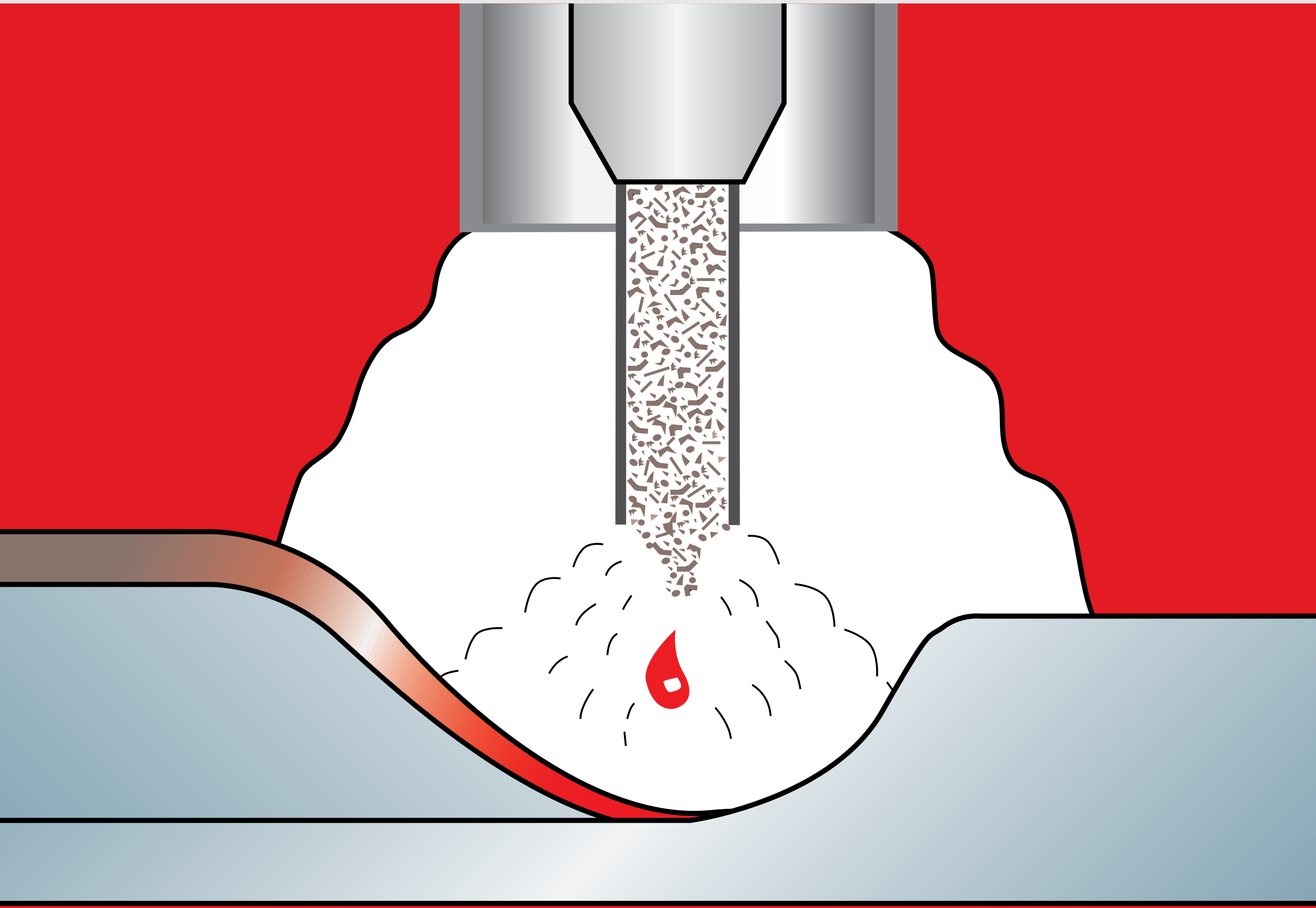
EW-492
TECHNICAL
GUIDE

HOBART INSTITUTE OF WELDING TECHNOLOGY

Flux Cored Arc Welding



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CHAPTER 1
INTRODUCTION TO THE PROCESS

Flux cored arc welding (FCAW) is an arc welding process in which the heat for welding is produced by an arc between a continuously fed tubular electrode wire and the work. Shielding is obtained by a flux contained within the tubular electrode wire or by the flux and an externally supplied shielding gas. Some trade names for this process are FabCO®, Fabshield®, Innershield®, and Dual Shield®. A diagram of the process is shown in Illustration 1-1.

