenable and usually requires preheat and PWHT. The individual electrodes classified under this electrode group have been designed to match the mechanical properties and corrosion resistance of the high-strength, low-alloy pressure vessel steels, such as ASTM A 302 Gr. B.

5.5.1.6 E(X)XXXX-G (General Low-Alloy Steel) Electrodes. These electrodes are described in 5.3. These electrode classifications may be either modifications of other discrete classifications or totally new classifications. Purchaser and user should determine from the supplier what the description and intended use of the electrode is.

5.5.1.7 E(X)XXXXM(1) (Military Similar) Electrodes. These low-hydrogen electrodes were originally designed for military applications such as welding HY80 and HY100 type steels. To achieve desired weld-metal properties and soundness, these electrodes have small alloy additions (especially some Ni) and require careful control of moisture in the electrode covering. It is important that moisture levels in the coating be maintained during electrode manufacture, packaging, transport, and site storage. These electrodes are usually employed without subsequent postweld heat-treatment. However, hydrogen release treatments at lower temperatures, typically less than 500°F [260°C], are often applied. In the as-welded condition, the weld-metal mechanical properties include ultimate tensile strength minima ranging from 90 to 120 ksi [620 to 830 MPa] and good notch toughness at temperatures ranging from 0°F to –60°F [–20°C to –50°C]. With these properties, the E(X)XXXXM(1) type electrodes are suitable for joining many high-strength, low-alloy or microalloyed steels to themselves or to lower strength steels, including carbon steels.

5.5.1.8 EXX10-P1 (Pipeline) Electrodes. These electrodes have been designed primarily for welding typical high-strength pipe butt joints in the vertical welding position with downward or upward progression. With their cellulosic coverings, they produce deep penetrating, spray-type welding arcs and thin, easily removable slag. This combination is best suited for achieving full penetration and radiographic quality for the downhill welding of butt joints when the axis of the pipe is in the horizontal position. While weld metals produced from these electrodes do not have any minimum chemical composition requirements, the supplier must provide sufficient alloying elements to meet the increased mechanical property requirements. Special emphasis must be placed upon the minimum yield strength values, since most transmission pipeline materials and systems are designed to yield strength limits. Typical application for E7010-P1 [E4910-P1], E8010-P1 [E5510-P1], and E9010-P1 [E6210-P1] electrodes is the welding of API-5L-X52, API-5L-X65, and API-5L-X70 piping assemblies, respectively.

5.5.1.9 EXX18-P2 Pipe Welding Electrodes: These electrodes have been designed primarily for the welding of the hot, fill, and cap passes in high-strength pipe butt joints in the vertical position, in upward progression. Some electrodes of these classifications may also be used on fillet welds with downward progression. The low hydrogen nature of the covering of these electrodes makes them especially suited for joining crack-sensitive high-strength pipe. Typical application for electrodes of these classifications are the welding of API 5L pipe steels up to and including Grade X80, along with many other high strength, medium and high carbon, and low-alloy steels. Electrodes of these classifications are normally not recommended for the root pass (stringer bead) on open gaps.

5.5.1.10 E(X)XX45-P2 Pipe Welding Electrodes. These electrodes have specifically been designed for the welding of hot, fill, and cap passes in high-strength pipe butt joints using vertical downward progression. This classification is not recommended for welding with vertical upward progression. While specifically designed for butt welds, electrodes of these classifications can often be used on fillet welds with downward progression, such as repair welding when attaching pipe sleeves. The low hydrogen nature of the covering of these electrodes makes them especially suited for downhill welding of butt joints on crack sensitive high strength pipe when the axis of the pipe is horizontal. Typical application for electrodes of these classifications are the welding of API 5L pipe steels using the appropriate strength level electrode, along with many other high strength, medium and high carbon, and low-alloy steels. Electrodes of these classifications are normally not recommended for the root pass (stringer bead) on open gaps.

5.5.1.11 EXX18-WX (Weathering Steel) Electrodes. These low-hydrogen electrodes have been designed to produce weld metal that matches the corrosion resistance and the coloring of the ASTM weathering-type structural steels. These special properties are achieved by the addition of about 1/2% copper to the weld metal. To meet strength, ductility, and notch toughness in the weld metal, some chromium and nickel additions are also made. These electrodes are used to weld the typical weathering steels, such as ASTM A 242 and A 588.

6. Guide to AWS Specification for Carbon Steel Electrodes and Rods for Gas Shielded Arc Welding

6.1 Provisions. Excerpts from AWS A5.18/A5.18M:2005, *Specification for Carbon Steel Electrodes and Rods for Gas Shielded Arc Welding*.

6.2 Introduction. The purpose of this guide is to correlate the electrode and rod classifications with their intended applications so that the specification can be used effectively. Reference to appropriate base metal specifications is made whenever that can be done and when it would be helpful. Such references are intended only as examples rather than complete listings of the materials for which each filler metal is suitable.

6.3 Classification System

6.3.1 The system for identifying the electrode classifications in this specification follows the standard pattern used in other AWS filler metal specifications as shown in Figure 6.1.

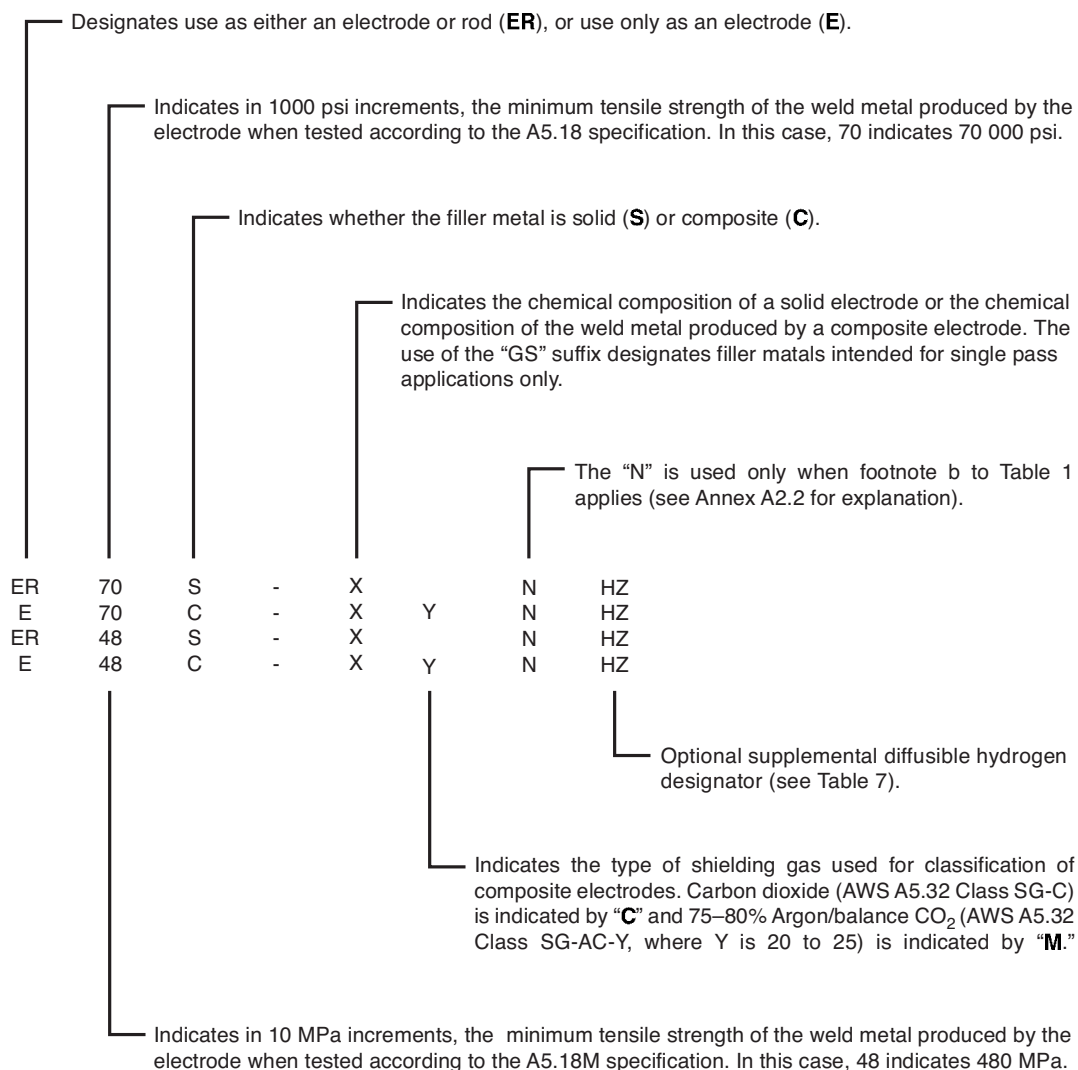
6.3.2 The prefix “E” designates an electrode as in other specifications. The letters “ER” indicate that the filler metal may be used either as an electrode or a rod. For A5.18, the number 70 indicates the required minimum tensile strength, as a multiple of 1000 psi, of the weld metal in a test weld made in accordance with specification A5.18. Similarly, for A5.18M, the number 48 indicates the required minimum tensile strength, as a multiple of 10 MPa, of the weld metal in a test weld made in accordance with specification A5.18M. The letter “S” designates a solid electrode or rod. The letter “C” designates a composite electrode. The digit following the hyphen, 2, 3, 4, 6, 7, G, or GS, indicates the chemical composition and/or impact testing requirements specified in the specification. In the case of some composite stranded and metal-cored electrodes, the letter “M” or “C” will follow, indicating the type of shielding gas. The addition of the letter “N” as a suffix to a classification indicates that the electrode is intended for certain very special welds in nuclear applications. These welds are found in the core belt region of the reactor vessel.

