CHAPTER 3

Flux Cored Arc Welding Equipment, Setup, and Operation

OBJECTIVES

After completing this chapter, the student should be able to

- describe the flux cored arc (FCA) welding process
- list the equipment required for an FCA welding workstation
- list five advantages of FCA welding, and explain four of its limitations
- tell how electrodes are manufactured and explain the purpose of the electrode cast and helix
- list four things flux can provide to the weld and how fluxes are classified
- explain what each of the digits in a standard FCAW electrode identification number mean
- describe the proper care and handling of FCAW electrodes
- list two common shielding gases used in FCAW, and contrast their benefits related to cost, productivity, and quality
- list three differences in an FCA weld when the gun angle is changed
- identify the two modes of metal transfer and contrast them in regard to application and quality
- list four effects that electrode extension has on FCA welding
- list three things that can cause weld porosity and how it can be prevented

KEY TERMS

- air-cooled
- coils
- deoxidizers
- dual shield
- flux cored arc welding (FCAW)
- lime-based flux
- rutile-based flux
- self-shielding
- slag
- smoke extraction nozzles
- spools
- water-cooled

AWS SENSE EG2.0

Key Indicators Addressed in this Chapter:

Module 6: Flux Cored Arc Welding (FCAW-G, FCAW-S)

Key Indicator 1: Performs safety inspections of FCAW-G/GM, FCAW-S equipment and accessories

Key Indicator 2: Makes minor external repairs to FCAW-G/GM, FCAW-S equipment and accessories

Key Indicator 3: Sets up for FCAW-G/GM, FCAW-S operations on carbon steel
INTRODUCTION

Flux cored arc welding (FCAW) is a fusion welding process in which weld heating is produced from an arc between the work and a continuously fed filler metal electrode. Atmospheric shielding is provided completely or in part by the flux sealed within the tubular electrode, Figure 3.1. Extra shielding may or may not be supplied through a nozzle in the same way as in GMAW.

Although the process was introduced in the early 1950s, it represented less than 5% of the total amount of welding done in 1965. In 2005, it passed the 50% mark and is still rising. The rapid rise in the use of FCAW has been due to a number of factors. Improvements in the fluxes, smaller electrode diameters, increased reliability of the equipment, better electrode feed systems, and improved guns have all led to the increased usage. Guns equipped with smoke extraction nozzles and electronic controls are the latest in a long line of improvements to this process, Figure 3.2.

PRINCIPLES OF OPERATION

FCA welding is similar in a number of ways to the operation of GMA welding, Figure 3.3. Both processes use a constant-potential (CP) or constant-voltage (CV) power supply. Constant potential and voltage are terms that have the same meaning. CP power supplies provide a controlled voltage (potential) to the welding electrode. The amperage (current) varies with the speed that the electrode is being fed into the molten weld pool. Just as in GMA welding, higher electrode feed speeds produce higher currents and slower feed speeds result in lower currents, assuming all other conditions remain constant.

The effects on the weld of electrode extension, gun angle, welding direction, travel speed, and other welder manipulations are similar to those experienced in GMA welding. As in GMA welding, having a correctly set welder does not ensure a good weld. The skill of the welder is an important factor in producing high-quality welds.

The flux inside the electrode protects the molten weld pool from the atmosphere, improves strength through chemical reactions and alloys, and improves the weld shape.

Atmospheric contamination of molten weld metal occurs as it travels across the arc gap and within the pool before it solidifies. The major atmospheric contaminations come from oxygen and nitrogen, the major elements in air. The addition of fluxing and gas-forming elements to the core electrode reduces or eliminates their effects.

Improved strength and other physical or corrosion-resistant properties of the finished weld are improved by the flux. Small additions of alloying elements, deoxidizers, and gas-forming and slag agents all can improve the desired weld properties. Carbon, chromium, and vanadium can be added to improve hardness, strength, creep resistance, and corrosion resistance. Aluminum, silicon, and titanium all help remove oxides and/or nitrides in the weld. Potassium, sodium, and zirconium are added to the flux and form a slag.
A discussion of weld metal additives and flux elements and their effects on the weld can be found later in this chapter.

The flux core additives that serve as deoxidizers, gas formers, and slag formers either protect the molten weld pool or help to remove impurities from the base metal. Deoxidizers may convert small amounts of surface...
oxides like mill scale back into pure metal. They work much like the elements used to refine iron ore into steel.

Gas formers rapidly expand and push the surrounding air away from the molten weld pool. If oxygen in the air were to come in contact with the molten weld metal, the weld metal would quickly oxidize. Sometimes this can be seen at the end of a weld when the molten weld metal erupts in a shower of tiny sparks.

Figure 3.2 Smoke extraction
(A) FCA welding without smoke extraction and (B) with smoke extraction. (C) Typical FCAW smoke extraction gun. (D) Typical smoke exhaust system.
Source: Courtesy of Lincoln Electric Company
The slag covering of the weld is useful for several reasons. *Slag* is a nonmetallic product resulting from the mutual dissolution of the flux and nonmetallic impurities in the base metal. Slag helps the weld by protecting the hot metal from the effects of the atmosphere, controlling the bead shape by serving as a dam or mold, and serving as a blanket to slow the weld’s cooling rate, which improves its physical properties, Figure 3.4.

**EQUIPMENT**

**Power Supply**

The FCA welding power supply is the same type that is required for GMAW, called constant-potential, constant-voltage (CP, CV). The words *potential* and *voltage* have the same electrical meaning and are used interchangeably. FCAW machines can be much more powerful than GMAW machines and are available with up to 1500 amperes of welding power.

**Guns**

FCA welding guns are available as *water-cooled* or *air-cooled*, Figure 3.5. Although most of the FCA welding guns that you will find in schools are air-cooled, our industry often needs water-cooled guns because of the

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**Figure 3.3** Large-capacity wire-feed unit used with FCAW or GMAW

*Source: Courtesy of Lincoln Electric Company*

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**Figure 3.4** Slag blanketing the weld

The slag covering keeps the welding heat from escaping quickly, thus slowing the cooling rate.
higher heat caused by longer welds made at higher currents. The water-cooled FCA welding gun is more efficient than an air-cooled gun at removing waste heat. The air-cooled gun is more portable because it has fewer hoses, and it may be made lighter so it is easier to manipulate than the water-cooled gun.

