Filler Metal Selection

OBJECTIVES

After completing this chapter, the student should be able to:

• Explain various identification systems for filler metals.
• List what technical information is provided by electrode manufacturers and how this information can be used by a welder.
• Describe the parts of an shielded metal arc welding (SMAW) electrode and their function.
• Name some of the factors to consider when selecting an SMAW filler metal.
• Name the characteristics of a particular filler metal by interpreting the series of letters and numbers used to describe the filler metal.

KEY TERMS

alloying elements  
core wire  
arc blow  
fast freezing  
filler metals  
flux covering

INTRODUCTION

Manufacturers of filler metals may use any one of a variety of identification systems. There is not a mandatory identification system for filler metals. Manufacturers may use their own numbering systems, trade names, color codes, or a combination of methods to identify filler metal. They may voluntarily choose to use any one of several standardized systems.

The most widely used numbering and lettering system is the one developed by the American Welding Society (AWS). Other numbering and lettering systems have been developed by the American Society for Testing and Materials (ASTM) and the American Iron and Steel Institute (AISI). A system of using colored dots has also been developed by the National Electrical...
Manufacturers Association (NEMA). Some manufacturers have produced systems that are similar to the AWS system. Most major manufacturers include both the AWS identification and their own identification on the box, on the package, and/or directly on the filler metal.

Information that pertains directly to specific filler metals is readily available from most electrode manufacturers. The information given in charts, pamphlets, and pocket electrode guides is specific to their products, and they may or may not include standard AWS tests, terms, or classifications within their identification systems.

The AWS publishes a variety of books, pamphlets, and charts showing the minimum specifications for filler metal groups. It also publishes comparison charts that include all of the information manufacturers provide to the AWS regarding their filler metals. Both the literature on filler metal specifications and filler metal comparisons may be obtained directly from the AWS.

The AWS classification system is for minimum requirements within a grouping. Filler metals manufactured within a grouping may vary but still be classified under that grouping’s classification.

A manufacturer may add elements to the metal or flux, such as more arc stabilizers. When one characteristic is improved, another characteristic may also change. The added arc stabilizer may make a smoother weld with less penetration. Other changes may affect the strength and ductility or other welding characteristics.

Because of the variables within a classification, some manufacturers make more than one type of filler metal that is included in a single classification. This and other information may be included in the data supplied by manufacturers.

Understanding the Electrode Data

Technical procedures, physical properties, and chemical analysis information given by manufacturers include the following:

- Number of welding electrodes per pound
- Number of inches of weld per welding electrode
- Welding amperage range setting for each size of welding electrode
- Welding codes for which the electrode can be used
- Types of metal that can be welded
- Ability to weld on rust, oil, paint, or other surface contamination
- Weld joint penetration characteristics
- Preheating and postheating temperatures
- Weld deposit physical strengths: ultimate tensile strength, yield point, yield strength, elongation, and impact strength
- Percentages of such alloys as carbon, sulfur, phosphorus, manganese, silicon, chromium, nickel, molybdenum, and other alloys

The information supplied by the manufacturer can be used for a variety of purposes, including the following:

- Estimates of the pounds of electrodes needed for a job
- Welding conditions under which the electrode can be used—for example, on clean or dirty metal
- Welding procedure qualification information regarding amperage, joint preparation, penetration, and welding codes
- Physical and chemical characteristics affecting the weld’s strengths and metallurgical properties

Manufacturers’ Electrode Information

The type of information given by different manufacturers ranges from general information to technical, chemical, and physical information. A mixture of different types of information may be given.

General information given by manufacturers may include some or all of the following: welding electrode manipulation techniques, joint design, prewelding preparation, postwelding procedures, types of equipment that can be welded, welding currents, and welding positions.

Data Resulting from Mechanical Tests

Most of the technical information supplied is self-explanatory and easily understood. The mechanical properties of the weld are given as the results of standard tests. The following are some of the standard tests and the meaning of each test:

- Minimum tensile strength, psi—The load in pounds that would be required to break a section of sound weld that has a cross-sectional area of 1 sq in.
Filler Metal Selection

Nickel (Ni)—As the percentage of nickel increases, tensile strength, toughness, and corrosion resistance increase. It is also an austenite former.

Molybdenum (Mo)—As the percentage of molybdenum increases, tensile strengthens at elevated temperatures; creep resistance and corrosion resistance increase. It is also a ferrite and carbide former.

Copper (Cu)—As the percentage of copper increases, the corrosion resistance and cracking tendency increases.

Columbium (Cb)—As the percentage of columbium (niobium) increases, the tendency to form chrome-carbides is reduced in stainless steels. It is also a strong ferrite former.

Aluminum (Al)—As the percentage of aluminum increases, the high-temperature scaling resistance improves. It is also a good oxidizer and ferrite former.

Data Resulting from Chemical Analysis

Chemical analysis of the weld deposit may also be included in the information given by manufacturers. It is not so important to know what the different percentages of the alloys do, but it is important to know how changes in the percentages of the alloys affect the weld. Chemical composition can easily be compared from one electrode to another. The following are the major elements and the effects of their changes on the iron in carbon steel:

- Carbon (C)—As the percentage of carbon increases, the tensile strength increases, the hardness increases, and ductility is reduced. Carbon also causes austenite to form.
- Sulfur (S)—It is usually a contaminant, and the percentage should be kept as low as possible below 0.04%. As the percentage of carbon increases, sulfur can cause hot shortness and porosity.
- Phosphorus (P)—It is usually a contaminant, and the percentage should be kept as low as possible. As the percentage of phosphorus increases, it can cause weld brittleness, reduced shock resistance, and increased cracking.
- Manganese (Mn)—As the percentage of manganese increases, the tensile strength, hardness, resistance to abrasion, and porosity all increase; hot shortness is reduced. It is also a strong austenite former.
- Silicon (Si)—As the percentage of silicon increases, tensile strength increases, and cracking may increase. It is used as a deoxidizer and ferrite former.
- Chromium (Cr)—As the percentage of chromium increases, tensile strength, hardness, and corrosion resistance increase with some decrease in ductility. It is also a good ferrite and carbide former.