This region is subject to intense neutron radiation, and it is necessary, therefore, that the phosphorus, vanadium, and copper contents of the weld metal be limited in order to resist neutron radiation-induced embrittlement. It is also necessary that the weld metal has a high upper shelf energy level in order to withstand some embrittlement, yet remain serviceable over the years. Optional designators are also used in this specification in order to identify electrodes and rods that have met mandatory classification requirements and certain supplementary requirements as agreed to between the supplier and purchaser. An optional supplemental diffusible hydrogen designator (H16, H8, or H4) may follow the classification designation, indicating whether the electrode will meet a maximum hydrogen level of 16, 8, or 4 mL/100 g of deposited metal when tested as outlined in AWS A4.3. Electrodes that are designated as meeting the lower or lowest hydrogen limits are also understood to be able to meet any higher hydrogen limits without necessarily being designated as such.

6.3.3 “G” Classification. This specification includes filler metals classified as ER70S-G [ER48S-G], E70C-G [E48C-G], and E70C-GS [E48C-GS]. The “G” (multiple pass) or “GS” (single pass) indicates that the filler metal is of a “general” classification. It is general because not all of the particular requirements specified for each of the other classifications are specified for this classification. The intent in establishing these classifications is to provide a means by which filler metals that differ in one respect or another (chemical composition, for example) from all other classifications (meaning that the composition of the filler metal, in the case of the example, does not meet the composition specified for any of the classifications in the specification) can still be classified according to the specification. The purpose is to allow a useful filler metal—one that otherwise would have to await a revision of the specification—to be classified immediately under the existing specification. This means, then, that two filler metals, each bearing the same “G” classification, may be quite different in some particular respect (chemical composition, again, for example).

6.4 Welding Considerations

6.4.1 Gas metal arc welding (GMAW) can be divided into three categories based on the mode of metal transfer. These modes are (1) spray (conventional or pulsed), (2) globular, and (3) short circuiting transfer. In the spray, pulsed spray, and globular



Source: MODIFIED FIGURE A1 OF AWS A5.18/A5.18M:2005

Figure 6.1—Classification System

modes, transfer occurs as distinct droplets that are detached from the electrode, transferring along the arc column into the weld pool. In the short circuiting mode, the metal is deposited during frequent short circuiting of the electrode in the molten pool.

6.4.2 Spray Transfer

6.4.2.1 The spray transfer mode, for carbon steel, is most commonly obtained with argon shielding gas mixtures with up to 5% of oxygen (AWS A5.32 Class SG-AO-X, where X is 1 to 5) or up to 15% carbon dioxide (AWS A5.32 Class SG-AC-Y, where Y is 5 to 15). A characteristic of this shielding gas is the smooth arc plasma through which hundreds of very fine droplets are transferred to the weld pool each second.

6.4.2.2 Spray transfer with argon–oxygen (AWS A5.32 Class SG-AO-X) or argon–carbon dioxide (AWS A5.32 Class SG-AC-Y) shielding gas is, primarily, a function of current density, polarity, and resistance heating of the electrode. The high droplet rate (approximately 250 droplets per second) develops suddenly above a critical current level, commonly referred to as the transition current (for each size of electrode). Below this current, the metal is transferred in drops generally larger in diameter than the electrode and at a rate of from 10 to 20 per second (globular transfer). The transition current is also dependent, to some extent, on the chemical composition of the electrode. For 1/16 in [1.6 mm]

diameter carbon steel electrodes, a transition current of 270 amperes [direct current, electrode positive (dcep)] is common. Alternating current is not recommended for this type of welding because it does not produce a stable arc.

6.4.2.3 Pulsed Spray. Metal transfer in pulsed spray welding is similar to that of the spray transfer described above, but it occurs at a lower average current. The lower average current is made possible by rapid pulsing of the welding current between a high level, where metal will transfer rapidly in the spray mode, and a low level, where no transfer will take place. At a typical rate of 60 to 120 pulses per second, a melted drop is formed by the low current arc, which is then “squeezed off” by the high current pulse. This permits all-position welding.

6.4.3 Globular Transfer. The mode of transfer that characterizes 100% CO₂ (AWS A5.32 Class SG-C) as a shielding gas is globular. Common practice with globular transfer is to use low arc voltage to minimize spatter. This shortens the arc length causing the arc to be “buried” and results in deeper penetration and better containment of spatter within the weld pool. Electrodes of 0.045 in through 1/16 in [1.2 mm through 1.6 mm] diameter normally are used at welding currents in the range of 275 to 400 amperes (dcep), for this type of transfer. The rate at which droplets (globules) are transferred ranges from 20 to 70 per second, depending on the size of the electrode, the amperage, polarity, and arc voltage.

6.4.4 Short Circuiting Transfer. This mode of transfer is obtained with small diameter electrodes 0.030 to 0.045 in [0.8 to 1.2 mm] using low arc voltages and amperages, and a power source designed for short circuiting transfer. The electrode short-circuits to the weld metal, usually at a rate of from 50 to 200 times per second. Metal is transferred with each short circuit, but not across the arc. Short circuiting GMAW of carbon steel is done most commonly with mixtures of argon and CO₂ (AWS A5.32 Class SG-AC-Y) as the shielding gas or with CO₂ (AWS A5.32 Class SG-C) alone. The penetration of such welds is greater with CO₂ than it is with argon–CO₂ mixtures. Mixtures of 50 to 80% argon with CO₂ remainder (AWS A5.32 Class SG-AC-Y, where Y is 20 to 50) can be advantageous for thin material. However shielding gas mixtures of 50 to 70% argon with CO₂ remainder (AWS A5.32 Class SG-AC-Y, where Y is 30 to 50) are unstable in the gaseous state and must be mixed from single gas components immediately prior to use. They provide low penetration, higher short circuiting rates, and lower minimum currents and voltages than CO₂ alone does. This can be an advantage in welding thin plate.

6.5 Description and Intended Use of Electrodes and Rods

6.5.1 ER70S-2 [ER48S-2]. Electrodes and rods of the ER70S-2 [ER48S-2] classification are primarily used for single-pass welding of killed, semi-killed, and rimmed steels, but may be used for some multipass applications. Because of the added deoxidants, these filler metals can be used for welding steels that have a rusty or dirty surface, with a possible sacrifice of weld quality depending on the condition of the surface. ER70S-2 [ER48S-2] filler metals are used extensively to produce high quality, high toughness welds with the GTAW process. These filler metals are also well suited for use in single side, melt through welding without a protective root shielding gas on the backside of the joint. Typical specifications for these steels are ASTM A 36, A 285-C, A 515-55, and A 516-70, which have UNS numbers K02600, K02801, K02001, and K02700, respectively.

6.5.2 ER70S-3 [ER48S-3]. Electrodes and rods of the ER70S-3 [ER48S-3] classification are intended for welding single-pass and multipass welds. Typical base metal specifications are often the same as those for the ER70S-2 [ER48S-2] classification. Electrodes of the ER70S-3 [ER48S-3] classification are the most widely used of the GMAW electrodes classified under this specification.