Also, the water-cooled gun requires a water reservoir or another system to give the needed cooling. There are two major ways that water can be supplied to the gun for cooling. Cooling water can be supplied directly from the building’s water system, or it can be supplied from a recirculation system.

Cooling water supplied directly from the building’s water system is usually dumped into a wastewater drain once it has passed through the gun. When this type of system is used, a pressure regulator must be installed to prevent pressures that are too high from damaging the hoses. Water pressures higher than 35 psi (241 kg/mm²) may cause the water hoses to burst. Check valves must also be installed in the supply line to prevent contaminated water from being drawn back into the water supply. Some cities and states have laws that restrict the use of open systems because of the need for water conservation. Check with your city or state for any restrictions before installing an open water-cooling system.

Recirculating cooling water systems eliminate any of the problems associated with open systems. Chemicals may be added to the water in recirculating systems to prevent freezing, to aid in pump lubrication, and
to prevent algae growth. Only manufacturer-approved additives should be used in a recirculation system. Read all of the manufacturer’s safety and data sheets before using these chemicals.

**Smoke Extraction Nozzles**

Because of the large quantity of smoke that can be generated during FCA welding, systems for smoke extraction that fit on the gun have been designed, Figure 3.2B. These systems use a vacuum to pull the smoke back into a specially designed smoke extraction nozzle on the welding gun. The disadvantage of this slightly heavier gun is offset by the system’s advantages. The advantages of the system are as follows:

- Cleaner air for the welder to breathe because the smoke is removed before it rises to the welder’s face.
- Reduced heating and cooling cost because the smoke is concentrated, so less shop air must be removed with the smoke.

**Electrode Feed**

Electrode feed systems are similar to those used for GMAW; in fact many feed systems are designed with dual feeders so that solid wire and flux core may be run in sequence. The major difference is that the more robust FCAW feeders are designed to use large-diameter wire and most often have two sets of feed rollers. The two sets of rollers help reduce the drive pressure on the electrode. Excessive pressure can distort the electrode wire diameter, which can allow some flux to be dropped inside the electrode guide tube.

**ADVANTAGES**

FCA welding offers the welding industry a number of important advantages.

**High Deposition Rate**

High rates of depositing weld metal are possible. FCA welding deposition rates of more than 25 lb/hr (11 kg/hr) of weld metal are possible. This compares to about 10 lb/hr (5 kg/hr) for shielded metal arc (SMA) welding using a very large-diameter electrode of 1/4 in. (6 mm).

**Minimum Electrode Waste**

The FCA method makes efficient use of filler metal; from 75% to 90% of the weight of the FCAW electrode is metal, the remainder being flux. SMAW electrodes have a maximum of 75% filler metal; some SMAW electrodes have much less. Also, a stub must be left at the end of each SMA welding electrode. The stub will average 2 in. (51 mm) in length, resulting in a loss of 11% or more of the SMAW filler electrode purchased. FCA welding has no stub loss, so nearly 100% of the FCAW electrode purchased is used.
Narrow Groove Angle

Because of the deep penetration characteristic of FCAW, no edge-beveling preparation is required on some joints in metal up to 1/2 in. (13 mm) in thickness. When bevels are cut, the joint-included angle can be reduced to as small as 35°, Figure 3.6. The reduced groove angle results in a smaller-sized weld. This can save 50% of filler metal with about the same savings in time and weld power used.

Minimum Precleaning

The addition of deoxidizers, which combine with and remove harmful oxides on the base metal or its surface, and other fluxing agents permits high-quality welds to be made on plates with light surface oxides and mill scale. This eliminates most of the precleaning required before GMA welding can be performed. Often it is possible to make excellent welds on plates in the “as cut” condition; no cleanup is needed.

All-position Welding

Small-diameter electrode sizes in combination with special fluxes allow excellent welds in all positions. The slags produced assist in supporting the weld metal. This process is easy to use, and, when properly adjusted, it is much easier to use than other all-position arc welding processes.

Flexibility

Changes in power settings can permit welding to be done on thin-gauge sheet metals or thicker plates using the same electrode size. Multipass welds allow joining metals with no limit on thickness. This, too, is attainable with one size of electrode.

High Quality

Many codes permit welds to be made using FCAW. The addition of the flux gives the process the high level of reliability needed for welding on boilers, pressure vessels, and structural steel.
**Excellent Control**

The molten weld pool is more easily controlled with FCAW than with GMAW. The surface appearance is smooth and uniform even with less operator skill. Visibility is improved by removing the nozzle when using self-shielded electrodes.

**LIMITATIONS**

The main limitation of flux cored arc welding is that it is confined to ferrous metals and nickel-based alloys. Generally, all low- and medium-carbon steels and some low-alloy steels, cast irons, and a limited number of stainless steels are presently weldable using FCAW.

The equipment and electrodes used for the FCAW process are more expensive. However, the cost is quickly recoverable through higher productivity.

The removal of postweld slag requires another production step. The flux must be removed before the weldment is finished (painted) to prevent crevice corrosion.

With the increased welding output comes an increase in smoke and fume generation. The existing ventilation system in a shop might need to be increased to handle the added volume.

**ELECTRODES**

**Methods of Manufacturing**

The electrodes have flux tightly packed inside. One method used to make them is to first form a thin sheet of metal into a U-shape, Figure 3.7. A measured quantity of flux is poured into the U-shape before it is squeezed shut. It is then passed through a series of dies to size it and further compact the flux.

A second method of manufacturing the electrode is to start with a seamless tube. The tube is usually about 1 in. in diameter. One end of the tube is sealed, and the flux powder is poured into the open end. The tube is vibrated during the filling process to ensure that it fills completely. Once the tube is full, the open end is sealed. The tube is now sized using a series of dies, Figure 3.8.

In both these methods of manufacturing the electrode, the sheet and tube are made up of the desired alloy. Also in both cases, the flux is compacted inside the metal skin. This compacting helps make the electrode operate more smoothly and consistently.