SMAW Electrode Operating Information

Shielded metal arc welding electrodes, sometimes referred to as welding rods, arc welding rods, stick electrodes, or simply electrodes, have two parts. These two parts are the inner core wire and a flux covering, Figure 26-1.

The functions of the core wire include the following:

- To carry the welding current
- To serve as most of the filler metal in the finished weld

The functions of the flux covering may include the following:

- To provide some of the alloying elements
- To provide an arc stabilizer (optional)
- To serve as an insulator

![Figure 26-1 The two parts of a welding electrode.](https://example.com/fig26-1.png)
• To provide a slag cover to protect the weld bead and slow cooling rate
• To provide a protective gaseous shield during welding

**CORE WIRE**

A **core wire** is the primary metal source for a weld. For fabricating structural and low alloy steels, the core wires of the electrode use inexpensive rimmed or low carbon steel. For more highly alloyed materials, such as stainless steel, high nickel alloys, or non-ferrous alloys, the core wires are of the approximate composition of the material to be welded. The core wire also supports the coating that carries the fluxing and alloying materials to the arc and weld pool.

**Functions of the Flux Covering**

**Provides Shielding Gases**

Heat generated by the arc causes some constituents in the flux covering to decompose and others to vaporize, forming shielding gases. These gases prevent the atmosphere from contaminating the weld metal as it transfers across the arc gap. They also protect the molten weld pool as it cools to form solid metal. In addition, shielding gases and vapors greatly affect both the drops that form at the electrode tip and their transfer across the arc gap, Figure 26-2. They also cause the spatter from the arc and greatly determine arc stiffness and penetration. For example, the E6010 electrode contains cellulose. Cellulose decomposes into the hydrogen responsible for the deep electrode penetration so desirable in pipeline welding.

**Alloying Elements**

Elements in the flux are mixed with the filler metal. Some of these elements stay in the weld metal as alloys.

**Filler Metal Selection**

Selecting the best filler metal for a job in large shops is seldom delegated to you. The selection of the correct process and filler metal is a complex undertaking. If
Shielded Metal Arc Welding Electrode Selection

- **Type of electrode**—What electrode has been specified in the blueprints or in the contract for this job?
- **Type of current**—Can the welding power source supply AC only, DC only, or both AC and DC?
- **Power range**—What is the amperage range on the welder and its duty cycle? Different types of electrodes require different amperage settings even for the same size welding electrode. For example, the amperage range for a 1/8-in. (3-mm) diameter E6010 electrode is 75 A to 125 A, and the amperage range for a 1/8-in. (3-mm) diameter E7018 electrode is 90 A to 165 A.
- **Type of metal**—Some welding electrodes may be used to join more than one similar type of metal. Other electrodes may be used to join together two different types of metal. For example, an E309-15 electrode can be used to join 305 stainless steel to 1020 mild steel.
- **Thickness of metal**—The penetration characteristics of each welding electrode may differ. Selecting one electrode that will weld on a specific thickness of material is important. For example, E6013 has very little penetration and is therefore good for welding on sheet metal.
- **Weld position**—Some welding electrodes can be used to make welds in all positions. Other electrodes may be restricted to making flat, horizontal, and/or vertical position welds; a few electrodes may be used to make flat position welds only.
- **Joint design**—The type of joint and whether it is grooved or not may affect the performance of the welding electrode. For example, the E7018 electrode does not produce a large, gaseous cloud to protect the molten metal. For this reason, the electrode movement is restricted so that the molten weld pool is not left unprotected by the gaseous cloud.
- **Surface condition**—It is not always possible to work on new, clean metal. Some welding electrodes will weld on metal that is rusty, oily, painted, dirty, or galvanized.
- **Number of passes**—The amount of reinforcement needed may require more than one welding pass. Some welding electrodes will build up faster, and others will penetrate deeper. The slag may be removed more easily from some welds than from others.

Covering all of the variables for selecting a filler metal would be well beyond the scope of this text. A sample of the factors that must be considered for the selection of an SAW electrode follow. To further complicate things, welding electrodes have more than one application, and many welding electrodes may be used for the same type of work.

The following conditions that you should consider when choosing a welding electrode are not in order of importance. They are also not all of the factors that must be considered.
others. For example, E6013 will build up a weld faster than E6010, and the slag is also more easily removed between weld passes.

- Distortion—Welding electrodes that will operate on low-amperage settings will have less heat input and cause less distortion. Welding electrodes that have a high rate of deposition (fill the joint rapidly) and can travel faster will also cause less distortion. For example, the flux on an E7024 has 50% iron powder, which gives it a faster fill rate and allows it to travel faster, resulting in less distortion of the metal being welded.

- Preheat or postheat—On low carbon steel plate 1 in. (25 mm) thick or more, thick preheating is required with most welding electrodes. Postheating may be required to keep a weld zone from hardening or cracking when using some welding electrodes. However, no postheating may be required when welding low alloy steel using E310-15.

- Temperature service—Weld metals react differently to temperature extremes. Some welds become very brittle and crack easily in cryogenic (low-temperature) service. A few weld metals resist creep and oxidation at high temperatures. For example, E310Mo-15 can weld on most stainless and mild steels without any high-temperature problems.

- Mechanical properties—Mechanical properties such as tensile strength, yield strength, hardness, toughness, ductility, and impact strength can be modified by the selection of specific welding electrodes.

- Postwelding cleanup—The hardness or softness of the weld greatly affects any grinding, drilling, or machining. The ease with which the slag can be removed and the quantity of spatter will affect the time and amount of cleanup required.

- Shop or field weld—The general working conditions such as wind, dirt, cleanliness, dryness, and accessibility of the weld will affect the choice of the welding electrode. For example, the E7018 electrode must be kept very dry, but the E6010 electrode is not as affected by moisture.

- Quantity of welds—If a few welds are needed, a more expensive welding electrode requiring less skill may be selected. For a large production job requiring a higher skill level, a less expensive welding electrode may be best.

After deciding the specific conditions that may affect the welding, you have most likely identified more than one condition that needs to be satisfied.