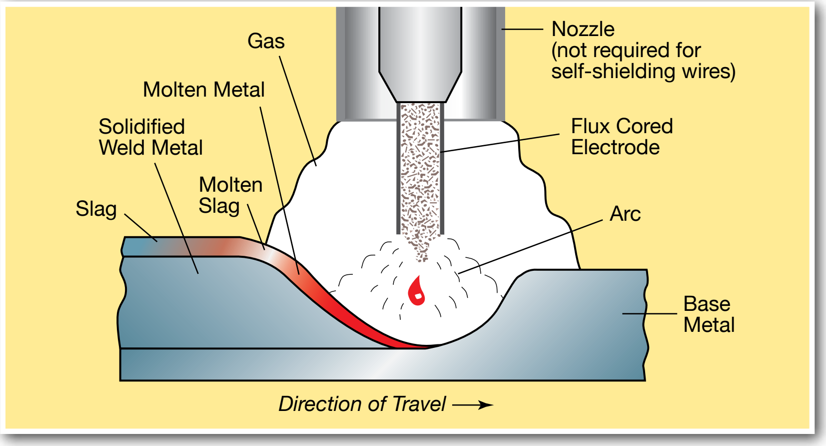


Illustration 1-1 – Flux Cored Arc Welding

Flux cored arc welding is similar to gas metal arc welding in many ways. The flux cored wires used for this process give it different characteristics. Flux cored arc welding is widely used for welding ferrous metals and is particularly good for applications where high deposition rates are desirable. At high welding currents, the arc is smoother and more manageable when compared to using large diameter gas metal arc welding electrodes with carbon dioxide. The arc and weld pool are clearly visible to the welder. A slag coating is left on the surface of the weld bead, which must be removed. Since the filler metal transfers across the arc, some spatter is created and some smoke is produced.

The gas-shielded metal arc welding process had its beginning in the early 1920's. Experiments conducted at that time proved that weld metal properties were improved when the welding arc and welding puddle were protected from atmospheric gases by an inert gas shield. However, the development of coated electrodes in the late 1920's reduced the interest in gas-shielded processes.

The gas tungsten-arc welding (GTAW) process became available commercially in the early 1940's and was the forerunner of the modern gas-shielded metal arc welding processes which includes flux cored and metal cored arc welding. In the GTAW process, a non-consumable electrode is used and the arc area is shielded by an inert gas.

This development was followed in the late 1940's by the gas metal arc welding (GMAW) process when a consumable electrode wire replaced the tungsten electrode. The gas metal arc or MIG (Metal Inert Gas) process was used for nonferrous metals and employed an inert gas, usually helium or argon. As gas metal arc welding developed, engineers learned that mild carbon and low alloy steels could be welded also. However, the high cost of inert shielding gas prevented this process from competing economically with the less costly manual shielded metal arc welding.

Research work conducted on manual coated electrode welds dealt with an analysis of the gas produced in the disintegration of electrode coatings. Results of this analysis showed that the predominate gas given off by electrode coatings was carbon dioxide. This discovery led quickly to the use of carbon dioxide gas for shielding when welding carbon steel with the gas metal arc welding process. Early experiments with carbon dioxide gas were not successful. However, continued research and experimentation with electrode wire composition and equipment did develop a practical gas metal arc process for the welding of carbon steels.

CO_2 shielded gas metal arc welding became very popular during the mid-1950's. Its most successful applications were for fully automatic welding installations in the automotive industry. High metal deposition rates and fast travel speeds characterized the process. Because of the extremely fluid weld puddle, the process was limited to flat position and horizontal fillet welds. Also, the process was so fast that it was difficult to do semiautomatic welding with manual travel. Weld spatter was a problem.

Flux cored or "inside out" coated electrode wires were experimented with in the early 1920's but, as with the gas-shielded systems, the development of covered electrodes reduced interest in the inadequately developed flux cored electrode wires.

The joining of the CO_2 gas shielding system to the flux cored consumable wire development provided a process that overcame many deficiencies. Operating characteristics were improved by the addition of the core materials and weld quality was improved by eliminating atmospheric contamination. The process was introduced publicly at the American Welding Society Exposition held at Buffalo, New York, in May 1954. The electrodes and equipment were refined and introduced in essentially the present form in 1957. Since the introduction, improvements have been made on the equipment and consumables for the process.

A major development in flux cored arc welding in the early 1960's was the introduction of flux cored wires, not requiring external gas shielding. These electrode wires became popular for many field construction applications because the need for a gas shielding system was eliminated, which made the equipment more portable.

Continuing work has been done on improving the mechanical properties, especially the impact toughness, of welds made by flux cored arc welding. The electrodes available today produce much better results than the wires originally introduced in the late 1950's and early 1960's. More flux cored wires for welding higher alloy steels have been developed. During the 1960's metal cored wires were introduced. An important difference between a flux cored wire and a metal cored wire is the absence of heavy slag on the weld.

Other major improvements in flux cored wires include improving the welder appeal. This has been done by reducing the smoke and spatter levels produced and improving the weld bead appearance characteristics. Development on these and other aspects of flux cored arc welding is continuing.

