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CHAPTER 5

FLUX CORED ARC WELDING

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CHAPTER 5

FLUX CORED ARC WELDING

INTRODUCTION

Flux cored arc welding (FCAW) is a welding process that uses an arc between a continuous filler metal electrode and the weld pool. The process is used with shielding from a flux contained within the tubular electrode, with or without additional shielding from an externally supplied gas, and without the application of pressure.[1, 2]

The remarkable operating characteristics and weld properties that distinguish FCAW from other arc welding processes are attributable to the continuously fed flux cored electrode. The tubular electrode is a filler metal composite consisting of a metal sheath and a core of various powdered materials manufactured in the form of wire. During welding, an extensive protective slag cover is produced on the face of the weld bead.

Flux cored arc welding offers two major variations, self-shielded (FCAW-S) and gas-shielded (FCAW-G), which add great flexibility to the process. These variations differ in the method of shielding the arc and weld pool from atmospheric contamination (oxygen and nitrogen).

Flux cored arc welding is an efficient welding process readily adaptable to semiautomatic or automatic welding operations and capable of producing high-quality weld metal at a high deposition rate. Many industries rely on flux cored arc welding to produce high-integrity welds. Users of the process include manufacturers or builders of pressure vessels, submarines, aircraft carriers, earth-moving equipment, and buildings and other structures.

This chapter covers the fundamental operating principles of the flux cored arc welding process and describes the necessary equipment and materials. Significant information is included for a variety of flux cored electrodes used in the major applications of FCAW. Welding procedures, process control, and weld quality are discussed. The chapter ends with comments on the economics of the process and important information on safe practices.

1. American Welding Society (AWS) Committee on Definitions and Symbols, 2001, *Standard Welding Terms and Definitions*, A3.0:2001, Miami: American Welding Society.
2. At the time of preparation of this chapter, the referenced codes and other standards were valid. If a code or other standard is cited without a date of publication, it is understood that the latest edition of the document referred to applies. If a code or other standard is cited with the date of publication, the citation refers to that edition only, and it is understood that any future revisions or amendments to the code or standard are not included. As codes and standards undergo frequent revision, the reader is advised to consult the most recent edition.

FUNDAMENTALS

The history of gas-shielded arc welding provides the background for the technology and evolution of flux cored arc welding. Gas-shielded metal arc welding processes have been in use since the early 1920s, when it was demonstrated that a significant improvement of weld metal properties could be produced if the arc and molten weld metal were protected from atmospheric contamination. However, the development of covered electrodes in the late 1920s diminished interest in gas-shielding methods. Interest was renewed in the early 1940s with the introduction and commercial acceptance of gas tungsten arc welding (GTAW) and, later in the same decade, gas metal arc welding (GMAW). Argon and helium were the two primary shielding gases used at that time.

Research conducted on manual welds made with covered electrodes focused on the analysis of the gas produced in the disintegration of electrode coverings. Results confirmed that carbon dioxide (CO_2) was the predominant gas given off by electrode coverings. This discovery quickly led to the use of CO_2 as a shielding gas for welds made on carbon steels with GMAW. Although early experiments with CO_2 were unsuccessful, techniques were eventually developed which permitted its use. Gas metal arc welding using CO_2 became available in the mid-1950s.

In concurrent research, CO_2 shielding was combined with a flux-containing tubular electrode, which overcame many of the problems previously encountered. Operating characteristics were improved by the addition of the core materials, and weld quality was improved by eliminating atmospheric contamination. These experiments resulted in the development of flux cored arc welding. This new process was introduced at the American Welding Society (AWS) Exposition in Buffalo, New York, in 1954. By 1957 the electrodes and equipment were refined, and the process was introduced commercially in essentially its present form.

During the 1990s significant improvements were made in both gas-shielded and self-shielded electrode arc stability that resulted in much less spatter than the earlier electrodes produced. The impact resistance of FCAW electrodes was also significantly improved. The development and production of alloy electrodes and small-diameter electrodes, down to 0.8 millimeters (mm) (0.030 inches [in.]), were other advances.

Improvements continue to be made to the FCAW process. Modern power sources and electrode (wire) feeders are greatly simplified and more dependable than their predecessors. Welding guns are lightweight and rugged, and electrodes undergo continuous improvement.

PROCESS VARIATIONS

The two major variations of the FCAW process, the self-shielded and the gas-shielded versions, are shown in Figure 5.1. Both illustrations in Figure 5.1 emphasize the melting and deposition of filler metal and flux and show the formation of a slag covering the weld metal. Cross sections of examples of FCAW electrodes also are shown in Figure 5.1.