Some of the conditions will not interfere with others. For example, the type of current and whether a welder makes one or more weld passes have little or no effect on each other. However, if a welder needs to machine the finished weld, hardness is a consideration. When two or more conditions conflict, you are seldom the person who will make the decision. It may be necessary to choose more than one welding electrode. When welding pipe, E6010 and E6011 are often used for the root pass because of their penetration characteristics, and E7018 is used for the cover pass because of its greater strength and resistance to cracking.

Each AWS electrode classification has its own welding characteristics. Some manufacturers have more than one welding electrode in some classifications. In these cases, the minimum specifications for the classification have been exceeded. An example of more than one welding electrode in a single classification is Lincoln’s Fleetweld 35, Fleetweld 35LS, and Fleetweld 180R. These electrodes are all in AWS classification E6011. For the manufacturer’s complete description of these electrodes, consult Table 26-1.

The characteristics of each manufacturer’s filler metals can be compared to one another by using data sheets supplied by the manufacturer. General comparisons can be made easily using an electrode comparison chart. When making an electrode selection, many variables must be kept in mind, and the performance characteristics must be compared before making a final choice.

**AWS Filler Metal Classifications**

The AWS classification system uses a series of letters and numbers in a code that gives the important information about the filler metal. The prefix letter is used to indicate the filler’s form, a type of process the filler is to be used with, or both. The prefix letters and their meanings are as follows:

- **E**—Indicates an arc welding electrode. The filler carries the welding current in the process. We most often think of the E standing for an SMA “stick” welding electrode. It also is used to indicate wire electrodes used in GMAW, FCAW, SAW, ESW, EGW, etc.

- **R**—Indicates a rod that is heated by some source other than electric current flowing directly through it. Welding rods are sometimes referred to as being “cut length” or “welding wire.” It is often used with OFW and GTAW.
### Electrode Identification and Operating Data

<table>
<thead>
<tr>
<th>Coating Color</th>
<th>AWS Number on Coating</th>
<th>(L) Lincoln</th>
<th>Electrode</th>
<th>Electrode Polarities</th>
<th>Sizes and Current Ranges (Amps)</th>
<th>(Electrodes Are Manufactured in These Sizes for Which Current Ranges Are Given)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brick red</td>
<td>6010</td>
<td></td>
<td>Fleetweld SP</td>
<td>DC+2</td>
<td>40–75</td>
<td>75–130</td>
</tr>
<tr>
<td>Gray</td>
<td>6011</td>
<td></td>
<td>Fleetweld 35</td>
<td>AC</td>
<td>50–85</td>
<td>75–120</td>
</tr>
<tr>
<td>Brown</td>
<td>6011</td>
<td></td>
<td>Fleetweld 180</td>
<td>AC</td>
<td>40–90</td>
<td>60–120</td>
</tr>
<tr>
<td>Pink</td>
<td>7010-A1</td>
<td>Green</td>
<td>Shield-arc 85</td>
<td>DC+</td>
<td>50–90</td>
<td>75–130</td>
</tr>
<tr>
<td>Pink</td>
<td>7010-A1</td>
<td>Green</td>
<td>Shield-arc 85P</td>
<td>DC+</td>
<td>50–90</td>
<td>75–130</td>
</tr>
<tr>
<td>Gray</td>
<td>8010-G</td>
<td></td>
<td>Shield-arc 70+</td>
<td>DC+</td>
<td>75–130</td>
<td>90–185</td>
</tr>
</tbody>
</table>

1) Range for 5/16" size is 240–400 amps. DC+ is Electrode Positive. DC− is Electrode Negative.

All tests were performed in conformance with specifications AWS A5.5 and ASME SFA5.5 in the aged condition for the E7010-G and E8010-G electrodes and in the stress-relieved condition for Shield-Arc 85 & 85P. Tests for the other products were performed in conformance with specifications AWS A5.1 and ASME SF A5.1 for the as-welded condition.

### Typical Mechanical Properties

Low figures in the stress-relieved tensile and yield strength ranges below for Shield-Arc 85 and 85P are AWS minimum requirements.

Low figures in the as-welded tensile and yield strength ranges below for the other products are AWS minimum requirements.

<table>
<thead>
<tr>
<th>Properties</th>
<th>Fleetweld 5P</th>
<th>Fleetweld 3S</th>
<th>Fleetweld 3SLS</th>
<th>Fleetweld 180</th>
<th>Shield-arc 85</th>
<th>Shield-arc 85P</th>
<th>Shield-arc Hyp</th>
<th>Shield-arc 70+</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tensile strength—psi</td>
<td>62–69,000</td>
<td>62–68,000</td>
<td>62–67,000</td>
<td>62–71,000</td>
<td>70–78,000</td>
<td>70–78,000</td>
<td>70–84,000</td>
<td>80–92,000</td>
</tr>
<tr>
<td>Yield point—psi</td>
<td>52–62,000</td>
<td>50–62,000</td>
<td>50–60,000</td>
<td>50–64,000</td>
<td>60–71,000</td>
<td>56–63,000</td>
<td>60–77,000</td>
<td>67,000–83,000</td>
</tr>
<tr>
<td>Charpy V-notch toughness—ft. lb</td>
<td>20–60</td>
<td>20–90</td>
<td>20–57</td>
<td>20–54</td>
<td>68 @ 70°F</td>
<td>68 @ 70°F</td>
<td>30 @ 20°F</td>
<td>40 @ 50°F</td>
</tr>
<tr>
<td>Hardness, Rockwell B (avg)³</td>
<td>76–82</td>
<td>76–85</td>
<td>73–88</td>
<td>75–85</td>
<td>83–92</td>
<td>88–93</td>
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<tr>
<td>Stress-relieved @ 1150°F tensile strength—psi</td>
<td>60–69,000</td>
<td>60–66,000</td>
<td>60–65,000</td>
<td>70–83,000</td>
<td>70–74,000</td>
<td>80–82,000</td>
<td>80–84,000</td>
<td></td>
</tr>
<tr>
<td>Yield point—psi</td>
<td>46–56,000</td>
<td>46–56,000</td>
<td>46–51,000</td>
<td>57–69,000</td>
<td>57–65,000</td>
<td>72–76,000</td>
<td>71–76,000</td>
<td></td>
</tr>
<tr>
<td>Charpy V-notch toughness—ft. lb</td>
<td>71 @ 70°F</td>
<td>120 @ 70°F</td>
<td>64 @ 70°F</td>
<td>68 @ 70°F</td>
<td>68 @ 70°F</td>
<td>30 @ –20°F</td>
<td>30 @ –50°F</td>
<td></td>
</tr>
<tr>
<td>Hardness, Rockwell B (avg)³</td>
<td>80–89</td>
<td>80–87</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

³Hardness values obtained from welds made in accordance with AWS A5.1.