Electrodes are available in sizes from 0.030 in. to 5/32 in. (0.8 mm to 3.9 mm) in diameter. Smaller-diameter electrodes are much more expensive per pound than the same type in a larger diameter due to the high cost of drawing and filling cored wires to small sizes. Larger-diameter electrodes produce such large welds they cannot be controlled in all positions. The most popular diameters range from 0.035 in. to 3/32 in. (0.9 mm to 2.3 mm).

The finished FCA filler metal is packaged in a number of forms for purchase by the end user, Figure 3.9. The AWS has a standard for the size of...
Figure 3.7 Putting the flux in the flux cored wire

Figure 3.8 One method of filling seamless FCA welding filler metal with flux

The vibration helps compact the granular flux inside the tube.
each of the package units. Although the dimensions of the packages are standard, the weight of filler wire is not standard. More of the smaller-diameter wire can fit into the same space compared with a larger-diameter wire, so a package of 0.030-in. (0.8-mm) wire weighs more than the same-sized package of 3/32-in. (2.3-mm) wire. The standard packing units for FCAW wires are spools, coils, reels, and drums, Table 3.1.

Spools are made of plastic or fiberboard and are disposable. They are completely self-contained and are available in approximate weights from

<table>
<thead>
<tr>
<th>Packaging</th>
<th>Outside Diameter</th>
<th>Width</th>
<th>Arbor (Hole) Diameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spools</td>
<td>4 in. (102 mm)</td>
<td>1-3/4 in. (44.5 mm)</td>
<td>5/8 in. (16 mm)</td>
</tr>
<tr>
<td></td>
<td>8 in. (203 mm)</td>
<td>2-1/4 in. (57 mm)</td>
<td>2-1/16 in. (52.3 mm)</td>
</tr>
<tr>
<td></td>
<td>12 in. (305 mm)</td>
<td>4 in. (102 mm)</td>
<td>2-1/16 in. (52.3 mm)</td>
</tr>
<tr>
<td></td>
<td>14 in. (356 mm)</td>
<td>4 in. (102 mm)</td>
<td>2-1/16 in. (52.3 mm)</td>
</tr>
<tr>
<td>Reels</td>
<td>22 in. (559 mm)</td>
<td>12-1/2 in. (318 mm)</td>
<td>1-5/16 in. (33.3 mm)</td>
</tr>
<tr>
<td></td>
<td>30 in. (762 mm)</td>
<td>16 in. (406 mm)</td>
<td>1-5/16 in. (33.3 mm)</td>
</tr>
<tr>
<td>Coils</td>
<td>16-1/4 in. (413 mm)</td>
<td>4 in. (102 mm)</td>
<td>12 in. (305 mm)</td>
</tr>
<tr>
<td>Drums</td>
<td>23 in. (584 mm)</td>
<td>16 in. (406 mm)</td>
<td>34 in. (864 mm)</td>
</tr>
</tbody>
</table>
1 lb up to around 50 lb (0.5 kg to 25 kg). The smaller spools, 4 in. and 8 in. (102-mm and 203 mm), weighing from 1 lb to 7 lb, are most often used for smaller production runs or for home/hobby use; 12-in. and 14-in. (305-mm and 356-mm) spools are often used in schools and welding fabrication shops.

Coils come wrapped and/or wire tied together. They are unmounted, so they must be supported on a frame on the wire feeder in order to be used. Coils are available in weights around 60 lb (27 kg). Because FCAW wires on coils do not have the expense of a disposable core, these wires cost a little less per pound, so they are more desirable for higher-production shops.

Reels are large wooden spools, and drums are shaped like barrels. Both reels and drums are used for high-production jobs. Both can contain approximately 300 lb to 1000 lb (136 kg to 454 kg) of FCAW wire. Because of their size, they are used primarily at fixed welding stations. Such stations are often associated with some form of automation, such as turntables or robotics.

Electrode Cast and Helix

To see the cast and helix of a wire, feed out 10 ft of wire electrode and cut it off. Lay it on the floor and observe that it forms a circle. The diameter of the circle is known as the cast of the wire, Figure 3.10.

Note that the wire electrode does not lay flat. One end is slightly higher than the other. This height is the helix of the wire.

The AWS has specifications for both cast and helix for all FCA welding wires.

The cast and helix cause the wire to rub on the inside of the contact tube, Figure 3.11. The slight bend in the electrode wire ensures a positive electrical contact between the contact tube and filler wire.
FLUX

The fluxes used are mainly based on lime or rutile (a mineral compound consisting of titanium dioxide, usually with a little iron). The purpose of the fluxes is the same as in the shielded metal arc welding (SMAW) process. That is, they can provide all or part of the following to the weld:

- **Deoxidizers:** Oxygen that is present in the welding zone has two forms. It can exist as free oxygen from the atmosphere surrounding the weld. Oxygen can also exist as part of a compound such as an iron oxide or carbon dioxide ($CO_2$). In either case it can cause porosity in the weld if it is not removed or controlled. Chemicals are added that react to the presence of oxygen in either form and combine to form a harmless compound, Table 3.2. The new compound can become part of the slag that solidifies on top of the weld, or some of it may stay in the weld as very small inclusions. Both methods result in a weld with better mechanical properties because of lower porosity.

- **Slag formers:** Slag serves several vital functions for the weld. It can react with the molten weld metal chemically, and it can affect the weld bead physically. In the molten state it moves through the molten weld pool and acts as a magnet or sponge to chemically combine with impurities in the metal and remove them, Figure 3.12. Slags can be refractory, so that they become solid at a high temperature. As they solidify over the weld, they help it hold its shape and they slow its cooling rate.

- **Fluxing agents:** Molten weld metal tends to have a high surface tension, which prevents it from flowing outward toward the edges of the weld. This causes undercutting along the junction of the

<table>
<thead>
<tr>
<th>Deoxidizing Element</th>
<th>Strength</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminum (Al)</td>
<td>Very strong</td>
</tr>
<tr>
<td>Manganese (Mn)</td>
<td>Weak</td>
</tr>
<tr>
<td>Silicon (Si)</td>
<td>Weak</td>
</tr>
<tr>
<td>Titanium (Ti)</td>
<td>Very strong</td>
</tr>
<tr>
<td>Zirconium (Zr)</td>
<td>Very strong</td>
</tr>
</tbody>
</table>

**Table 3.2 Deoxidizing Elements Added to Filler Wire (to Minimize Porosity in the Molten Weld Pool)**

![Figure 3.12 Impurities being floated to the surface by slag](image-url)
weld and the base metal. Fluxing agents make the weld more fluid and allow it to flow outward, filling the undercut.