In the gas-shielded method, the shielding gas (CO_2 or a mixture of argon and CO_2) protects the molten metal from the oxygen and nitrogen present in air by forming an envelope of gas around the arc and over the weld pool. Little need exists for denitrification of the weld metal because air is mostly excluded, along with the nitrogen it contains. However, some oxygen may be generated from the dissociation of CO_2, which forms carbon monoxide and oxygen. The compositions of the electrodes are formulated to provide deoxidizers that combine with small amounts of oxygen in the gas shield.

Self-shielded flux cored arc welding is often the process of choice for field welding because it can tolerate stronger air currents than the gas-shielded variation. The main reason for this distinction is that some shielding is provided by the high-temperature decomposition of some of the electrode core ingredients. The vaporization of these ingredients displaces air from the area immediately surrounding the arc. In addition, the wire contains a large proportion of scavengers (deoxidizers and denitrifiers) that combine with undesirable elements that might contaminate the weld pool. A slag cover protects the metal from the air surrounding the weld.

APPLICATIONS

Both self-shielded and gas-shielded flux cored arc welding can be used in most welding applications. However, the specific characteristics of each method make each suitable for different operating conditions. The process is used to weld carbon- and low-alloy steels, stainless steels, cast irons, and nickel and cobalt alloys. It is also used for the arc spot welding of lap joints in sheet and plate, as well as for cladding and hardfacing.

Flux cored arc welding is widely used in fabrication shops, for maintenance applications, and in field erection work. An example of field erection work is shown in Figure 5.2, in which both self-shielded and gas-shielded FCAW are used in the fabrication of an offshore oil drilling structure.

Flux cored arc welding can be used to produce weldments that conform to the *ASME Boiler and Pressure Vessel Code*,[3] the rules of the American Bureau of Shipping,[4] and *Structural Welding Code—Steel*, AWS D1.1.[5] The process is given prequalified status in AWS D1.1. Stainless steel, self-shielded, and gas-shielded flux cored electrodes are used in general fabrication, surfacing, joining dissimilar metals, and maintenance and repair.

Figure 5.3, which shows the fabrication of a suction filter used in the pulp and paper industry, illustrates the versatility of the FCAW process. The base material in this application was ST-360-C; E308LT1 electrodes were used.

The self-shielded method can often be used for applications that are normally welded with the shielded metal arc welding (SMAW) process. Gas-shielded FCAW can also be used for some applications that are welded by the GMAW process. The selection of self-shielded or gas-shielded FCAW depends on the type of electrodes available, the type of welding equipment available, the environment in which the welding is to be

3. American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code Committee, 1998, *Boiler and Pressure Vessel Code*. New York: American Society of Mechanical Engineers.
4. American Bureau of Shipping (ABS) Group, ABS Plaza, 166855 Northchase Drive, Houston, TX 77060-6008.
5. American Welding Society (AWS) Committee on Structural Welding, 2002, *Structural Welding Code—Steel*, AWS D1.1/D1.1M:2002, Miami: American Welding Society.