Conformance certificate available.

### Conformances and Approvals

See Lincoln Price Book for certificate numbers, size, and position limitations, and other data.

<table>
<thead>
<tr>
<th></th>
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<td>A1</td>
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</tr>
<tr>
<td>American Bureau of Shipping and U.S. Coast Guard</td>
<td>Approved</td>
<td>Approved</td>
<td>Approved</td>
<td>Approved</td>
<td>Approved</td>
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</tr>
<tr>
<td>Conformance certificate available</td>
<td>Yes</td>
<td>Yes</td>
<td>Approved</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
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<td>Lloyds</td>
<td>Approved</td>
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<td>Military specifications</td>
<td>MIL-QE-450</td>
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<td>MIL-QE-450</td>
<td>MIL-E-22200/7</td>
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<td></td>
<td></td>
</tr>
</tbody>
</table>

³Hardness values obtained from welds made in accordance with AWS A5.1.

⁴Certificate of Conformance to AWS classification test requirements is available. These are needed for Federal Highway Administration projects.

Table 26-1  Fleetweld 35®, Fleetweld 35LS®, and Fleetweld 180® Lincoln Electrodes (Lincoln Electric Company)
welding current to be used with stainless steel covered electrodes.

**Carbon Steel**

**Carbon and Low Alloy Steel Covered Electrodes**

The AWS specification for carbon steel covered arc electrodes is A5.1, and for low alloy steel covered arc electrodes it is A5.5. Filler metals classified within these specifications are identified by a system that uses the letter E followed by a series of numbers to indicate the minimum tensile strength of a good weld, the position(s) in which the electrode can be used, the type of flux coating, and the type(s) of welding current, Figure 26-5.

The tensile strength is given in pounds per square inch (psi). The actual strength is obtained by adding three zeros to the right of the number given. For example, E60XX is 60,000 psi, E110XX is 110,000 psi, and so on.

The next number located to the right of the tensile strength—1, 2, or 4—designates the welding position capable—for example:

- **1**—in an E601X means all positions flat, horizontal, vertical, and overhead.
- **2**—in an E602X means horizontal fillets and flat.
- **3**—is an old term no longer used; it meant flat only.
- **4**—in an E704X means flat, horizontal, overhead, and vertical-down.

The last two numbers together indicate the major type of covering and the type of welding current. For example, EXX10 has an organic covering and uses DCEP polarity. The AWS classification system for A5.1 and A5.5 covered arc welding electrodes is shown in Table 26-2. The type of welding current for

In addition to the prefix, there are some suffix identifiers. The suffix may be used to indicate a change in the alloy in a covered electrode or the type of welding current to be used with stainless steel covered electrodes.

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**Carbon and Low Alloy Steel Covered Electrodes**

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In addition to the prefix, there are some suffix identifiers. The suffix may be used to indicate a change in the alloy in a covered electrode or the type of welding current to be used with stainless steel covered electrodes.
Some of the more popular arc welding electrodes and their uses in these specifications are as follows.

**E6010**

The E6010 electrodes are designed to be used with DCEP polarity and have an organic-based flux (cellulose, C6H10O5). They have a forceful arc that results in deep penetration and good metal transfer in the vertical and overhead positions, Figure 26-6. The electrode is usually used with a whipping or stepping motion. This motion helps remove unwanted surface materials such as paint, oil, dirt, and galvanizing. Both the burning of the organic compound in the flux to form CO₂, which protects the molten metal, and the rapid expansion of the hot gases force the atmosphere away from the weld. A small amount of slag remains on the finished weld, but it is difficult to remove, especially along the weld edges. E6010 electrodes are commonly used for welding on pipe and in construction jobs, and for doing repair work.
E6010 or E6011, the weld pool may be slightly concave from the forceful action of the rapidly expanding gas. This forceful action also results in more spatter and sparks during welding. E6011 is the most commonly used electrode for agricultural welding.

E6012

The E6012 electrodes are designed to be used with AC or DCEN polarity and have rutile-based flux (titanium dioxide, TiO\(_2\)). This electrode has a very stable arc that is not very forceful, resulting in a shallow penetration characteristic, Figure 26-8. This limited penetration characteristic helps with poor-fitting joints or thin materials. Thick sections can be welded, but the joint must be grooved. Less smoke is generated with this welding electrode than with E6010 or E6011, but a thicker slag layer is deposited on the weld. If the weld is properly made, the slag can be removed easily and may even free itself after cooling. Spatter can be held to a minimum when using both AC and DC. E6012 electrodes are commonly used for all new work, including storage tanks, machinery fabrication, ornamental iron, and general repair work.

Table 26-4  Major Alloying Elements in Electrodes

<table>
<thead>
<tr>
<th>Suffix Symbol</th>
<th>Molybdenum (Mo) %</th>
<th>Nickel (Ni) %</th>
<th>Chromium (Cr) %</th>
<th>Manganese (Mn) %</th>
<th>Vanadium (Va) %</th>
</tr>
</thead>
<tbody>
<tr>
<td>A 1</td>
<td>0.5</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
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*Only one of these alloys may be used.