- **Arc stabilizers**: Chemicals in the flux affect the arc resistance. As the resistance is lowered, the arc voltage drops and penetration is reduced. When the arc resistance is increased, the arc voltage increases and weld penetration is increased. Although the resistance within the ionized arc stream may change, the arc is more stable and easier to control. It also improves the metal transfer by reducing spatter caused by an erratic arc.

- **Alloying elements**: Because of the difference in the mechanical properties of metal that is formed by rolling or forging and metal that is melted to form a weld bead, the metallurgical requirements of the two also differ. Some elements change the weld’s strength, ductility, hardness, brittleness, toughness, and corrosion resistance. Other alloying elements in the form of powder metal can be added to increase deposition rates.

- **Shielding gas**: As elements in the flux are heated by the arc, some of them vaporize and form voluminous gaseous clouds hundreds of times larger than their original volume. This rapidly expanding cloud forces the air around the weld zone away from the molten weld metal, Figure 3.13. Without the protection this process affords the molten metal, it would rapidly oxidize. Such oxidization would severely affect the weld’s mechanical properties, rendering it unfit for service.

All FCAW fluxes are divided into two groups based on the acid or basic chemical reactivity of the slag. The AWS classifies T-1 as acid and T-5 as basic.

![Figure 3.13 Rapidly expanding gas cloud](Source: Courtesy of Larry Jeffus)
The rutile-based flux is acidic, T-1. It produces a smooth, stable arc and a refractory high-temperature slag for out-of-position welding. These electrodes produce a fine drop transfer, a relatively low fume, and an easily removed slag. The main limitation of the rutile fluxes is that their fluxing elements do not produce as high a quality deposit as do the T-5 systems.

The lime-based flux is basic, T-5. It is very good at removing certain impurities from the weld metal, but its low-melting-temperature slag is fluid, which makes it generally unsuitable for out-of-position welding. These electrodes produce a more globular transfer, more spatter, more fume, and a more adherent slag than do the T-1 systems. These characteristics are tolerated when it is necessary to deposit very tough weld metal and for welding materials having a low tolerance for hydrogen.

Some rutile-based electrodes allow the addition of a shielding gas. With the weld partially protected by the shielding gas, more elements can be added to the flux, which produces welds with the best of both flux systems, high-quality welds in all positions.

Some fluxes can be used on both single- and multiple-pass welds, and others are limited to single-pass welds only. Using a single-pass welding electrode for multipass welds may result in an excessive amount of manganese. The manganese is necessary to retain strength when making large, single-pass welds. However, with the lower dilution associated with multipass techniques, it can strengthen the weld metal too much and reduce its ductility. In some cases, small welds that deeply penetrate the base metal can help control this problem.

Table 3.3 lists the shielding and polarity for the flux classifications of mild steel FCAW electrodes. The letter G is used to indicate an unspecified classification. The G means that the electrode has not been classified by the American Welding Society. Often the exact composition of fluxes is kept as a manufacturer’s trade secret. Therefore, only limited information about the electrode’s composition will be given. The only information often supplied is current, type of shielding required, and some strength characteristics.

<table>
<thead>
<tr>
<th>Classification</th>
<th>Comments</th>
<th>Shielding Gas</th>
</tr>
</thead>
<tbody>
<tr>
<td>T-1</td>
<td>Requires clean surfaces and produces little spatter. It can be used for single- and multiple-pass welds in all positions.</td>
<td>Carbon dioxide (CO₂) or Argon/Carbon dioxide mixes</td>
</tr>
<tr>
<td>T-2</td>
<td>Requires clean surfaces and produces little spatter. It can be used for single-pass welds in the flat (1G and 1F) and horizontal (2F) positions only.</td>
<td>Carbon dioxide (CO₂)</td>
</tr>
<tr>
<td>T-3</td>
<td>Used on thin-gauge steel for single-pass welds in the flat (1G and 1F) and horizontal (2F) positions only.</td>
<td>None</td>
</tr>
<tr>
<td>T-4</td>
<td>Low penetration and moderate tendency to crack for single- and multiple-pass welds in the flat (1G and 1F) and horizontal (2F) positions.</td>
<td>None</td>
</tr>
<tr>
<td>T-5</td>
<td>Low penetration and a thin, easily removed slag, used for single- and multiple-pass welds in the flat (1G and 1F) position only.</td>
<td>With or without carbon dioxide (CO₂)</td>
</tr>
<tr>
<td>T-6</td>
<td>Similar to T-5 without externally applied shielding gas.</td>
<td>None</td>
</tr>
<tr>
<td>T-G</td>
<td>The composition and classification of this electrode are not given in the preceding classes. It may be used for single- or multiple-pass welds.</td>
<td>With or without shielding</td>
</tr>
</tbody>
</table>
As a result of the relatively rapid cooling of the weld metal, the weld may tend to become hard and brittle. This factor can be controlled by adding elements to the flux that affect the content of both the weld and the slag. Table 3.4. Ferrite is the softer, more ductile form of iron. The addition of ferrite-forming elements can control the hardness and brittleness of a weld. Refractory fluxes are sometimes called “fast-freeze” because they solidify at a higher temperature than the weld metal. By becoming solid first, this slag can cradle the molten weld pool and control its shape. This property is very important for out-of-position welds.

The impurities in the weld pool can be metallic or nonmetallic compounds. Metallic elements that are added to the metal during the manufacturing process in small quantities may be concentrated in the weld. These elements improve the grain structure, strength, hardness, resistance to corrosion, or other mechanical properties in the metal’s as-rolled or formed state. But the deposited weld metal, or weld nugget, is like a small casting because the liquid weld metal freezes in a controlled shape, and some alloys adversely affect the properties of this casting (weld metal). Nonmetallic compounds are primarily slag inclusions left in the metal from the fluxes used during manufacturing. The welding fluxes form slags that are less dense than the weld metal so that they will float to the surface before the weld solidifies.