6.5.3 ER70S-4 [ER48S-4]. Electrodes and rods of the ER70S-4 [ER48S-4] classification are intended for welding steel where conditions require more deoxidation than is provided by the ER70S-3 [ER48S-3] filler metal. Typical base metal specifications are often the same as those for the ER70S-2 [ER48S-2] classification. This classification does not require impact testing.

6.5.4 ER70S-6 [ER48S-6]. Electrodes and rods of the ER70S-6 [ER48S-6] classification are intended for both single- and multiple-pass welding. They are especially suited for sheet metal applications, where smooth weld beads are desired, and structural and plate steels that have moderate amounts of rust or mill scale. These electrodes permit the use of higher current ranges with either AWS A5.18/A5.18M:2005 CO₂ (AWS A5.32 Class SG-C) shielding gas or with mixtures of argon and oxygen (AWS A5.32 Class SG-AO-X) or argon and carbon dioxide (AWS A5.32 Class SG-AC-Y). However, these electrodes do require a higher level of oxidation than the previously described electrodes when using either binary or ternary argon shielding gas mixtures per the AWS A5.32 specification. Typical base metal specifications are often the same as those for the ER70S-2 [ER48S-2] classification.

6.5.5 ER70S-7 [ER48S-7]. Electrodes and rods of the ER70S-7 [ER48S-7] classification are intended for single- and multiple-pass welding. They may permit welding with higher travel speeds compared with ER70S-3 filler metals. They also provide somewhat better wetting action and bead appearance when compared with those filler metals. These

electrodes permit the use of higher current ranges with either CO₂ (AWS A5.32 Class SG-C) shielding gas or with mixtures of argon and oxygen (AWS A5.32 Class SG-AO-X) or argon and carbon dioxide (AWS A5.32 Class SG-AC-Y). However, these electrodes do require a higher level of oxidation (more CO₂ or O₂) like the previously described electrode when using either binary or ternary argon shielding gas mixtures per the AWS A5.32 specification. Typical base metal specifications are often the same as those for the ER70S-2 [ER48S-2] classifications.

6.5.6 ER70S-G [ER48S-G] and E70C-G [E48C-G]. Electrodes and rods of the ER70S-G [ER48S-G] and electrodes of the E70C-G [E48C-G] classifications are those filler metals not included in the preceding classes and for which only certain mechanical property requirements are specified. Electrodes of the E70C-G [E48C-G] classification may be classified with either CO₂ (AWS A5.32 Class SG-C) or 75 to 80% Ar/balance CO₂ (AWS A5.32 Class SG-AC-Y, where Y is 20 to 25) as shown by the “C” or “M” suffix. Absence of the C or M suffix means that the shielding gas used for testing was not one of the above AWS classes and the electrode manufacturer should be consulted for the recommended shielding gas to be used. The electrodes are intended for both single- and multiple-pass applications. The filler metal supplier should be consulted for the composition, properties, characteristics, and intended use of these classifications (see A2.3 for further information).

6.5.7 E70C-GS [E48C-GS]. Electrodes of the E70C-GS [E48C-GS] classification are composite stranded or metal cored electrodes intended for only single-pass applications. The electrodes may be classified with either CO₂ (AWS A5.32 Class SG-C) or 75 to 80% Ar/balance CO₂ (AWS A5.32 Class SG-AC-Y, where Y is 20 to 25) as shown by the “C” or “M” suffix. Absence of the C or M suffix means that the shielding gas used for testing was not one of the above AWS classes and the electrode manufacturer should be consulted for the recommended shielding gas to be used. The filler metal supplier should be consulted for the properties, characteristics, and intended use of these classifications. These electrodes may have higher alloy contents which improve single-pass applications (such as tolerance to mill scale, etc.) but could preclude their use on multiple-pass applications due to higher alloy recovery.

6.5.8 E70C-3 [E48C-3] and E70C-6 [E48C-6]. Electrodes of the E70C-3 [E48C-3] and E70C-6 [E48C-6] classifications are composite stranded or metal cored electrodes intended for both single- and multiple-pass applications. They are characterized by a spray arc and excellent bead wash characteristics. The electrodes may be classified with either CO₂ (AWS A5.32 Class SG-C) or 75 to 80% Ar/balance CO₂ (AWS A5.32 Class SG-AC-Y, where Y is 20 to 25) as shown by the “C” or “M” suffix. Classification E70C-3 [E48C-3] requires impacts at 0°F [–20°C] while E70C-6 [E48C-6] requires impacts at –20°F [–30°C].

7. Guide to AWS Specification for Low-Alloy Steel Electrodes and Rods for Gas Shielded Arc Welding

7.1 Provisions. Excerpts from AWS A5.28/A5.28M:2005, *Specification for Low-Alloy Steel Electrodes and Rods for Gas Shielded Arc Welding*.

7.2 Introduction. The purpose of this guide is to correlate the electrode and rod classifications with their intended applications so that the specification can be used effectively. Reference to appropriate base metal specifications is made whenever that can be done and when it would be helpful. Such references are intended only as examples rather than complete listings of the materials for which each filler metal is suitable.

7.3 Classification System

7.3.1 The system for identifying the electrode classifications in this specification follows the standard pattern used in other AWS filler metal specifications.

7.3.2 The prefix “E” designates an electrode as in other specifications. The letters “ER” indicate that the filler metal may be used either as an electrode or a rod. For A5.28, the number 70, for example, indicates the required minimum tensile strength, as a multiple of 1000 psi, of the weld metal in a test weld made in accordance with specification A5.28. Similarly, for A5.28M, the number 49, for example, indicates the required minimum tensile strength, as a multiple of 10 MPa, of the weld metal in a test weld made in accordance with specification A5.28M. The letter “S” designates a solid electrode or rod. The letter “C” designates a composite electrode. The suffix following the hyphen indicates the chemical composition of the filler metal itself, in the case of solid electrodes and rods, or the weld metal under certain specified test conditions, in the case of composite stranded or metal cored electrodes. Optional designators are also used in this specification in order to identify electrodes and rods that have met mandatory classification requirements and certain supplementary requirements as agreed to between the supplier and purchaser. An optional supplemental diffusible

hydrogen designator (H16, H8, H4, or H2) may follow the classification designation, indicating whether the electrode will meet a maximum hydrogen level of 16, 8, 4, or 2 ml/100 g of weld metal when tested as outlined in AWS A4.3. Electrodes that are designated as meeting the lower or lowest hydrogen limits are also understood to be able to meet any higher hydrogen limits without necessarily being designated as such.

7.3.3 “G” Classification. These specifications include filler metals classified as ER80S-G [ER55S-G], E80C-G [E55C-G], etc. The letter “G” indicates that the filler metal is of a “general” classification. It is general because not all of the particular requirements specified for each of the other classifications are specified for this classification. The intent in establishing these classifications is to provide a means by which filler metals that differ in one respect or another (chemical composition, for example) from all other classifications (meaning that the composition of the filler metal, in the case of the example, does not meet the composition specified for any of the classifications in the specification) can still be classified according to the specification. The purpose is to allow a useful filler metal—one that otherwise would have to await a revision of the specification—to be classified immediately under the existing specification. This means, then, that two filler metals, each bearing the same “G” classification, may be quite different in some particular respect (chemical composition, again, for example).

7.4 Welding Considerations

7.4.1 Gas metal arc welding (GMAW) can be divided into three categories based on the mode of metal transfer. These modes are (1) spray (conventional or pulsed), (2) globular, and (3) short circuiting transfer. In the spray, pulsed spray, and globular modes, transfer occurs as distinct droplets that are detached from the electrode, transferring along the arc column into the weld pool. In the short circuiting mode, the metal is deposited during frequent short circuiting of the electrode in the molten pool.

7.4.2 Spray Transfer

7.4.2.1 The spray transfer mode, for carbon steel, is most commonly obtained with argon shielding gas mixtures with up to 5% of oxygen (AWS A5.32 Class SG-AO-X, where X is 1 to 5) or up to 15% carbon dioxide (AWS A5.32 Class SG-AC-Y, where Y is 5 to 15). A characteristic of these shielding gas mixtures is the smooth arc plasma through which hundreds of very fine droplets are transferred to the weld pool each second.