Figure 26-6 E6010. © Cengage Learning 2012

Figure 26-7 E6011. © Cengage Learning 2012

Figure 26-8 E6012. © Cengage Learning 2012
E6013

The E6013 electrodes are designed to be used with AC or DC, either polarity. They have a rutile-based flux. The E6013 electrode has many of the same characteristics of the E6012 electrode, Figure 26-9. The slag layer is usually thicker on the E6013 and is easily removed. The arc of the E6013 is as stable, but there is less penetration, which makes it easier to weld very thin sections. The weld bead will also be built up slightly higher than the E6012. E6013 electrodes are commonly used for sheet metal fabrication, metal buildings, surface buildup, truck and tractor work, and other farm equipment.

E7014

The E7014 electrodes are designed to be used with AC or DC, either polarity. They have a rutile-based flux with iron powder added. The E7014 electrode has many arc and weld characteristics that are similar to those of the E6013 electrode, Figure 26-10. Approximately 30% iron powder is added to the flux to allow it to build up a weld faster or have a higher travel speed. The penetration characteristic is light. This welding electrode can be used on metal with a light coating of rust, dirt, oil, or paint. The slag layer is thick and hard but can be completely removed with chipping. E7014 electrodes are commonly used for welding on heavy sheet metal, ornamental iron, machinery, frames, and general repair work.

E7024

The E7024 electrodes are designed to be used with AC or DC, either polarity. They have a rutile-based flux with iron powder added. This welding electrode has a light penetration and fast-fill characteristic, Figure 26-11. The flux contains about 50% iron powder, which gives the flux its high rate of deposition. The heavy flux coating helps control the arc and can support the electrode so that a drag technique can be used. The drag technique allows this electrode to be used by welders with less skill. The slag layer is heavy and hard but can easily be removed. If the weld is performed correctly, the slag may remove itself. Because of the large, fluid molten weld pool, this electrode is equally used in the flat and horizontal position only, although it can be used on work that is slightly vertical. E7024 electrodes are commonly used in welding new equipment.

E7016

The E7016 electrodes are designed to be used with AC or DCEP polarity. They have a low-hydrogen–based (mineral) flux. This electrode has moderate penetration and little buildup, Figure 26-12. There is no iron powder in the flux, which helps when welding in the vertical or overhead positions. Welds on high sulfur and cold-rolled metals can be made with little porosity. Low alloy and mild steel heavy plates
Wire-Type Carbon Steel Filler Metals

Solid Wire

The AWS specification for carbon steel filler metals for gas shielded welding wire is A5.18. Filler metal classified within these specifications can be used for GMAW, GTAW, and PAW processes. Because in GTAW and PAW the wire does not carry the welding current, the letters ER are used as a prefix. The ER is followed by two numbers to indicate the minimum tensile strength of a good weld. The actual strength is obtained by adding three zeros to the right of the number given. For example, ER70S-x is 70,000 psi.

The S located to the right of the tensile strength indicates that this is a solid wire. The last number—2, 3, 4, 5, 6, or 7—or the letter G is used to indicate the filler metal composition and the weld’s mechanical properties, Figure 26-14.

ER70S-2

This is a deoxidized mild steel filler wire. The deoxidizers allow this wire to be used on metal that has light coverings of rust or oxides. There may be a slight reduction in the weld’s physical properties if the weld is made on rust or oxides, but this reduction is only slight, and the weld will usually still pass the classification test standards. This is a general purpose filler that can be used on killed, semikilled, and rimmed steels. Argon-oxygen, argon-CO$_2$, and CO$_2$ can be used as shielding gases. Welds can be made in all positions.

can be welded with minimum preheating. E7016 electrodes are commonly used for building construction and equipment fabrication.

E7018

The E7018 electrodes are designed to be used with AC or DCEP, either polarity. They have a low-hydrogen–based flux with iron powder added. The E7018 electrodes have moderate penetration and buildup, Figure 26-13. The slag layer is heavy and hard but can be removed easily by chipping. The weld metal is protected from the atmosphere primarily by the molten slag layer and not by rapidly expanding gases. For this reason, these electrodes should not be used for open root welds. The atmosphere may attack the root, causing a porosity problem. The E7018 welding electrodes are very susceptible to moisture, which may lead to weld porosity. These electrodes are commonly used for pipe, plate, trailer axles, and low-temperature equipment. E7018 electrodes are sometimes referred to as Lo-Hi rods because they allow very little hydrogen into the weld pool.
ER70S-3
This is a popular agricultural filler wire. It can be used in single- or multiple-pass welds in all positions. ER70S-3 does not have the deoxidizers required to weld over rust, over oxides, or on rimmed steels. It produces high-quality welds on killed and semikilled steels. Argon-oxygen, argon-CO₂, and CO₂ can be used as shielding gases.

ER70S-6
This is a good general purpose filler wire. It has the highest levels of manganese and silicon. The wire can be used to make smooth welds on sheet metal or thicker sections. Welds over rust, oxides, and other surface impurities will lower the mechanical properties, but not normally below the specifications of this classification. Argon-oxygen, argon-CO₂, and CO₂ can be used as shielding gases. Welds can be made in all positions.

Tubular Wire
The AWS specification for carbon steel filler metals for flux cored arc welding wire is A5.20. Filler metal classified within this specification can be used for the FCAW process. The letter E, for electrode, is followed by a single number to indicate the minimum tensile strength of a good weld. The actual strength is obtained by adding four zeros to the right of the number given. For example, E6xT-x is 60,000 psi, and E7xT-x is 70,000 psi.

The next number, 0 or 1, indicates the welding position. Ex0T is to be used in a horizontal or flat position only. Ex1T is an all-position filler metal.

The T located to the right of the tensile strength and weld position numbers indicates that this is a tubular, flux cored wire. The last number—2, 3, 4, 5, 6, 7, 8, 10, or 11—or the letter G or GS is used to indicate if the filler metal can be used for single- or multiple-pass welds. The electrodes with the numbers ExxT-2, ExxT-3, ExxT-10, and ExxT-GS are intended for single-pass welds only, Figure 26-15.