**Flux Cored Steel Electrode Identification**

The American Welding Society revised its A5.20 Specification for Carbon Steel Electrodes for Flux Cored Arc Welding in 1995 to reflect changes in the composition of the FCA filler metals. Table 3.5 lists the AWS specifications for flux cored filler metals.

**Mild Steel**

The electrode number E70T-10 is used as an example to explain the classification system for mild steel FCAW electrodes (Figure 3.14):

- E—Electrode.
- 7—Tensile strength in units of 10,000 psi for a good weld. This value is usually either 6 for 60,000 or 7 for 70,000 psi minimum

<table>
<thead>
<tr>
<th>Table 3.4 Ferrite-forming Elements Used in FCA Welding Fluxes</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Element</strong></td>
</tr>
<tr>
<td>Silicon (Si)</td>
</tr>
<tr>
<td>Chromium (Cr)</td>
</tr>
<tr>
<td>Molybdenum (Mo)</td>
</tr>
<tr>
<td>Columbium (Cb)</td>
</tr>
<tr>
<td>Aluminum (Al)</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Table 3.5 Filler Metal Classification Numbers</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Metal</strong></td>
</tr>
<tr>
<td>Mild steel</td>
</tr>
<tr>
<td>Stainless steel</td>
</tr>
<tr>
<td>Chromium-molybdenum</td>
</tr>
</tbody>
</table>
weld strength. An exception is for the number 12, which is used to
denote filler metals having a range from 70,000 to 90,000 psi.

- 0—0 is used for flat and horizontal fillets only, and 1 is used for all-
  position electrodes.
- T—Tubular (flux cored) electrode.
- 10—The number in this position can range from 1 to 14 and is
  used to indicate the electrode’s shielding gas if any, number of
  passes that may be applied one on top of the other, and other
  welding characteristics of the electrode. The letter G is used to
  indicate that the shielding gas, polarity, and impact properties are
  not specified. The letter G may or may not be followed by the letter
  S.S indicates an electrode suitable only for single-pass welding.

The electrode classification E70T-10 can have some optional identifiers
added to the end of the number, as in E70T-10MJH8. These additions are
used to add qualifiers to the general classification so that specific codes or
standards can be met. These additions have the following meanings:

- M—Mixed gas of 75% to 80% Ar and CO₂ for the balance. If there is
  no M, either the shielding gas is CO₂ or the electrode is self-
  shielded.
- J—Describes the Charpy V-notch impact test value of 20 ft-lb at
  40°F.
- H8—Describes the residual hydrogen levels in the weld: H4 equals
  less than 4 ml/100 g; H8, less than 8 ml/100 g; H16, less than 16
  ml/100 g.

**Stainless Steel Electrodes**
The AWS classification for stainless steel for FCAW electrodes starts with
the letter E as its prefix. Following the E 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 1 is used to indicate an all-position filler metal, and the number 3 is used to indicate an electrode to be used in the flat and horizontal positions only.

**Metal Cored Steel Electrode Identification**

The addition of metal powders to the flux core of FCA welding electrodes has produced a new classification of filler metals. The new filler metals evolved over time, and a new identification system was established by the AWS to identify these filler metals. Some of the earlier flux cored filler metals that already had powder metals in their core had their numbers changed to reflect the new designation. The designation was changed from the letter T for tubular to the letter C for core. For example, E70T-1 became E70C-3C. The complete explanation of the cored electrode E70C-3C follows:

- **E**—Electrode.
- **7**—Tensile strength in units of 10,000 psi for a good weld. This value is usually either 6 for 60,000 or 7 for 70,000 psi minimum weld strength. An exception is for the number 12, which is used to denote filler metals having a range from 70,000 to 90,000 psi.
- **0**—0 is used for flat and horizontal fillets only, and 1 is used for all-position electrodes.
- **C**—Metal-cored (tubular) electrode.
- **3**—3 is used for a Charpy impact of 20 ft-lb at 0°F, and 6 represents a Charpy impact of 20 ft-lb at 20°F.
- **C**—The second letter C indicates CO₂. The letter M in this position would indicate a mixed gas, 75% to 80% Ar, with the balance being CO₂. If there is no M or C, then the shielding gas is CO₂. The letter G is used to indicate that the shielding gas, polarity, and impact properties are not specified. The letter G may or may not be followed by the letter S.S indicates an electrode suitable only for single-pass welding.

**Care of Flux Core Electrodes**

Wire electrodes may be wrapped in sealed plastic bags for protection from the elements. Others may be wrapped in a special paper, and some are shipped in cans or cardboard boxes.

A small paper bag of a moisture-absorbing material, crystal desiccant, is sometimes placed in the shipping containers to protect wire electrodes from moisture. Some wire electrodes require storage in an electric rod oven to prevent contamination from excessive moisture. Read the manufacturer’s recommendations located in or on the electrode shipping container for information on use and storage.

Weather conditions affect your ability to make high-quality welds. Humidity increases the chance of moisture entering the weld zone. Water (H₂O), which consists of two parts hydrogen and one part oxygen, separates in the weld pool. When only one part of hydrogen is expelled, hydrogen entrapment occurs. Hydrogen entrapment can cause weld beads to crack or become brittle. The evaporating moisture will also cause porosity.

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**NOTE**

The powdered metal added to the core flux can provide additional filler metal and/or alloys. This is one way the micro-alloys can be added in very small and controlled amounts, as low as 0.0005% to 0.005%. These are very powerful alloys that dramatically improve the metal’s mechanical properties.
To prevent hydrogen entrapment, porosity, and atmospheric contamination, it may be necessary to preheat the base metal to drive out moisture. Storing the wire electrode in a dry location is recommended. The electrode may develop restrictions due to the tangling of the wire or become oxidized with excessive rusting if the wire electrode package is mishandled, thrown, dropped, or stored in a damp location.

**SHIELDING GAS**

FCA welding wire can be manufactured so that all of the required shielding of the molten weld pool is provided by the vaporization of some of the flux within the tubular electrode. When the electrode provides all of the shielding, it is called **self-shielding** and the welding process is abbreviated FCAW-S (S for self-shielding). Other FCA welding wire must use an externally supplied shielding gas to provide the needed protection of the molten weld pool. When a shielding gas is added, the combined shielding is called **dual shield** and the process is abbreviated FCAW-G (G for gas).