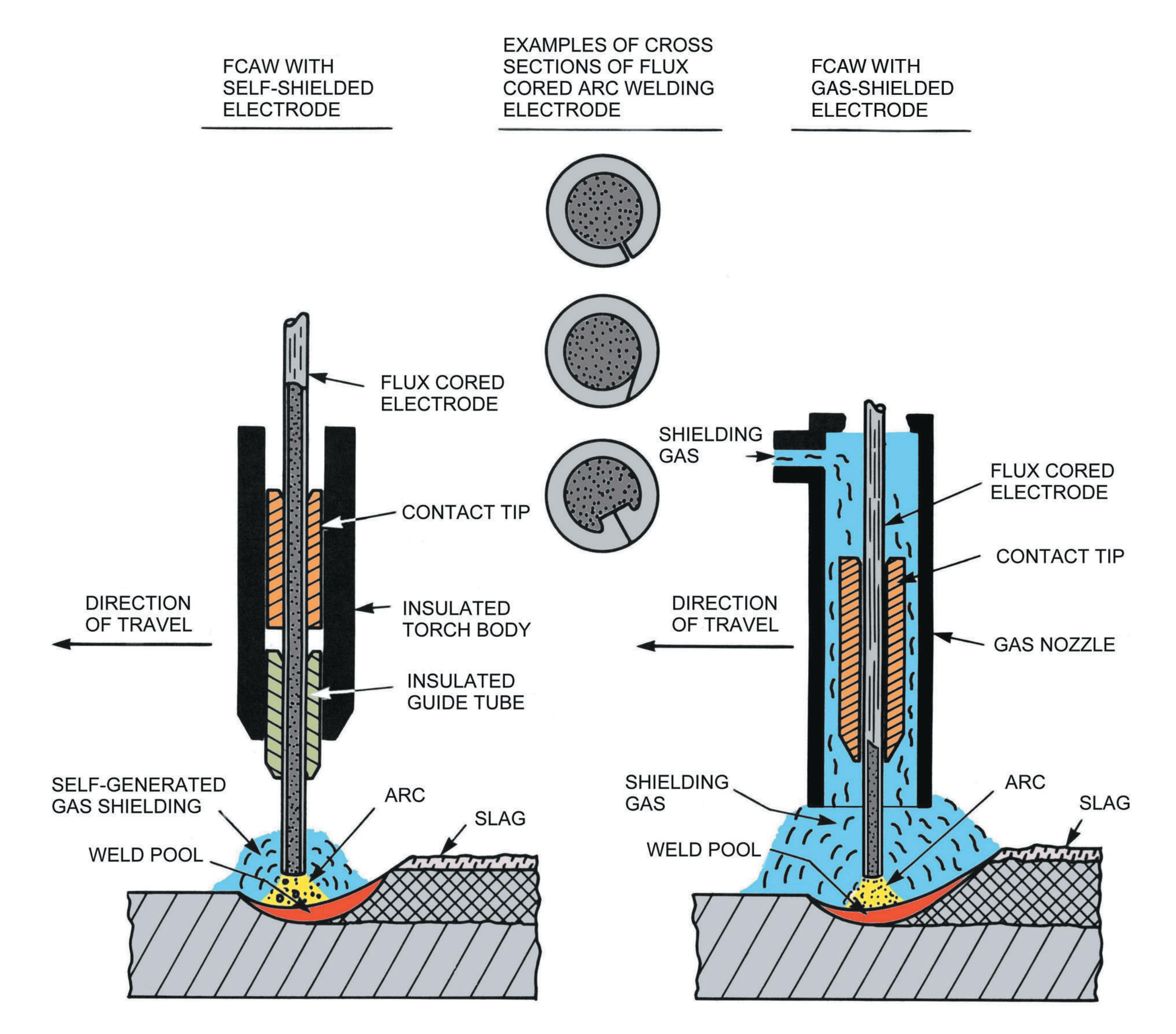


Figure 5.1—Self-Shielded and Gas-Shielded Flux Cored Arc Welding

done, the mechanical property requirements of the welded joints, and the joint design and fitup. The advantages and disadvantages of FCAW should be compared to those of other processes when it is evaluated for a specific application.