E70T-1, E71T-1
E70T-1 and E71T-1 have a high-level deoxidizer in the flux core. They have high levels of silicon and manganese, which allow it to weld over some surface contaminations such as oxides or rust. This filler metal can be used for single- or multiple-pass welds. Argon 75% with 25% CO₂ or 100% CO₂ can be used as the shielding gas. It can be used on ASME A36, A106, A242, A252, A285, A441, and A572 or similar metals. Applications include railcars, heavy equipment, earth-moving equipment, shipbuilding, and general fabrication. The weld metal deposited has a chemical and physical composition similar to that of E7018 low-hydrogen electrodes.

E70T-2, E71T-2
E70T-2 and E71T-2 are highly deoxidized flux cored filler metal that can be used for single-pass welds only. The high levels of deoxidizers allow this electrode to
be used over mill scale and light layers of rust and still produce sound welds. Because of the high level of manganese, if the filler is used for multiple-pass welds, there might be manganese-caused center-line cracking of the weld; 100% CO₂ can be used as the shielding gas. E70T-2 can be used on ASME A36, A106, A242, A252, A285, A441, and A572 or similar metals. Applications include repair and maintenance work and general fabrication.

**E70T-4, E71T-4**

E70T-4 and E71T-4 are self-shielding, flux cored filler metal. The fluxing agents produce a slag, which allows a larger-than-usual molten weld pool. The large weld pool permits high deposition rates. Weld deposits are ductile and have a high resistance to cracking. E70T-4 can be used to weld joints that have larger-than-usual root openings. Applications include large weldments and earth-moving equipment.

**E71T-7**

E71T-7 is a self-shielding, all-position, flux cored filler metal. The fluxing system allows the control of the molten weld pool required for out-of-position welds. The high level of deoxidizers reduces the tendency for cracking in the weld. It can be used for single- or multiple-pass welds.

**Stainless Steel Electrodes**

The AWS specification for stainless steel covered arc electrodes is A5.4 and for stainless steel bare, cored, and stranded electrodes and welding rods is A5.9. Filler metal classified within the A5.4 uses the letter E as its prefix, and the filler metal within the A5.9 uses the letters ER as its prefix, Table 26-5.

Following the prefix, the American Iron and Steel Institute’s (AISI) three-digit stainless steel number is used. This number indicates the type of stainless steel in the filler metal.

To the right of the AISI number, the AWS adds a dash followed by a suffix number. The number 15 is used to indicate that there is a lime base coating, and the DCEP polarity welding current should be used. The number 16 is used to indicate there is a titania-type coating, and AC or DCEP polarity welding currents can be used. Examples of this classification system are E308-15 and E308-16 electrodes.

The letter L may be added to the right of the AISI number before the dash and suffix number to indicate a low-carbon stainless welding electrode. E308L-15 and E308L-16 arc welding electrodes and ER308L and ER316L are examples of the use of the letter L, Table 26-6.

Stainless steel may be stabilized by adding columbium (Cb) as a carbide former. The designation Cb is added after the AISI number for these electrodes, such as E309Cb-16. Stainless steel filler metals are stabilized to prevent chromium-carbide precipitation.

**E308-15, E308-16, E308L-15, E308-16, ER308, and ER308L**

All are filler metals for 308 stainless steels, which are used for food or chemical equipment, tanks, pumps, hoods, and evaporators. All E308 and ER308 filler metals can be used to weld on all 18-8-type stainless steels such as 301, 302, 302B, 303, 304, 305, 308, 201, and 202.


All are filler metals for 309 stainless steels, which are used for high-temperature service, such as furnace parts and mufflers. All E309 filler metals can be used to weld on 309 stainless or to join mild steel to any 18-8-type stainless steel.


All are filler metals for 310 stainless steels, which are used for high-temperature service where low creep is desired, such as for jet engine parts, valves, and furnace parts. All E310 filler metals can be used to weld 309 stainless or to join mild steel to stainless or to weld most hard-to-weld carbon and alloy steels. E310Mo-15 and 16 electrodes have molybdenum added to improve their strength at high temperatures and to resist corrosive pitting.

**E316-15, E316-16, E316L-15, E316L-16, ER316, ER316L, and ER316L-Si**

All are filler metals for 316 stainless steels, which are used for high-temperature service where high strength with low creep is desired. Molybdenum is added to improve these properties and to resist corrosive pitting.
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†Preheat.
††No preheat necessary.

Note: Bold numbers indicate first choice; light numbers indicate second and third choices. This choice can vary with specific applications and individual job requirements.