Note: Sometimes the shielding gas(es) are referred to as the shielding **medium**. For example, the shielding gas, or medium, for E71T-5 is either 75% argon with 25% CO$_2$ or 100% CO$_2$.

Care must be taken to use the cored electrodes with the recommended gases, and not to use gas at all with the self-shielded electrodes. Using a self-shielding flux cored electrode with a shielding gas may produce a defective weld. The shielding gas will prevent the proper disintegration of much of the deoxidizers. This results in the transfer of these materials across the arc to the weld. In high concentrations, the deoxidizers can produce slags that become trapped in the welds, causing undesirable defects. Lower concentrations may cause brittleness only. In either case, the chance of weld failure is increased. If these electrodes are used correctly, there is no problem.

The selection of a shielding gas will affect the arc and weld properties. The weld bead width, buildup, penetration, spatter, chemical composition, and mechanical properties are all affected as a result of the shielding gas selection.

Shielding gas comes in high-pressure cylinders. These cylinders are supplied with 2000 psi of pressure. Because of this high pressure, it is important that the cylinders be handled and stored safely. For specific cylinder safety instructions see Chapter 2 in Introduction to Welding, the first book in this series.

Gases used for FCA welding include CO$_2$ and mixtures of argon and CO$_2$. Argon gas is easily ionized by the arc. Ionization results in a highly concentrated path from the electrode to the weld. This concentration results in a smaller droplet size that is associated with the axial spray mode of metal transfer, Figure 3.15. A smooth, stable arc results and there is a minimum of spatter. This transfer mode continues as CO$_2$ is added to the argon until the mixture contains more than 25% of CO$_2$.

As the percentage of CO$_2$ increases in the argon mixture, weld penetration increases. This increase in penetration continues until a 100% CO$_2$ shielding gas is reached. But as the percentage of CO$_2$ is increased the arc stability decreases. The less stable arc causes an increase in spatter.

**Caution**

Always keep the wire electrode dry and handle it as you would any important tool or piece of equipment.
A mixture of 75% argon and 25% CO\(_2\) works best for jobs requiring a mixed gas. This mixture is sometimes called C-25.

Straight CO\(_2\) is used for some welding. But the CO\(_2\) gas molecule is easily broken down in the welding arc. It forms carbon monoxide (CO) and free oxygen (O). Both gases are reactive to some alloys in the electrode. As these alloys travel from the electrode to the molten weld pool, some of them form oxides. Silicon and manganese are the primary alloys that become oxidized and lost from the weld metal.

Most FCA welding electrodes are specifically designed to be used with or without shielding gas and for a specific shielding gas or percentage mixture. For example, an electrode designed specifically for use with 100% CO\(_2\) will have higher levels of silicon and manganese to compensate for the losses to oxidization. But if 100% argon or a mixture of argon and CO\(_2\) is used, the weld will have an excessive amount of silicon and manganese. The weld will not have the desired mechanical or metallurgical properties. Although the weld may look satisfactory, it will probably fail prematurely.

**WELDING TECHNIQUES**

A welder can control weld beads made by FCA welding by making changes in the techniques used. The following explains how changing specific welding techniques will affect the weld produced.

**Gun Angle**

The *gun angle*, *work angle*, and *travel angle* are terms used to refer to the relation of the gun to the work surface, Figure 3.16. The gun angle can be used to control the weld pool. The electric arc produces an electrical force known as the arc force. The arc force can be used to counteract the gravitational pull that tends to make the liquid weld pool sag or run ahead of the arc. By manipulating the electrode travel angle for the flat and horizontal position of welding to a 20° to 45° angle from the vertical, the weld pool can be controlled. A 40° to 50° angle from the vertical plate is recommended for fillet welds.
Changes in this angle will affect the weld bead shape and penetration. Shallower angles are needed when welding thinner materials to prevent burn-through. Steeper, perpendicular angles are used for thicker materials.

FCAW electrodes have a flux that is mineral based, often called low-hydrogen. These fluxes are refractory and become solid at a high temperature. If too steep a forehand, or pushing, angle is used, slag from the electrode can be pushed ahead of the weld bead and solidify quickly on the cooler plate, Figure 3.17. Because the slag remains solid at higher temperatures than the temperature of the molten weld pool, it can be trapped under the edges of the weld by the molten weld metal. To avoid this problem, most flat and horizontal welds should be performed with a backhand angle.

Vertical up welds require a forehand gun angle. The forehand angle is needed to direct the arc deep into the groove or joint for better control of the weld pool and deeper penetration, Figure 3.18. Slag entrapment associated with most forehand welding is not a problem for vertical welds.

A gun angle around 90° to the metal surface either slightly forehand or backhand works best for overhead welds, Figure 3.19. The slight angle aids with visibility of the weld, and it helps control spatter buildup in the gas nozzle.
Forehand/Perpendicular/Backhand Techniques

*Forehand*, *perpendicular*, and *backhand* are the terms most often used to describe the gun angle as it relates to the work and the direction of travel. The forehand technique is sometimes referred to as *pushing* the weld bead, and backhand may be referred to as *pulling* or *dragging* the weld bead. The term *perpendicular* is used when the gun angle is at approximately 90° to the work surface, Figure 3.20.

Advantages of the Forehand Technique

The forehand welding technique has several advantages:

- Joint visibility—You can easily see the joint where the bead will be deposited, Figure 3.21.
- Electrode extension—The contact tube tip is easier to see, making it easier to maintain a constant extension length.
- Less weld penetration—It is easier to weld on thin sheet metal without melting through.
- Out-of-position welds—This technique works well on vertical up and overhead joints for better control of the weld pool.

Disadvantages of the Forehand Technique

The disadvantages of using the forehand welding technique are the following:

- Weld thickness—Thinner welds may occur because less weld reinforcement is applied to the weld joint.

Figure 3.19 Weld gun position to control spatter buildup on an overhead weld

Figure 3.20 Gun angles

Changing the welding gun angle between forehand, perpendicular, and backhand angles will change the shape of the weld bead produced.
Welding speed—Because less weld metal is being applied, the rate of travel along the joint can be faster, which may make it harder to create a uniform weld.

Slag inclusions—Some spattered slag can be thrown in front of the weld bead and be trapped or included in the weld, resulting in a weld defect.