7.4.2.2 Spray transfer with argon–oxygen (AWS A5.32 Class SG-AO-X) or argon–carbon dioxide (AWS A5.32 Class SG-AC-Y) shielding gas is, primarily, a function of current density, polarity, and resistance heating of the electrode. The high droplet rate (approximately 250 droplets per second) develops suddenly above a critical current level, commonly referred to as the transition current (for each size of electrode). Below this current, the metal is transferred in drops generally larger in diameter than the electrode and at a rate of from 10 to 20 per second (globular transfer). The transition current is also dependent, to some extent, on the chemical composition of the electrode. For 1/16 in [1.6 mm] diameter carbon steel electrodes, a transition current of 270 amperes [direct current, electrode positive (dcep)] is common. Alternating current is not recommended for this type of welding because it does not produce a stable arc.

7.4.2.3 Pulsed Spray. Metal transfer in pulsed spray welding is similar to that of the spray transfer described above, but it occurs at a lower average current. The lower average current is made possible by rapid pulsing of the welding current between a high level, where metal will transfer rapidly in the spray mode, and a low level, where no transfer will take place. At a typical rate of 60 to 120 pulses per second, a melted drop is formed by the low current arc, which is then “squeezed off” by the high current pulse. This permits all-position welding.

7.4.3 Globular Transfer. The mode of transfer that characterizes 100% CO₂ (AWS A5.32 Class SG-C) as a shielding gas is globular. Common practice with globular transfer is to use low arc voltage to minimize spatter. This shortens the arc length causing the arc to be “buried” and results in deeper penetration and better containment of spatter within the weld pool. Electrodes of 0.045 in through 1/16 in [1.2 through 1.6 mm] diameter normally are used at welding currents in the range of 275 to 400 amperes (dcep), for this type of transfer. The rate at which droplets (globules) are transferred ranges from 20 to 70 per second, depending on the size of the electrode, the amperage, polarity, and arc voltage.

7.4.4 Short Circuiting Transfer. This mode of transfer is obtained with small diameter electrodes 0.030 to 0.045 in [0.8 to 1.2 mm] using low arc voltages and amperages, and a power source designed for short circuiting transfer. The electrode short-circuits to the weld metal, usually at a rate of from 50 to 200 times per second. Metal is transferred with each short circuit, but not across the arc. Short circuiting gas metal arc welding of carbon steel is done most commonly with mixtures of argon and CO₂ (AWS A5.32 Class SG-AC-Y) as the shielding gas or with CO₂ (AWS A5.32 Class SG-C) alone. The penetration of such welds is greater with CO₂ than it is with argon–CO₂ mixtures. Mixtures of 50 to 80% argon with CO₂ remainder (AWS A5.32 Class SG-AC-Y, where Y is 20 to 50) can be advantageous for thin material. However

shielding gas mixtures of 50 to 70% argon with CO₂ remainder (AWS A5.32 Class SG-AC-Y, where Y is 30 to 50) are unstable in the gaseous state and must be mixed from single gas components immediately prior to use. They provide low penetration, higher short circuiting rates, and lower minimum currents and voltages than CO₂ alone does. This can be an advantage in welding thin plate. Regardless of gas used, the total heat input limits fusion and penetration. Therefore, many users limit this process to material thickness not exceeding 1/2 in [13 mm].

7.5 Description and Intended Use of Electrodes and Rods

7.5.1 The following is a description of the characteristics and intended use of the filler metals classified by this specification.

7.5.2 It should be noted that weld properties may vary appreciably depending on filler metal size and current used, plate thickness, joint geometry, preheat and interpass temperatures, surface conditions, base-metal composition and extent of alloying with the filler metal, and shielding gas. For example, when filler metals having a certain analysis are deposited, the weld metal chemical composition will not vary greatly from the as-manufactured composition of the filler metal when used with argon-oxygen shielding gas. However, they will show a considerable reduction in the content of manganese, silicon, and other deoxidizers when used with CO₂ as the shielding gas.

7.5.3 ER70S-A1 [ER49S-A1] Classification (1/2 Mo). Filler metal of this classification is similar to many of the carbon steel filler metals classified in AWS A5.18/A5.18M, except that 0.5% molybdenum has been added. This addition increases the strength of the weld metal, especially at elevated temperatures, and provides some increase in corrosion resistance; however, it will likely reduce the notch toughness of the weld metal. Typical applications include the welding of C-Mo base metals such as ASTM 204 plate and A335-P1 pipe.

7.5.4 ER80S-B2 [ER55S-B2] and E80C-B2 [E55C-B2] Classification (1¼ Cr-1/2 Mo). Filler metals of these classifications are used to weld 1/2Cr-1/2Mo, 1Cr-1/2Mo, and 1¼Cr-1/2Mo steels for elevated temperatures and corrosive service. They are also used for joining dissimilar combinations of Cr-Mo and carbon steels. All transfer modes of the GMAW process may be used. Careful control of preheat, interpass temperatures, and postheat is essential to avoid cracking. These electrodes are classified after postweld heat treatment. Special care must be used when using them in the as-welded condition due to higher strength levels.

7.5.5 ER70S-B2L [ER49S-B2L] and E70C-B2L [E49C-B2L] Classifications (1¼ Cr-1/2 Mo). These filler metals are identical to the types ER80S-B2 [ER55S-B2] and E80C-B2 [E55C-B2] except for the low-carbon content (0.05% maximum) and thus the lower strength levels. This also reduces hardness and under some conditions improves corrosion resistance. This alloy exhibits greater resistance to cracking and is more suitable for welds to be left in the as-welded condition or when the accuracy of the postweld heat treatment operation is questionable. These classifications were previously ER80S-B2L and E80C-B2L in the A5.28-79 specification. The strength requirements and classification designator have been changed to reflect the true strength capabilities of the chemical composition.

7.5.6 ER90S-B3 [ER62S-B3] and E90C-B3 [E62C-B3] Classifications (2¼ Cr-1 Mo). Filler metals of these classifications are used to weld the 2¼ Cr-1Mo steels used for high-temperature/high-pressure piping and pressure vessels. These may also be used for joining combinations of Cr-Mo and carbon steel. All GMAW modes may be used. Careful control of preheat, interpass temperatures, and postweld heat treatment is essential to avoid cracking. These electrodes are classified after postweld heat treatment. Special care must be used when using them in the as-welded condition due to higher strength levels.

7.5.7 ER80S-B3L [ER55S-B3L] and E80C-B3L [E55C-B3L] Classifications (2¼ Cr-1 Mo). These filler metals are identical to the types ER90S-B3 [ER62S-B3] and E90C-B3 [E62C-B3] except for the low-carbon content (0.05% maximum) and, therefore, the lower strength levels. These alloys exhibit greater resistance to cracking and are more suitable for welds to be left in the as-welded condition. These classifications were previously ER90S-B3L and E90C-B3L in the A5.28-79 specification. The strength requirements and classification designator have been changed to reflect the true strength capabilities of the chemical composition.

7.5.8 ER80S-Ni1 [ER55S-Ni1] and E80C-Ni1 [E55C-Ni1] Classifications (1.0 Ni). These filler metals deposit weld metal similar to E8018-C3 covered electrodes, and are used for welding low-alloy, high-strength steels requiring good toughness at temperatures as low as -50 °F [-45 °C].

7.5.9 ER80S-Ni2 [ER55S-Ni2], E70C-Ni2 [E49C-Ni2], and E80C-Ni2 [E55C-Ni2] Classifications (2¼ Ni). These filler metals deposit weld metal similar to E8018-C1 electrodes. Typically, they are used for welding 2.5 nickel steels and other materials requiring good toughness at temperatures as low as -80 °F [-60 °C].

7.5.10 ER80S-Ni3 [ER55S-Ni3] and E80C-Ni3 [E55C-Ni3] Classifications (3 ¼ Ni). These filler metals deposit weld metal similar to E8018-C2 electrodes. Typically they are used for welding 3.5 nickel steels for low-temperature service.