**Table 26-5** Filler Metal Selector Guide for Joining Different Types of Stainless Steel to the Same Type or Another Type of Stainless Steel (Thermacote Welco)
<table>
<thead>
<tr>
<th>UTP Designation</th>
<th>AWS/SFA5.4 Covered</th>
<th>AWS/SFA5.9 TIG and MIG</th>
<th>Description and Applications</th>
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<tbody>
<tr>
<td><strong>6820</strong></td>
<td>E 308-16</td>
<td>ER 308</td>
<td>For welding conventional 308 type SS</td>
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<tr>
<td><strong>68 Kb</strong></td>
<td>E 308-15</td>
<td>ER 308L</td>
<td>Low hydrogen coating</td>
</tr>
<tr>
<td><strong>6820 Lc</strong></td>
<td>E 308 L-16</td>
<td>ER 308L</td>
<td>Low carbon grade, prevents carbide precipitation adjacent to weld</td>
</tr>
<tr>
<td><strong>308L Fe Hp</strong></td>
<td>E 308 L-16</td>
<td>ER 308L</td>
<td>Fast depositing for maintenance and production coating</td>
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<td><strong>68 LcHL</strong></td>
<td>E 308 L-16</td>
<td>ER 308L</td>
<td>High-performance electrode with rutile-acid coating, core wire alloyed, for stainless and acid-resisting CrNi steels</td>
</tr>
<tr>
<td><strong>68 LcKb</strong></td>
<td>E 308 L-15</td>
<td>ER 309</td>
<td>Low carbon electrode for stainless, acid-resisting CrNi steels</td>
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<tr>
<td><strong>6824</strong></td>
<td>E 309-16</td>
<td>ER 309</td>
<td>For welding 309 type SS and carbon steel to SS</td>
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<tr>
<td><strong>6824 Kb</strong></td>
<td>E 309-15</td>
<td>ER 309</td>
<td>Special lime-coated electrode for corrosion and heat-resistant 22/12 CrNi steels</td>
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<tr>
<td><strong>6824 Lc</strong></td>
<td>E 309 L-16</td>
<td>ER 309L</td>
<td>Same as 309 but with low carbon content</td>
</tr>
<tr>
<td><strong>6824 Nb</strong></td>
<td>E 309 Cb-16</td>
<td>ER 309</td>
<td>Corrosion and heat-resistant 22/12 CrNi steels</td>
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<tr>
<td><strong>6824 MoNb</strong></td>
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<td>ER 309</td>
<td>Corrosion and heat-resistant 22/12 CrNi steels</td>
</tr>
<tr>
<td><strong>309L Fe Hp</strong></td>
<td>E 309 L-16</td>
<td>ER 309</td>
<td>High deposition rate, easy to use</td>
</tr>
<tr>
<td><strong>6824 Mo Lc</strong></td>
<td>E 309 L-16</td>
<td>ER 309</td>
<td>For welding similar and dissimilar SS</td>
</tr>
<tr>
<td><strong>68H</strong></td>
<td>E 310-16</td>
<td>ER 310</td>
<td>For high-temperature service and cladding steel</td>
</tr>
<tr>
<td><strong>6820 Mo</strong></td>
<td>E 316-16</td>
<td>ER 316</td>
<td>For welding acid-resistant stainless steels</td>
</tr>
<tr>
<td><strong>6820 Mo Lc</strong></td>
<td>E 316 L-16</td>
<td>ER 316L</td>
<td>Low carbon grade, prevents intergranular corrosion</td>
</tr>
<tr>
<td><strong>68 Ti Mo</strong></td>
<td>E 316 L-16</td>
<td>ER 316L</td>
<td>Most efficient type, for maintenance and production, high performance</td>
</tr>
<tr>
<td><strong>68 MoLcHL</strong></td>
<td>E 316 L-16</td>
<td>ER 316L</td>
<td>High-performance electrode with rutile-acid coating, core wire alloyed, for stainless and acid-resisting CrNiMo steels</td>
</tr>
<tr>
<td><strong>68 MoLcKb</strong></td>
<td>E 316 L-15</td>
<td>ER 316L</td>
<td>Low carbon electrode for stainless and acid-resisting CrNiMo steels</td>
</tr>
<tr>
<td><strong>317 Lc Titan</strong></td>
<td>E 317 L-16</td>
<td>ER 317L</td>
<td>Deposit resists sulphuric acid corrosion</td>
</tr>
</tbody>
</table>

**Table 26-6** Stainless Steel Electrodes, Filler Metals, and Wires (UTP Welding Materials, Inc.)
E316 filler metals are used for welding tubing, chemical pumps, filters, tanks, and furnace parts. All E316 filler metals can be used on 316 stainless steels or when weld resistance to pitting is required.

**Nonferrous Electrode**

The AWS identification system for covered nonferrous electrodes is based on the atomic symbol or symbols of the major alloy(s) or the metal’s identification number. The alloy having the largest percentage appears first in the identification. The atomic symbol is prefixed by the letter E. For example, ECu is a covered copper arc welding electrode, and ECuNiAl is a copper-nickel-aluminum alloy covered arc welding electrode. A letter, number, or letter-number combination may be added to the right of the atomic symbol to indicate some special alloys. For example, ECuAl-A2 is a copper-aluminum welding electrode that has 1.59% iron added.

**Aluminum and Aluminum Alloys**

The AWS specifications for aluminum and aluminum alloy filler metals are A5.3 for covered arc welding electrodes and A5.10 for bare welding rods and electrodes. Filler metal classified within the A5.3 uses the atomic symbol Al, and in the A5.10 the prefix ER is used with the Aluminum Association number for the alloy, Table 26-7.

**Aluminum Covered Arc Welding Electrodes**

**Al-2 and Al-43**

The aluminum electrodes do not use the letter E before the electrode number. Aluminum covered arc welding electrodes are designed to weld with DCEP polarity. These electrodes can be used on thin or thick sections, but thick sections must be preheated to between 300°F (150°C) and 600°F (315°C). The preheating of these thick sections allows the weld to penetrate immediately when the weld starts. Aluminum arc welding electrodes can be used on 2024, 3003, 5052, 5154, 5454, 6061, and 6063 aluminum. When welding on aluminum, a thin layer of surface oxide may not prevent welding. Thicker oxide layers must be removed mechanically or chemically. Excessive penetration can be supported by carbon plates or carbon paste. Most arc welding electrodes can also be used for oxyfuel gas welding of aluminum.

**Aluminum Bare Welding Rods and Electrodes**

**ER1100**

1100 aluminum has the lowest percentage of alloy agents of all of the aluminum alloys, and it melts at 1215°F (657°C). The filler wire is also relatively pure. ER1100 produces welds that have good corrosion resistance and high ductility, with tensile strengths ranging from 11,000 to 17,000 psi. The weld deposit has a high resistance to cracking during welding. This wire can be used with OFW, GTAW, and GMAW. Preheating to 300°F to 350°F (150°C to 175°C) is required for GTA welding on plate or pipe 3/8 in. (10 mm) and thicker to ensure good fusion. Flux is required for OFW. 1100 aluminum is commonly used for items such as food containers, food-processing equipment, storage tanks, and heat exchangers. ER1100 can be used to weld 1100 and 3003 grade aluminum.

**ER4043**

ER4043 is a general purpose welding filler metal. It has 4.5 to 6.0% silicon added, which lowers its melting temperature to 1155°F (624°C). The lower melting temperature helps promote a free-flowing molten weld pool. The weld has high ductility and a high resistance to cracking during welding. This wire can be used with OFW, GTAW, and GMAW. Preheating to 300°F to 350°F (150°C to 175°C) is required for GTA welding on plate or pipe 3/8 in. (10 mm) and thicker to ensure good fusion. Flux is required for OFW. ER4043 can be used to weld on 2014, 3003, 3004, 4043, 5052, 6061, 6062, and 6063 and cast alloys 43, 355, 356, and 214.