Spatter—Depending on the electrode, the amount of spatter may be slightly increased with the forehand technique.

**Advantages of the Perpendicular Technique**

The perpendicular welding technique has the following advantages:

- Machine and robotic welding—The perpendicular gun angle is used on automated welding because there is no need to change the gun angle when the weld changes direction.
- Uniform bead shape—The weld’s penetration and reinforcement are balanced between those of forehand and backhand techniques.

**Disadvantages of the Perpendicular Technique**

The disadvantages of using the perpendicular welding technique are the following:

- Limited visibility—Because the welding gun is directly over the weld, there is limited visibility of the weld unless you lean your head way over to the side.
- Weld spatter—Because the weld nozzle is directly under the weld in the overhead position, more weld spatter can collect in the nozzle, causing gas flow problems or even shorting the tip to the nozzle.

**Advantages of the Backhand Technique**

The backhand welding technique has the following advantages:

- Weld bead visibility—It is easy to see the back of the molten weld pool as you are welding, which makes it easier to control the bead shape, Figure 3.22.
- Travel speed—Because of the larger amount of weld metal being applied, the rate of travel may be slower, making it easier to create a uniform weld.
- Depth of fusion—The arc force and the greater heat from the slower travel rate both increase the depth of weld joint penetration.
Disadvantages of the Backhand Technique

The disadvantages of the backhand welding technique are the following:

- **Weld buildup**—The weld bead may have a convex (raised or rounded) weld face when you use the backhand technique.
- **Postweld finishing**—Because of the weld bead shape, more work may be required if the product has to be finished by grinding smooth.
- **Joint following**—It is harder to follow the joint because your hand and the FCAW gun are positioned over the joint, and you may wander from the seam.
- **Loss of penetration**—An inexperienced welder sometimes directs the wire too far back into the weld pool causing the wire to build up in the face of the weld pool reducing joint penetration.

Travel Speed

The American Welding Society defines travel speed as the linear rate at which the arc is moved along the weld joint. Fast travel speeds deposit less filler metal. If the rate of travel increases, the filler metal cannot be deposited fast enough to adequately fill the path melted by the arc. This causes the weld bead to have a groove melted into the base metal next to the weld and left unfilled by the weld. This condition is known as undercut.

Undercut occurs along the edges or toes of the weld bead. Slower travel speeds will, at first, increase penetration and increase the filler weld metal deposited. As the filler metal increases, the weld bead will build up in the weld pool. Because of the deep penetration of flux cored wire, the angle at which you hold the gun is very important for a successful weld.

If all welding conditions are correct and remain constant, the preferred rate of travel for maximum weld penetration is a travel speed that allows you to stay within the selected welding variables and still control the fluidity of the weld pool. This is an intermediate travel speed, or progression, which is not too fast or too slow.

Another way to figure out correct travel speed is to consult the manufacturer’s recommendations chart for the inches per minute (ipm) burn-off rate for the selected electrode.
Mode of Metal Transfer

The mode of metal transfer is used to describe how the molten weld metal is transferred across the arc to the base metal. The mode of metal transfer that is selected, the shape of the completed weld bead, and the depth of weld penetration depend on the welding power source, wire electrode size, type and thickness of material, type of shielding gas used, and best welding position for the task.

Spray Transfer with FCAW-G

The spray transfer mode is the most common process used with gas-shielded FCAW (FCAW-G), Figure 3.15.

As the gun trigger is depressed, the shielding gas automatically flows and the electrode bridges the distance from the contact tube to the base metal, making contact with the base metal to complete a circuit. The electrode shorts and becomes so hot that the base metal melts and forms a weld pool. The electrode melts into the weld pool and burns back toward the contact tube. A combination of high amperage and the shielding gas along with the electrode size produces a pinching effect on the molten electrode wire, causing the end of the electrode wire to spray across the arc.

The characteristic of spray-type transfer is a smooth arc, through which hundreds of small droplets per second are transferred through the arc from the electrode to the weld pool. At that moment a transfer of metal is taking place. Spray transfer can produce a high quantity of metal droplets, up to approximately 250 per second above the transition current, or critical current. This means the current required for a spray transfer to take place is dependent on the electrode size, composition of the electrode, and shielding gas. Below the transition current (critical current), globular transfer takes place.

In order to achieve a spray transfer, high current and larger-diameter electrode wire are needed. A shielding gas of carbon dioxide (CO₂), a mixture of carbon dioxide (CO₂) and argon (Ar), or an argon (Ar) and oxygen (O₂) mixture is needed. FCAW-G is a welding process that, with the correct variables, can be used

- on thin or properly prepared thick sections of material
- on a combination of thick to thin materials
- with small or large electrode diameters
- with a combination of shielding gases

Globular Transfer with FCAW-G

Globular transfer occurs when the welding current is below the transition current, Figure 3.23. The electrode forms a molten ball at its end that grows in size to approximately two to three times the original electrode diameter. These large molten balls are then transferred across the arc at the rate of several drops per second.

The arc becomes unstable because of the gravitational pull from the weight of these large drops. A spinning effect caused by a natural phenomenon takes place when argon gas is introduced to a large ball of molten metal on the electrode. The molten ball spins as it transfers across the arc to the base metal. This unstable globular transfer can produce excessive spatter.
Both FCAW-S and FCAW-G use direct current electrode negative (DCEN) when welding on thin-gauge materials to keep the heat in the base metal and the small-diameter electrode at a controllable burn-off rate. The electrode can then be stabilized, and it is easier to manipulate and control the weld pool in all weld positions. Larger-diameter electrodes are welded with direct current electrode positive (DCEP) because the larger diameters can keep up with the burn-off rates.

The recommended weld position means the position in which the workpiece is placed for welding. All welding positions use either spray or globular transfer, but for now we will concentrate on the flat and horizontal welding positions.

In the flat welding position the workpiece is placed flat on the work surface. In the horizontal welding position the workpiece is positioned perpendicular to the workbench surface.

The amperage range may be from 30 to 400 amperes or more for welding materials from gauge thickness up to 1-1/2 inches. On square groove weld joints, thicker base metals can be welded with little or no edge preparation. This is one of the great advantages of FCAW. If edges are prepared and cut at an angle (beveled) to accept a complete joint weld penetration, the depth of penetration will be greatly increased. FCAW is commonly used for general repairs to mild steel in the horizontal, vertical, and overhead welding positions, sometimes referred to as out-of-position welding.