7.5.11 ER80S-D2 [ER55S-D2], ER90S-D2 [ER62SD2], and E90C-D2 [E62C-D2] Classifications (1/2 Mo). The ER80S-D2 [ER55S-D2] and ER90S-D2 [ER62S-D2] classifications have the same chemical requirements as the E70S-1B classification of AWS A5.18-69. The differences between the ER80S-D2 [ER55S-D2] and the ER90S-D2 [ER62S-D2] classifications are the change in shielding gas and the mechanical property requirements specified. Filler metals of these classifications contain molybdenum for increased strength and a high level of deoxidizers (Mn and Si) to control porosity when welding with CO₂ (AWS A5.32 Class SG-C) as the shielding gas. They will give radiographic quality welds with excellent bead appearance in both ordinary and difficult-to-weld carbon and low-alloy steels. They exhibit excellent out-of-position welding characteristics with the short circuiting and pulsed arc processes. The combination of weld soundness and strength makes filler metals of these classifications suitable for single- and multiple-pass welding of a variety of carbon and low-alloy, higher-strength steels in both the as-welded and postweld heat-treated conditions. The chemical composition of these classifications differs from those of the “-D2” type electrodes in AWS A5.5.

7.5.12 ER100S-1 [ER69S-1], ER110S-1 [ER76S-1], and ER120S-1 [ER83S-1] Classifications. These filler metals deposit high-strength, very tough weld metal for critical applications. Originally developed for welding HY-80 and HY-100 steels for military applications, they are also used for a variety of structural applications where tensile strength requirements exceed 100 ksi [690 MPa], and excellent toughness is required to temperatures as low as -60°F [-50°C]. Mechanical properties obtained from weld deposits made with electrodes of these classifications will vary depending on the heat input used.

7.5.13 ER80S-B6 [ER55S-B6], E80C-B6 [E55C-B6] Classification (5 Cr-1/2 Mo). This classification contains about 4.5 to 6% chromium and about 0.5% molybdenum. It is used for welding material of similar composition, usually in the form of pipe or tubing. The alloy is an air-hardening material and, therefore, while welding with this filler metal, preheat and postweld heat treatment are required. This electrode is similar to that previously classified as ER502 in AWS A5.9-93.

7.5.14 ER80S-B8 [ER55S-B8], E80C-B8 [E55C-B8] Classification (9 Cr-1 Mo). This classification contains 8 to 10.5% chromium and about 1% molybdenum. Filler metal of this classification is used for welding base metal of similar compositions, usually in the form of pipe or tubing. The alloy is an air-hardening material, and therefore, when welding with this filler metal, preheating and postweld heat treatment are required. This electrode is similar to that previously classified as ER505 in AWS A5.9-93.

7.5.15 ER90S-B9 [ER62S-B9], E90C-B9 [E62C-B9] Classification [9 Cr-1 Mo-0.2V-0.07Nb (Cb)]. ER90S-B9 [ER62S-B9] and E90C-B9 [E62C-B9] are 9Cr-1Mo wires modified with niobium (columbium) and vanadium designed to provide strength, toughness, fatigue life, oxidation resistance, and corrosion resistance at elevated temperatures. Due to the higher elevated temperature properties of this alloy, components that are now fabricated from stainless and ferritic steels may be fabricated from a single alloy, eliminating problems associated with dissimilar welds. In addition to the classification requirements in this specification, either impact toughness or high-temperature creep strength properties should be determined. Due to the influence of various levels of carbon and niobium (columbium), specific values and testing must be agreed to by the supplier and purchaser. Thermal treatment of this alloy is critical and must be closely controlled. The temperature at which the microstructure has complete transformation into martensite (Mf) is relatively low; therefore, upon completion of welding and before postweld heat treatment, it is recommended to allow the weldment to cool to at least 200°F [93°C] to maximize transformation to martensite. The maximum allowable temperature for postweld heat treatment is also critical in that the lower transformation temperature (Ac1) is also comparably low. To aid in allowing for an adequate postweld heat treatment, the restriction of Mn + Ni has been imposed. The combination of Mn and Ni tends to lower the Ac1 temperature to the point where the PWHT temperature approaches the Ac1, possibly causing partial transformation of the microstructure. By restricting the Mn + Ni, the PWHT temperature will be sufficiently below the Ac1 to avoid this partial transformation.

7.5.16 E90C-K3 [E62C-K3], E100C-K3 [E69C-K3], E110C-K3 [E76C-K3] Classifications. Some electrodes in these classifications produce weld metal with a typical composition of 1.5% nickel and up to 0.35% molybdenum. These electrodes are used on many high-strength applications ranging from 80 to 110 ksi [550 to 760 MPa] minimum yield strength and are primarily intended for as-welded applications. Typical applications would include the welding of ships, offshore structures, and many other structural applications where low-temperature toughness is required. Steels welded would include HY-80, HY-100, ASTM A 710, A 514, A 517, and other similar high-strength steels. Other electrodes of

these types produce weld deposits with higher levels of manganese, nickel and molybdenum and usually have higher strength levels. Typical applications include the welding of HY-100, A 514, and A 517 steels.

7.5.17 E110C-K4 [E76C-K4], E120C-K4 [E83C-K4] Classifications. Electrodes of these types produce weld deposits similar to that of the EXXC-K3 electrodes, with the addition of approximately 0.5% chromium. The additional alloy provides the higher strength necessary for many applications needing in excess of 120 000 psi [830 MPa] tensile, such as armor plate.

7.5.18 E80C-W2 [E55C-W2] Classification (Weathering Steel). This classification has been designed to produce weld metal that matches the corrosion resistance and the coloring of the ASTM weathering-type structural steels such as A 242, A 588, and A 709 gr 50W. These special properties are achieved by the addition of about 0.5% copper to the weld metal. To meet strength, ductility, and notch toughness in the weld metal, chromium and nickel additions are also introduced.

7.5.19 ERXXS-G and EXXC-G Classifications. Electrodes and rods of the ERXXS-G and electrodes of the EXXC-G classifications are those filler metals not included in the preceding classes and for which only certain mechanical property requirements are specified. The electrodes are intended for single- and multiple-pass applications. The filler metal supplier should be consulted for the composition, properties, characteristics, and intended use of these classifications.

8. Guide to AWS Specification for Carbon Steel Electrodes for Flux Cored Arc Welding

8.1 Provisions. Excerpts from AWS A5.20/A5.20M:2005, *Specification for Carbon Steel Electrodes for Flux Cored Arc Welding*.

8.2 Introduction. The purpose of this guide is to correlate the electrode classifications with their intended applications so that the specification can be used effectively. This guide provides examples rather than complete listings of the materials and applications for which each filler metal is suitable.

8.3 Classification System

8.3.1 Classification of Electrodes. The system for identifying the electrode classifications in the A5.20 and A5.20M specifications follows, for the most part, the standard pattern used in other AWS filler metal specifications. The system is shown in Figure 8.1.

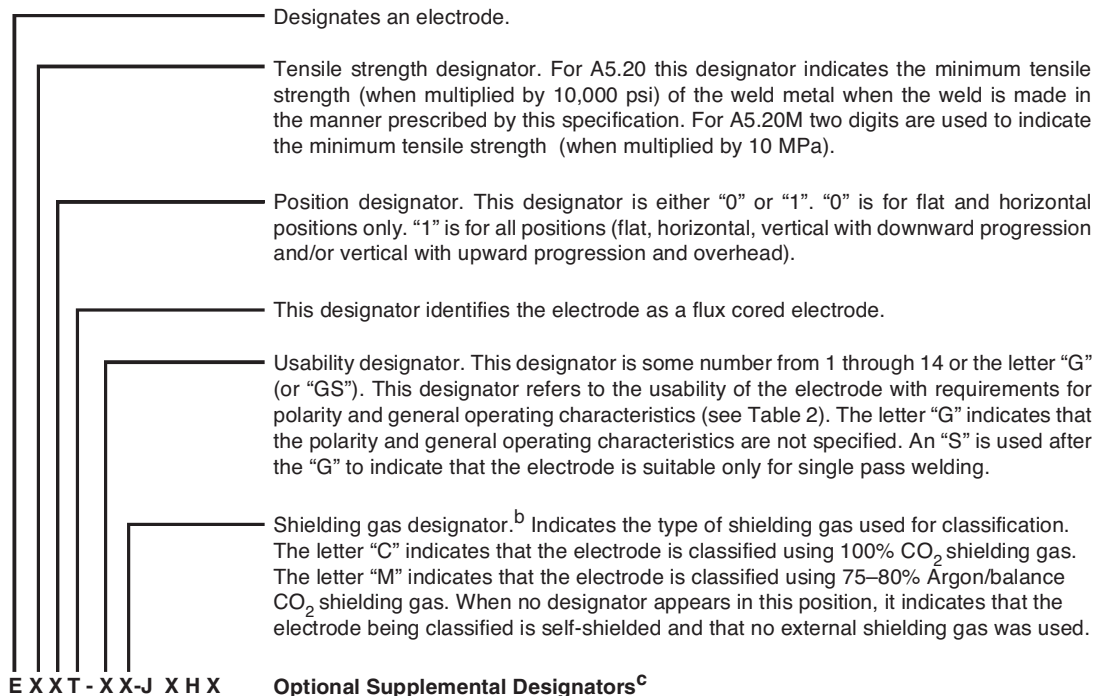
8.3.2 Some of the classifications are intended to weld only in the flat and horizontal positions (EX0T-5C, -5M, for example). Others are intended for welding in all positions (EX1T-1C, -1M, for example). As in the case of covered electrodes, the smaller sizes of flux cored electrodes are the ones used for out-of-position work. Flux cored electrodes larger than 5/64 in [2 mm] in diameter are usually used for horizontal fillets and flat position welding.