**ER5356**

ER5356 has 4.5 to 5.5% magnesium added to improve the tensile strength. The weld has high ductility but only an average resistance to cracking during welding. This wire can be used for GTAW and GMAW. Preheating to 300°F to 350°F (150°C to 175°C) is required for GTA welding on plate or pipe 3/8 in. (10 mm) and thicker to ensure good fusion. ER5356 can be used to weld on 5050, 5052, 5056, 5083, 5086, 5154, 5356, 5454, and 5456.

**ER5556**

ER5556 has 4.7 to 5.5% magnesium and 0.5 to 1.0% manganese added to produce a weld with high strength.
CHAPTER 26

Special Purpose Filler Metals

ENi

The nickel arc welding electrodes are designed to be used with AC or DCEP polarity. These arc welding electrodes are used for cast-iron repair. The carbon in cast iron will not migrate into the nickel weld metal, and the weld has high ductility and only average resistance to cracking during welding. This wire can be used for GTAW and GMAW. Preheating to 300°F to 350°F (150°C to 175°C) is required for GTA welding on plate or pipe 3/8 in. (10 mm) and thicker to ensure good fusion. ER5556 can be used to weld on 5052, 5083, 5356, 5454, and 5456.

Table 26-7  Recommended Filler Metals for Joining Different Types of Aluminum to the Same Type or a Different Type of Aluminum  (Thermacote Welco)

The weld has high ductility and only average resistance to cracking during welding. This wire can be used for GTAW and GMAW. Preheating to 300°F to 350°F (150°C to 175°C) is required for GTA welding on plate or pipe 3/8 in. (10 mm) and thicker to ensure good fusion. ER5556 can be used to weld on 5052, 5083, 5356, 5454, and 5456.

Special Purpose Filler Metals

ENi

The nickel arc welding electrodes are designed to be used with AC or DCEP polarity. These arc welding electrodes are used for cast-iron repair. The carbon in cast iron will not migrate into the nickel weld metal, and the weld has high ductility and only average resistance to cracking during welding. This wire can be used for GTAW and GMAW. Preheating to 300°F to 350°F (150°C to 175°C) is required for GTA welding on plate or pipe 3/8 in. (10 mm) and thicker to ensure good fusion. ER5556 can be used to weld on 5052, 5083, 5356, 5454, and 5456.
thus preventing cracking and embrittlement. The cast iron may or may not be preheated. A very short arc length and a fast travel rate should be used with these electrodes.

**ECuAl**

The aluminum bronzed welding electrodes are designed to be used with DCEP polarity. This welding electrode has copper as its major alloy. The aluminum content is at a much lower percentage. Iron is usually added but at a percentage that is very low. These electrodes are sometimes referred to as arc brazing electrodes, although this is not an accurate description. Stringer beads and a short arc length should be used with these electrodes. Aluminum bronze welding electrodes are used for overlaying bearing surfaces; welding on castings of manganese, bronze, brass, or aluminum bronze; or assembling dissimilar metals.

**Surface and Buildup Electrode Classification**

Hardfacing or wear-resistant electrodes are the most popular special purpose electrodes; however, there are also cutting and brazing electrodes. Specialty electrodes may be identified by manufacturers’ trade names. Most manufacturers classify or group hard-facing or wear-resistant electrodes according to their resistance to impact, abrasion, or corrosion. Occasionally, electrode resistance to wear at an elevated temperature is listed. One electrode may have more than one characteristic or type of service listed.

**SUMMARY**

Proper filler metal selection is one of the most important factors affecting the successful welding of a joint. Many factors affect the selection of the most appropriate filler metal for a job. In some cases, cost is the greatest factor and in others it is structural strength. For example, if you were building an ultralight aircraft, you would be more concerned with strength than cost. However, if you were building an iron fence, you might be more concerned with cost. Every application is different, so it may be a help for you to list the items you feel are most important for selecting a filler metal. This will help you select the most appropriate filler metal for your needs.

Manufacturers’ literature on filler metals can be divided into two general sections. One section of the literature is technical and the other is advertisement. In the technical section you are provided with specific information on each filler metal’s operation, performance, and uses. In the advertisement section you are provided with marketing information and claims regarding performance. Knowing the types
of information in both sections will help you evaluate new material as you select filler metal.

If you are considering a large purchase of filler metals, it is advantageous for you to request samples of the various filler metals from manufacturers so that you can test their performance in your applications.

Pretesting of the products in your applications gives you an opportunity to determine which filler metal is going to give you the best value for your money. It may also be necessary to qualify the filler metal for your welding certification program before you make the purchase and begin using the product.

### REVIEW QUESTIONS

1. List various identification methods by which manufacturers may identify their filler metals.
2. What is the most widely used numbering and lettering system for filler metals?
3. Where is the identification number located?
4. Where would you go to find information that pertains directly to a specific filler metal?
5. What general information about the electrode may be given by the manufacturer?
6. How can you use the information supplied by the manufacturer about the electrodes?
7. What does minimum tensile strength psi mean?
8. What kind of information about the chemical analysis of the electrodes is provided by the manufacturer?
9. What are some of the other names for shielded metal arc welding electrodes?
10. What are the two parts of a shielded metal arc welding electrode?
11. What are the functions of the core wire in an electrode?
12. What is the purpose of the shielding gas?
13. What is the purpose of alloying elements in the flux?
14. What effect can welding fluxes have on the weld bead?
15. Why is the selection of the best filler metal for a job in large shops seldom delegated to the welder?
16. If a filler metal was labeled by the AWS classification system with the letters RG, what information does that provide about the filler metal?
17. Using the AWS classification system, what do the series of numbers following the letter E indicate on a carbon and low alloy steel covered electrode?
18. What would be the minimum tensile strength of a good weld for a wire-type carbon steel filler metal labeled ER70S-x?
19. In the AWS identification system for covered nonferrous electrodes, what is the meaning of the symbols immediately following the $E$?
20. What type of polarity are aluminum covered arc welding electrodes designed to be welded with?