ADVANTAGES

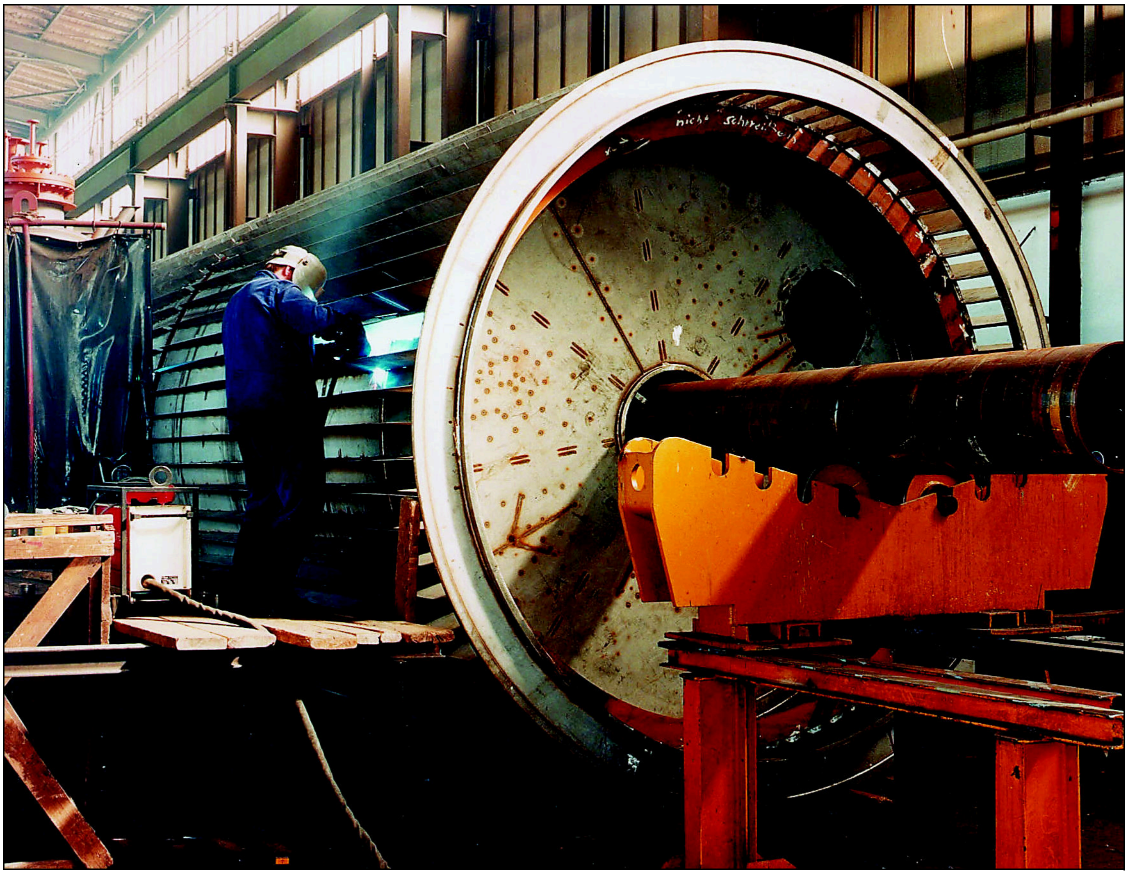
When compared to SMAW, higher productivity is the chief advantage of flux cored arc welding for many applications. This generally translates into lower overall costs per pound of metal deposited in joints that permit continuous welding and easy FCAW gun and equipment accessibility. The advantages are higher deposition rates, higher operating factors, and higher deposition efficiency (no stub loss).

In addition to the advantages of FCAW over the manual SMAW process, FCAW also provides certain advantages over submerged arc welding (SAW) and GMAW. In many applications, FCAW produces high-quality weld metal at lower cost with less effort on the part of the welder than SMAW. Flux cored arc welding

Figure 5.2—Offshore Drilling Structure Fabricated with Self-Shielded and Gas-Shielded Flux Cored Arc Welding

is more forgiving of minor disparities in procedures and differences in welder skill than GMAW, and it is more flexible and adaptable than SAW. Among the benefits offered by FCAW are the following:

1. High-quality weld metal deposit,
2. Excellent weld appearance,
3. Welds many steels in a wide thickness range,
4. High operating factor and easily mechanized,
5. High deposition rate (up to four times greater than SMAW) and high current density,
6. Relatively high electrode deposit efficiency,
7. Allows economical engineering of joint designs,
8. Visible arc contributes to easy use,
9. Requires less precleaning than GMAW,
10. Often results in less distortion compared to SMAW,
11. Exceptionally good fusion when used with shielding gas compared to GMAW-S,
12. High tolerance for contaminants that may cause weld cracking,
13. Resistance to underbead cracking,



Photograph courtesy of Bohler Thyssen Welding USA, Inc.

Figure 5.3—Flux Cored Arc Welding of a Suction Filter Used in the Pulp and Paper Industry

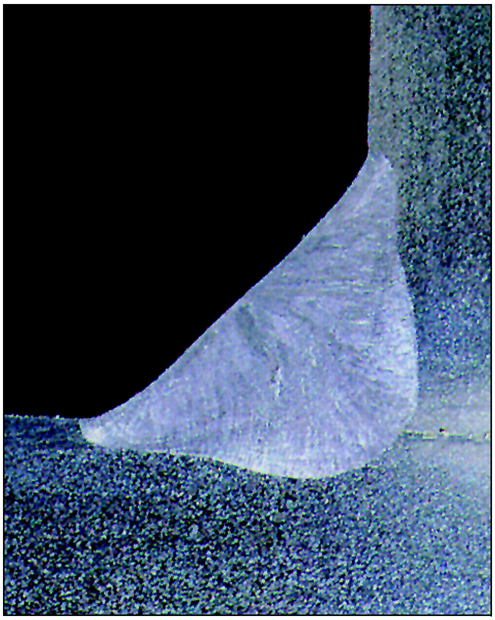
14. Self-shielding characteristic of electrodes eliminates the need for flux handling and gas apparatus, and
15. Self-shielding tolerates windy conditions in outdoor applications. (See No. 6 relative to gas shields under "Limitations" in the next section).