8.3.3 Optional Supplemental designators are also used in this specification in order to identify electrode classifications that have met certain supplemental requirements as agreed to between the supplier and the purchaser. The optional supplemental designators are not part of the electrode classification.

8.3.3.1 This specification has included the use of optional designators for diffusible hydrogen to indicate the maximum average value obtained under a clearly defined test condition in AWS A4.3. Electrodes that are designated as meeting the lower or lowest hydrogen limits are understood to be able to meet any higher hydrogen limits. Diffusible hydrogen is discussed in Section 8.7.

8.3.3.2 The A5.20/A5.20M specification has established multiple-pass classification requirements using a test assembly and welding procedures described in the specification. In addition, this specification has included the optional supplemental designators "J," "D," and "Q" to indicate conformance to optional, supplemental mechanical property requirements.

8.3.3.2.1 In order to include product with improved toughness at lower temperature an optional supplemental designator, "J," has been added to identify electrodes which, when tested, produce weld metal which exhibits 20 ft-lbf at -40° F [27 J at -40°C]. The user is cautioned that although improved weld metal toughness will be evidenced when welding is performed under conditions specified in this specification, other applications of the electrode, such as long-term postweld heat treatment or vertical up welding with higher heat input, may produce results markedly different from the improved toughness levels given. The users should always perform their own mechanical properties verification testing.

Mandatory Classification Designators^a**Optional Supplemental Designators^c**

- Optional supplemental diffusible hydrogen designator.
- The letter "D" or "Q" when present in this position indicates that the weld metal will meet supplemental mechanical property requirements with welding done using low heat input, fast cooling rate procedures and using high heat input, slow cooling rate procedures as prescribed in Section 17.
- The letter "J" when present in this position designates that the electrode meets the requirements for improved toughness and will deposit weld metal with Charpy V-Notch properties of at least 20 ft.lbf at –40°F [27J at –40°C] when the welds are made in a manner prescribed by this specification.

^a The combination of these designators constitutes the flux cored electrode classification.

^b See AWS A5.32/A5.32M.

^c These designators are optional and do not constitute a part of the flux cored electrode classification.

Source: AWS AS.20/A5.20M: 2005, Figure 1

Figure 8.1–A5.20/A5.20M Classification System

8.3.3.2.2 Two optional, supplemental designators have been added to identify electrodes which, when testing using both low heat input, fast cooling rate welding procedures and high heat input, slow cooling rate welding procedures, will conform to the classification radiographic requirements and to the tension test and Charpy V-Notch requirements specified in Table 10 of the specification. The first optional, supplemental designator, "D," is intended to demonstrate conformance to the FEMA guidelines for the welding of steel moment-frame connections for seismic applications as indicated in FEMA 353. The second of these optional, supplemental designators, "Q," is intended to demonstrate conformance to certain requirements for the welding of Navy ships.

8.3.4 "G" Classification. These specifications include electrodes classified as E6XT-G, E6XT-GS, E7XT-G, and E7XT-GS. The "G" or "GS" indicates that the electrode is of a "general" classification. It is "general" because not all of

the particular requirements specified for each of the other classifications are specified for this classification. The intent in establishing this classification is to provide a means by which electrodes that differ in one respect or another (description of usability and/or operating polarity, for example) from all other classifications can still be classified according to this specification. The purpose is to allow a useful filler metal—one that otherwise would have to await a revision of the specification—to be classified immediately, under the existing specification. This means, then, that two electrodes—each bearing the same “G” classification—may be quite different in some certain respect (usability characteristics and polarity, again, for example).

8.4 Welding Considerations

8.4.1 When examining the properties required of weld metal as a result of the tests made according to this specification, it should be recognized that in production, where the conditions and procedures may differ from those in this specification [electrode size, amperage, voltage, type and amount of shielding gas, position of welding, contact tip to work distance (CTWD), plate thickness, joint geometry, preheat and interpass temperatures, travel speed, surface condition, base metal composition and dilution, for example], the properties of the weld metal may also differ. Moreover, the difference may be large or small.

8.4.2 Since it has not been possible to specify one single, detailed, welding procedure for all products classified under any given classification in this specification, details of the welding procedure used in classifying each product should be recorded by the manufacturer and made available to the user, on request. The information should include each of the welding parameters referred to 8.4.1 above, as well as the actual number of passes and layers required to complete the weld test assembly.

8.4.3 The toughness requirements for the different classifications in this specification can be used as a guide in the selection of electrodes for applications requiring some degree of low temperature notch toughness. For an electrode of any given classification, there can be a considerable difference between the impact test results from one assembly to another, or even from one impact specimen to another, unless particular attention is given to the manner in which the weld is made and prepared (even the location and orientation of the specimen within the weld), the temperature of testing, and the operation of the testing machine.

8.5 Hardenability. There are inherent differences in the effect of the carbon content of the weld deposit on hardenability, depending on whether the electrode was gas shielded or self-shielded. Gas shielded electrodes generally employ a Mn-Si deoxidation system. The carbon and alloy content affects hardenability in a manner which is typical of many carbon equivalent formulas published for carbon steel. Most self-shielded electrodes utilize an aluminum-based deoxidation system to provide for protection and deoxidation. One of the effects of the aluminum is to modify the effect of carbon on hardenability which will, therefore, be lower than what the carbon content would indicate based on typical carbon equivalent formulas.

8.6 Description and Intended Use of Flux Cored Electrodes. This specification contains many different classifications of flux cored electrodes. The usability designation (1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, or the letter “G” or the letters “GS”) in each classification indicates a general grouping of electrodes that contain similar flux or core components and which have similar usability characteristics, except for the “G” classification where usability characteristics may differ between similarly classified electrodes.

8.6.1 EXXT-1C and EXXT-1M Classifications. Both the EXXT-1C and EXXT-1M electrodes have similar type slags and are designed for single- and multiple-pass welding using dcnp. The larger diameters (usually 5/64 in [2.0 mm] and larger) are typically used for welding in the flat position and for welding fillet welds in the horizontal position. The smaller diameters (usually 1/16 in [1.6 mm] and smaller) are typically used for welding in all positions. These electrodes are characterized by a spray transfer, low spatter loss, flat to slightly convex bead contour, and a moderate volume of slag, which completely covers the weld bead. Electrodes of this classification have a rutile base slag and have the ability to produce high deposition rates.

Electrodes in the EXXT-1C group are classified with CO₂ shielding gas (AWS A5.32/A5.32M, Class SG-C). However, other gas mixtures such as argon-CO₂ (AWS A5.32/A5.32M, Class SG-AC-25 or SG-AC-20) may be used to improve usability, especially for out-of-position applications, when recommended by the manufacturer. Increasing the amount of argon in the argon-CO₂ mixture will increase the manganese and silicon contents, along with certain other alloys such as chromium, in the weld metal. The increase in manganese, silicon, or other alloys will increase the yield and tensile strengths and may affect impact properties. Electrodes in the EXXT-1M group are classified with 75% to 80% argon/balance CO₂ shielding gas. Increasing the amount of argon in the argon-CO₂ mixture will reduce the manganese and

silicon losses, along with losses of certain other elements such as chromium, that occur in the welding arc. The resulting increase of manganese, silicon, or other elements will increase the yield and tensile strengths and may affect impact properties.