**Electrode Extension**

The electrode extension is measured from the end of the electrode contact tube to the point the arc begins at the end of the electrode, Figure 3.24. Compared to GMA welding, the electrode extension required for FCAW is much greater. The longer extension is required for several reasons. The electrical resistance of the wire causes the wire to heat up, which can drive out moisture from the flux. This preheating of the wire also results in a smoother arc with less spatter.

**Porosity**

FCA welding can produce high-quality welds in all positions, although porosity in the weld can be a persistent problem. Porosity can be caused by moisture in the flux, improper gun manipulation, or surface contamination.
The flux used in the FCA welding electrode is subject to picking up moisture from the surrounding atmosphere, so the electrodes must be stored in a dry area. Once the flux becomes contaminated with moisture, it is very difficult to remove. Water (H₂O) breaks down into free hydrogen and oxygen in the presence of an arc, Figure 3.25. The hydrogen can be absorbed into the molten weld metal, where it can cause postweld cracking. The oxygen is absorbed into the weld metal also, but it forms oxides in the metal.

If a shielding gas is used, the FCA welding gun gas nozzle must be close enough to the weld to provide adequate shielding gas coverage. If there is a wind or if the nozzle-to-work distance is excessive, the shielding will be inadequate and allow weld porosity. If welding is to be done outside or in an area subject to drafts, the gas flow rate must be increased or a wind shield must be placed to protect the weld, Figure 3.26.

A common misconception is that the flux within the electrode will either remove or control weld quality problems caused by surface contaminations. That is not true. The addition of flux makes FCA welding more tolerant to surface conditions than GMA welding, although it still is adversely affected by such contaminations.

New hot-rolled steel has a layer of dark gray or black iron oxide called mill scale. Although this layer is very thin, it may provide a source of enough oxygen to cause porosity in the weld. If mill scale causes porosity, it is usually uniformly scattered through the weld, Figure 3.27. Unless it is severe, uniformly scattered porosity is usually not visible in the finished weld. It is trapped under the surface as the weld cools.
Figure 3.25 Water and porosity
Water (H\textsubscript{2}O) breaks down in the presence of the arc and the hydrogen (H) is dissolved in the molten weld metal.

Figure 3.26 Wind and draft protection
A wind screen can keep the welding shielding from being blown away.

Figure 3.27 Uniformly scattered porosity
Because porosity is under the weld surface, nondestructive testing methods, including X ray, magnetic particle, and ultrasound, must be used to locate it in a weld. It can be detected by mechanical testing such as guided bend, free bend, and nick-break testing for establishing weld parameters. Often it is better to remove the mill scale before welding rather than risking the production of porosity.

All welding surfaces within the weld groove and the surrounding surfaces within 1 in. (25 mm) must be cleaned to bright metal, Figure 3.28. Cleaning may be either grinding, filing, sanding, or blasting.

Any time FCA welds are to be made on metals that are dirty, oily, rusty, or wet or that have been painted, the surface must be precleaned. Cleaning can be done chemically or mechanically.

One advantage of chemically cleaning oil and paint is that it is easier to clean larger areas. Both oil and paint smoke easily when heated, and such smoke can cause weld defects. They must be removed far enough from the weld so that weld heat does not cause them to smoke. In the case of small parts the entire part may need to be cleaned.

**SUMMARY**

Flux cored arc welding is used to produce more tons of welded fabrications than any other process. The ability to produce high-quality welds on a wide variety of material thicknesses and joint configurations has led to its popularity. As you learn and develop these skills, you will therefore significantly increasing your employability and productivity in the welding industry.

A wide variety of filler metals and shielding gas combinations for flux cored arc welding are available to you in industry. These various materials aid in producing welds of high quality under various welding conditions. Although the selection of the proper filler metal and gas coverage, if used, will significantly affect the finished weld’s quality in the field, there are very few differences in manipulation and setup among these...
filler metals. Therefore, as you practice welding in a school or training program and learn to use a specific wire and shielding gas mixture, these skills are easily transferable to the next group of materials you will encounter on the job.

**REVIEW**

1. List some factors that have led to the increased use of FCA welding.
2. How is FCAW similar to GMAW?
3. What does the FCA flux provide to the weld?
4. What are the major atmospheric contaminations of the molten weld metal?
5. How does slag help an FCA weld?
6. What is the electrical difference between a constant-potential and a constant-current power supply?
7. How can FCA welding guns be cooled?
8. What problems does excessive drive roller pressure cause?
9. List the advantages that FCA welding offers the welding industry.
10. Describe the two methods of manufacturing FCA electrode wire.
11. Why are large-diameter electrodes not used for all-position welding?
12. How do deoxidizers remove oxygen from the weld zone?
13. What do fluxing agents do for a weld?
14. Why are alloying elements added to the flux?
15. How does the flux form a shielding gas to protect the weld?
16. What are the main limitations of the rutile fluxes?
17. Why is it more difficult to use lime-based fluxed electrodes on out-of-position welds?
18. What benefit does adding an externally supplied shielding gas have on some rutile-based electrodes?
19. How do excessive amounts of manganese affect a weld?
20. Why are elements added that cause ferrite to form in the weld?
21. Why are some slags called refractory?
22. Why must a flux form a less dense slag?
23. Referring to Table 3.5, what is the AWS classification for FCA welding electrodes for stainless steel?
24. Describe the meaning of each part of the following FCA welding electrode identification: E81T-5.
25. What does the number 316 in E316T-1 mean?
26. What is the advantage of using an argon-CO₂ mixed shielding gas?
27. What are the primary alloying elements lost if 100% CO₂ shielding gas is used?
28. What can cause porosity in an FCA weld?
29. What happens to water in the welding arc?
30. What is the thin, dark gray or black layer on new hot-rolled steel? How can it affect the weld?
31. Why is uniformly scattered porosity hard to detect in a weld?
32. What cautions must be taken when chemically cleaning oil or paint from a piece of metal?
33. What can happen to slag that solidifies on the plate ahead of the weld?
34. How is the electrode extension measured?