An example of the good sidewall fusion, deep penetration and smooth weld profile that can be obtained with gas-shielded FCAW is shown in Figure 5.4

LIMITATIONS

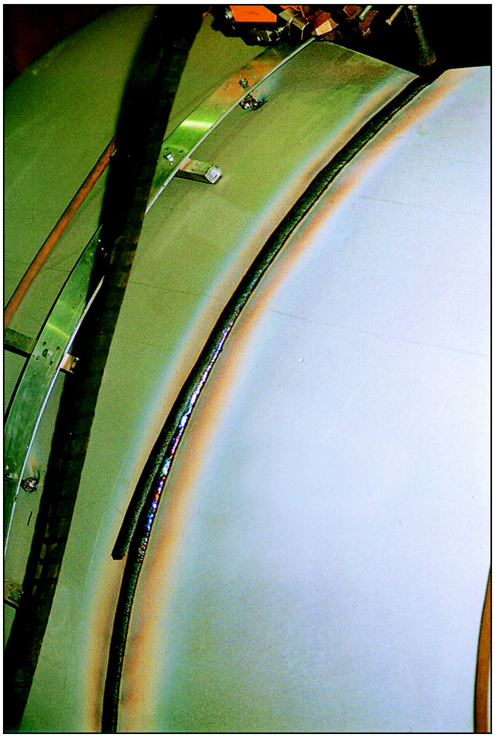
Compared to the SMAW process, the major limitations of FCAW are the higher cost of the equipment, the relative complexity of setup and control of the equipment, and the restriction on operating distance from the electrode wire feeder. Flux cored arc welding may generate large volumes of welding fumes and requires suitable exhaust equipment, except in field work. Compared to the slag-free GMAW process, the need for removing slag between passes is an added labor cost when using FCAW. This is especially true in making root pass welds.However, in most cases, slag is easily removed and cleanup time is minimized, as shown in Figure 5.5. The limitations of FCAW are summarized as follows:

1. FCAW is limited to welding ferrous metals and nickel-base alloys;
2. The process produces a slag covering that must be removed;
3. FCAW electrode wire is more expensive on a weight basis than solid electrode wires, except for some high-alloy steels;
4. The equipment is more expensive and complex than that required for SMAW, however, increased productivity usually compensates for this;



Photograph courtesy of Bohler Thyssen Welding USA, Inc.

Figure 5.4—Flux Cored Arc Weld Profile



Photograph courtesy of Bohler Thyssen Welding USA, Inc.

Figure 5.5—Self-Peeling Slag Reveals a Clean Flux Cored Arc Weld

5. The wire feeder and power source must be fairly close to the point of welding;
6. For gas-shielded FCAW, the external shield may be adversely affected by breezes and drafts;
7. Equipment is more complex than that used for SMAW, so more maintenance is required; and
8. More smoke and fumes are generated by FCAW than by GMAW and SAW.

It should be noted that self-shielded FCAW is not adversely affected by windy conditions, except in very high winds, because the shield is generated at the end of the electrode exactly where it is required.

EQUIPMENT

The basic equipment setup for flux cored arc welding is shown in Figure 5.6. Equipment consists of a power source, electrode feed and current controls, a shielding gas source, a wire electrode feeding system, a welding gun, and the associated cables and gas hoses. In addition, appropriate fume extraction equipment may be needed. Proper ventilation or some means of fume removal is necessary for FCAW.

SEMIAUTOMATIC EQUIPMENT

Control equipment for semiautomatic self-shielded and gas-shielded flux cored arc welding is similar. The major difference between the shielding variations is the provision for supplying and metering gas to the arc of the electrode in the gas-shielded method.

Power Source

The recommended power source is the direct current (dc) constant-voltage type, similar to power sources used for GMAW. The power source should be capable of operating at the maximum current required for the specific application. Most semiautomatic applications use less than 500 amperes (A). The voltage control should be capable of adjustments in increments of one volt or less. Constant-current dc power sources of adequate capacity with appropriate controls and wire feeders are sometimes used, but applications are rare.

Electrode Feed Control

The purpose of the electrode (wire) feed control is to supply the continuous electrode to the welding arc at a constant preset rate. The rate at which the electrode is fed into the arc determines the welding amperage supplied by a constant-voltage power source. If the