8.6.2 EXXT-2C and EXXT-2M Classification. Electrodes of these classifications are essentially EXXT-1C and EXXT-1M with higher manganese or silicon, or both, and are designed primarily for single-pass welding in the flat position and for welding fillet welds in the horizontal position. The higher levels of deoxidizers in these classifications allow single-pass welding of heavily oxidized or rimmed steel. Weld metal composition requirements are not specified for single-pass electrodes, since checking the composition of the undiluted weld metal will not provide an indication of the composition of a single-pass weld. These electrodes give good mechanical properties in single-pass welds. The manganese content and the tensile strength of the weld metal of multiple-pass welds made with EXXT-2C and EXXT-2M electrodes will be high. These electrodes can be used for welding base metals which have heavier mill scale, rust, or other foreign matter that cannot be tolerated by some electrodes of the EXXT-1C or EXXT-1M classifications. The arc transfer, welding characteristics and deposition rates of these electrodes, however, are similar.

8.6.3 EXXT-3 Classification. Electrodes of this classification are self-shielded, used on dcep and have a spray-type transfer. The slag system is designed to make very high welding speeds possible. The electrodes are used for single-pass welds in the flat, horizontal, and vertical (up to 20° incline) positions (downward progression) on sheet metal. Since these electrodes are sensitive to the effects of base metal quenching, they are not generally recommended for the following:

- (1) T- or lap joints in materials thicker than 3/16 in [5 mm]
- (2) Groove, edge, or corner joints in materials thicker than 1/4 in [6 mm].

The electrode manufacturer should be consulted for specific recommendations.

8.6.4 EXXT-4 Classification. Electrodes of this classification are self-shielded, operate on dcep, and have a globular-type transfer. The basic slag system is designed to make very high deposition rates possible and to produce a weld that is very low in sulfur for improved resistance to hot cracking. These electrodes produce welds with low penetration enabling them to be used on joints with varying gaps and for single- and multiple-pass welding.

8.6.5 EXXT-5C and EXXT-5M Classifications. Electrodes of the EXXT-5C and EXXT-5M classifications are used primarily for single- and multiple-pass welds in the flat position and for welding fillet welds in the horizontal position using dcep or DCEN, depending on the manufacturer's recommendation. These electrodes are characterized by a globular transfer, slightly convex bead contour, and a thin slag that may not completely cover the weld bead. These electrodes have lime-fluoride base slag. Weld deposits produced by these electrodes typically have impact properties and hot and cold crack resistance that are superior to those obtained with rutile base slags. Some of these electrodes, using DCEN, can be used for welding in all positions. However, the operator appeal of these electrodes is not as good as that of those with rutile base slags. Electrodes of the EXXT-5C classifications are designed to be used with CO₂ shielding gas (AWS A5.32/A5.32M, Class SG-C); however, as with the EXXT-1C classification, argon-CO₂ mixtures may be used to reduce spatter, when recommended by the manufacturer. Increasing the amount of argon in the argon-CO₂ mixture will increase the manganese and silicon contents, along with certain other alloys, which will increase the yield and tensile strengths and may affect impact properties.

Electrodes of the EXXT-5M classification are designed for use with 75% to 80% argon/balance CO₂ shielding. Their use with gas mixtures having reduced amounts of argon with CO₂ shielding gas will result in some deterioration in arc characteristics, an increase in spatter, and a reduction in manganese, silicon, and certain other alloy elements in the weld metal. This reduction in manganese, silicon, or other alloys will decrease the yield and tensile strengths and may affect impact properties.

8.6.6 EXXT-6 Classification. Electrodes of this classification are self-shielded, operate on dcep, and have a spray-type transfer. The slag system is designed to give good low temperature impact properties, good penetration into the root of the weld, and excellent slag removal, even in a deep groove. These electrodes are used for single- and multiple-pass welding in flat and horizontal positions.

8.6.7 EXXT-7 Classification. Electrodes of this classification are self-shielded, operate on DCEN and have a small droplet to spray-type transfer. The slag system is designed to allow the larger sizes to be used for high deposition rates in the horizontal and flat positions, and to allow the smaller sizes to be used for all welding positions. The electrodes are used for single- and multiple-pass welding and produce very low sulfur weld metal which is very resistant to hot cracking.

8.6.8 EXXT-8 Classification. Electrodes of this classification are self-shielded, operate on DCEN, and have a small droplet to spray-type transfer. These electrodes are suitable for all welding positions, and the weld metal has very good low temperature notch toughness and crack resistance. These electrodes are used for single- and multiple-pass welds.

8.6.9 EXXT-9C and EXXT-9M Classifications. Electrodes of the EXXT-9C group are classified with CO₂ shielding gas (AWS A5.32/A5.32M, Class SG-C). However, gas mixtures of argon-CO₂ are sometimes used to improve usability, especially for out-of-position applications. Increasing the amount of argon in the argon-CO₂ mixture will affect the weld metal analysis and mechanical properties of weld metal deposited by these electrodes, just as it will for weld metal deposited by EXXT-1C and EXXT-1M electrodes (see 8.6.1). Electrodes of the EXXT-9M group are classified with a 75–80% argon/balance CO₂ shielding gas (AWS A5.32/A5.32M, Class SG-AC-25 or SG-AC-20). Their use with argon-CO₂ shielding gas mixtures having reduced amounts of argon, or with CO₂ shielding gas, may result in some deterioration of arc characteristics and out-of-position welding characteristics. In addition, a reduction of the manganese and silicon contents in the weld will result, which will have some effect on properties of weld metal from these electrodes, just as it will on properties of weld metal deposited by EXXT-1C and EXXT-1M electrodes (see 8.6.1). Both the EXXT-9C and EXXT-9M electrodes are designed for single- and multiple-pass welding. The larger diameters (usually 5/64 in [2.0 mm] and larger) are used for welding in the flat position and for welding fillet welds in the horizontal position. The smaller diameters (usually 1/16 in [1.6 mm] and smaller) are often used for welding in all positions. The arc transfer, welding characteristics, and deposition rates of the EXXT-9C and EXXT-9M electrodes are similar to those of the EXXT-1C or EXXT-1M classifications (see 8.6.1). EXXT-9C and EXXT-9M electrodes are essentially EXXT-1C and EXXT-1M electrodes that deposit weld metal with improved impact properties. Some electrodes in this classification require that joints be relatively clean and free of oil, excessive oxide, and scale in order that welds of radiographic quality can be obtained.

8.6.10 EXXT-10 Classification. Electrodes of this classification are self-shielded, operate on DCEN, and have a small droplet transfer. The electrodes are used for single-pass welds at high travel speeds on material of any thickness in the flat, horizontal, and vertical (up to 20° incline) positions.

8.6.11 EXXT-11 Classification. Electrodes of this classification are self-shielded, operate on DCEN, and have a smooth spray-type transfer. They are general purpose electrodes for single- and multiple-pass welding in all positions. Their use is generally not recommended on thicknesses greater than 3/4 in [19 mm]. The electrode manufacturer should be consulted for specific recommendations.

8.6.12 EXXT-12C and EXXT-12M Classifications. Electrodes of these classifications are essentially EXXT-1C and EXXT-1M electrodes and are similar in arc transfer, welding characteristics and deposition rates; however, they have been modified to improve impact toughness and to meet the lower manganese requirements of the A-No. 1 Analysis Group in the ASME *Boiler and Pressure Vessel Code*, Section IX. They, therefore, have an accompanying decrease in tensile strength and hardness. Since welding procedures influence all-weld-metal properties, users are urged to check hardness on any application where a maximum hardness level is a requirement.

8.6.13 EXXT-13 Classifications. Electrodes of this classification are self-shielded and operate on DCEN and are usually welded with a short-arc transfer. The slag system is designed so that these electrodes can be used in all positions for the root pass on circumferential pipe welds. The electrodes can be used on all pipe wall thicknesses, but are only recommended for the first pass. They generally are not recommended for multiple-pass welding.

8.6.14 EXXT-14 Classification. Electrodes of this classification are self-shielded, operate on DCEN, and have a smooth spray-type transfer. They are intended for single-pass welding. The slag system is designed with characteristics so that these electrodes can be used to weld in all positions and also to make welds at high speed. They are used to make welds on sheet metal up to 3/16 in [5 mm] thick, and often are specifically designed for galvanized, aluminized, or other coated steels. Since these welding electrodes are sensitive to the effects of base metal quenching, they are not generally recommended for the following:

- (1) T- or lap joints in materials thicker than 3/16 in [5 mm]
- (2) Groove, edge, or corner joints in materials thicker than 1/4 in [6 mm].

The electrode manufacturer should be consulted for specific recommendations.

8.6.15 EXXT-G Classification. This classification is for multiple-pass electrodes that have usability characteristics not covered by any presently defined classification. Except for chemical requirements to assure a carbon steel deposit and the tensile strength, which is specified, the requirements for this classification are not specified. They are those that are agreed to by the purchaser and the supplier.

8.6.16 EXXT-GS Classification. This classification is for single-pass electrodes that have usability characteristics not covered by any presently defined classification. Except for the tensile strength, which is specified, the requirements for this classification are not specified. They are agreed upon by the purchaser and supplier.

8.7 Diffusible Hydrogen

8.7.1 Hydrogen-induced cracking of weld metal or the heat-affected zone generally is not a problem with carbon steels containing 0.3% or less carbon, nor with lower-strength alloy steels. However, the electrodes classified in this specification are sometimes used to join higher carbon steels or low-alloy, high-strength steels where hydrogen-induced cracking may be a serious problem.

8.7.2 As the weld metal or heat-affected zone strength or hardness increases, the concentration of diffusible hydrogen that will cause cracking under given conditions of restraint and heat input becomes lower. This cracking (or its detection) is usually delayed some hours after cooling. It may appear as transverse weld cracks, longitudinal cracks (especially in the root beads), and toe or underbead cracks in the heat-affected zone.

8.7.3 Since the available diffusible hydrogen level strongly influences the tendency toward hydrogen-induced cracking, it may be desirable to measure the diffusible hydrogen content resulting from welding with a particular electrode. This specification has, therefore, included the use of optional designators for diffusible hydrogen to indicate the maximum average value obtained under a clearly defined test condition in AWS A4.3.

8.7.4 Most flux cored electrodes deposit weld metal having diffusible hydrogen levels of less than 16 mL/100 g of deposited metal. For that reason, flux cored electrodes are generally considered to be low hydrogen. However, some commercially available products will, under certain conditions, produce weld metal with diffusible hydrogen levels in excess of 16 mL/100 g of deposited metal. Therefore it may be appropriate for certain applications to utilize the optional supplemental designators for diffusible hydrogen when specifying the flux cored electrodes to be used.

8.7.5 The use of a reference atmospheric condition during welding is necessitated because the arc is subject to atmospheric contamination when using either self-shielded or gas-shielded flux cored electrodes. Moisture from the air, distinct from that in the electrode, 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 can be very significant at the H4 level. An electrode meeting the H4 requirements under the reference atmospheric conditions may not do so under conditions of high humidity at the time of welding, especially if a long arc length is maintained.

8.7.6 The user of this information is cautioned that actual fabrication conditions may result in different diffusible hydrogen values than those indicated by the designator. The welding consumable is not the only source of diffusible hydrogen in the welding process. In actual practice, the following may contribute to the hydrogen content of the finished weldment.

(1) **Surface Contamination.** Rust, primer coating, anti-spatter compounds, dirt and grease can all contribute to diffusible hydrogen levels in practice. Consequently, standard diffusible hydrogen tests for classification of welding consumable require test material to be free of contamination. AWS A4.3 is specific as to the cleaning procedure for test material.

(2) **Atmospheric Humidity.** The welding arc is subject to atmospheric contamination when using either a self-shielded or gas-shielded welding consumable. Moisture from the air, distinct from that in the welding consumable, can enter the arc and subsequently the weld pool, contributing to the resulting observed diffusible hydrogen. AWS A4.3 has established a reference atmospheric condition at which the contribution to diffusible hydrogen from atmospheric humidity is considered to be negligible. This influence of atmospheric humidity also can be minimized by maintaining as short an arc length as possible, consistent with a steady arc. For flux cored electrodes arc length is controlled primarily by arc voltage. Experience has shown that the effect of arc length is minor at the H16 level, but can be very significant at the H4 level. An electrode meeting the H4 requirements under the reference atmospheric conditions may not do so under conditions of high humidity at the time of welding, especially if a long arc length is maintained.

(3) **Shielding Gas.** The reader is cautioned that the shielding gas itself can contribute significantly to diffusible hydrogen. Normally, welding grade shielding gases are intended to have very low dew points and very low impurity levels. This, however, is not always the case. Instances have occurred where a contaminated gas cylinder resulted in a significant increase of diffusible hydrogen in the weld metal. Further, moisture permeation through some hoses and moisture condensation in unused gas lines can become a source of diffusible hydrogen during welding. In case of doubt, a check of gas dew point is suggested. A dew point of -40°F [-40°C] or lower is considered satisfactory for most applications.

(4) **Absorbed/Adsorbed Moisture.** Flux cored electrodes can absorb/adsorb moisture over time which contributes to diffusible hydrogen levels. This behavior is well documented for shielded metal arc electrode coverings exposed to the atmosphere. Hydration of oxide films and lubricants on solid electrode surfaces under what may be considered “normal” storage conditions has also been reported to influence diffusible hydrogen. Moisture absorption/adsorption can be particularly significant if material is stored in a humid environment in damaged or open packages, or if unprotected for long periods of time. In the worst case of high humidity, even overnight exposure of unprotected electrodes can lead to a significant increase of diffusible hydrogen. For these reasons, indefinite periods of storage should be avoided. The storage and handling practices necessary to safeguard the condition of a welding consumable will vary from one product to another even within a given classification. Therefore, the consumable manufacturer should always be consulted for recommendations on storage and handling practice. In the event the electrode has been exposed, the manufacturer should be consulted regarding probable damage to its controlled hydrogen characteristics and possible reconditioning of the electrode.

(5) **Effect of Welding Process Variables.** Variations in welding process variables (e.g., amperage, voltage, contact tip to work distance CTWD, type of shielding gas, current type/polarity, and single electrode vs. multiple electrode welding) are all reported to influence diffusible hydrogen test results in various ways. For example, with respect to CTWD, a longer contact tip to work distance will promote more preheating of the electrode, causing some removal of hydrogen-bearing compounds (e.g., moisture and lubricants, etc.) before they reach the arc. Consequently, the result of longer contact tip to work distance can be reduced diffusible hydrogen. However, excessive contact tip to work distances with external gas-shielded welding processes may cause some loss of shielding if the contact tip is not adequately recessed in the gas cup. If shielding is disturbed, more air may enter the arc and increase the diffusible hydrogen. This may also cause porosity due to nitrogen pickup. Since welding process variables can have a significant effect on diffusible hydrogen test results, it should be noted that an electrode meeting the H4 requirements, for example, under the classification test conditions should not be expected to do so consistently under all welding conditions. Some variation should be expected and accounted for when making welding consumable selections and establishing operating ranges in practice.

9. Guide to AWS Specification for Low-Alloy Steel Electrodes for Flux Cored Arc Welding

9.1 Provisions. Excerpts from AWS A5.29/A5.29M:2005, *Specification for Low-Alloy Steel Electrodes for Flux Cored Arc Welding*.

9.2 Introduction. The purpose of this guide is to correlate the electrode classifications with their intended applications so that the specification can be used effectively. Appropriate base metal specifications or welding processes are referred to whenever that can be done and when it would be helpful. Such references are intended only as examples rather than complete listings of the materials or welding processes for which each electrode is suitable.

9.3 Classification System

9.3.1 The system for identifying the electrode classifications in this specification follows, for the most part, the standard pattern used in other AWS filler metal specifications.

9.3.2 Some of the classifications are intended to weld only in the flat and horizontal positions (E70T5-A1C, for example). Others are intended for welding in all positions (E81T1-Ni1M, for example). As in the case of shielded metal arc electrodes, the smaller sizes of flux cored electrodes are the ones used for out-of-position work. Flux cored electrodes larger than 5/64 in [2.0 mm] in diameter are usually used for horizontal fillets and flat position welding.

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

9.3.3.1 Many of the classifications included in this specification have requirements for impact testing at various test temperatures as shown in the specification. In order to include products with improved weld metal toughness at lower temperatures, an optional supplemental designator, “J,” has been added to identify classifications which, when tested, produce weld metal which exhibits 20 ft-lbf [27 J] at a temperature of 20°F [10°C] lower than the standard temperature shown in the specification. The user is cautioned that although the improved weld metal toughness will be evidenced