METHODS OF APPLICATION

Although flux cored arc welding may be applied semiautomatically, by machine, or automatically, the process is usually applied semiautomatically. In semiautomatic welding, the wire feeder feeds the electrode wire and the power source maintains the arc length. The welder manipulates the welding gun and adjusts the welding parameters. Flux cored arc welding is also used in machine welding where, in addition to feeding the wire and maintaining the arc length, the machinery also provides the joint travel. The welding operator continuously monitors the welding and makes adjustments in the welding parameters. Automatic welding is used in high production applications. In automatic welding, the welding operator only starts the operation.

ADVANTAGES AND LIMITATIONS

Flux cored arc welding has many advantages for a wide variety of applications. Flux cored arc welding often competes with shielded metal arc welding, gas metal arc welding, and submerged arc welding for many applications. Some of the advantages of this process are:

1) It has a high deposition rate and faster travel speeds are often used

2) Using small diameter electrode wires, welding can be done in all positions

3) Some flux cored wires do not need an external supply of shielding gas which simplifies the equipment

4) The electrode wire is fed continuously so there is very little time spent on changing electrodes

5) A higher percentage of the filler metal is deposited when compared to shielded metal arc welding

6) Better penetration is obtained than from shielded metal arc welding

CHAPTER 2
PRINCIPLES OF OPERATION

The flux cored arc welding process uses the heat of an electric arc between a consumable, tubular electrode and the part to be welded. Electric current passing through an ionized gas produces an electric arc. The gas atoms and molecules are broken up and ionized by losing electrons and leaving a positive charge. The positive gas ions then flow from the positive pole to the negative pole and the electrons flow from the negative pole to the positive pole. About 95% of the heat is carried by the electrons and the rest is carried by the positive ions. The heat of the arc melts the electrode and the surface of the base metal. The molten weld metal, heated weld zone, and electrode are shielded by one of two methods. One is by the decomposition of the flux core of the electrode. The second method is by a combination of an externally supplied shielding gas and the decomposition of the flux core of the electrode wire. The flux core has essentially the same purpose as the coating on an electrode for shielded metal arc welding. The molten electrode filler metal transfers across the arc and into the molten weld puddle. A slag forms on top of the weld bead which can be removed after welding.

The arc is struck by starting the wire feed which causes the electrode wire to touch the workpiece and initiate the arc. Arc travel is usually not started until a weld puddle is formed. The welding gun then moves along the weld joint manually or mechanically so that the edges of the weld joint are joined. The weld metal solidifies behind the arc which completes the welding process. A large amount of flux is contained in the core of a self-shielding wire as compared to a gas-shielded wire. This is needed to provide adequate shielding and because of this, a thicker slag coating is formed. In these wires, deoxidizing and denitrifying elements are needed in the filler metal and flux core because some nitrogen is introduced from the atmosphere. Most self-shielding wires also operate using longer electrode extensions than gas-shielded wires.

ARC SYSTEMS

The flux cored arc welding process may be operated on both constant voltage and constant current power sources. Any welding power source can be classified by its volt-ampere characteristics as either a constant voltage (also called constant potential) or constant current (also called variable voltage) type, although there are some machines that can produce both characteristics. Constant voltage power sources are preferred for a majority of flux cored arc welding applications.

In the constant voltage arc system, the voltage delivered to the arc is maintained at a relatively constant level which gives a flat or nearly flat volt-ampere curve, as shown in Illustration 2-1. This type of power source is widely used for the processes that require a continuously fed wire electrode. In this system, the arc length is controlled by setting the voltage level on the power source and the welding current is controlled by setting the wire feed speed. As shown in Illustration 2-1, a slight change in the arc length will produce a large change in the welding current.

Most power sources have a fixed slope that is built in for a certain type of flux cored arc welding. Some constant voltage welding machines are equipped with a slope control which is used to change the slope of the volt-ampere curve. Illustration 2-2 shows different slopes obtained from one power source. The slope has the effect of limiting the amount of short-circuiting current that the power supply can deliver. This is the current available from the power source on the short circuit between the electrode

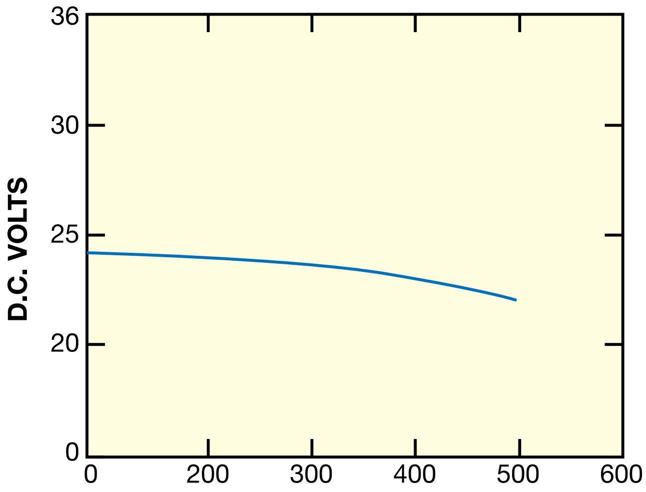


Illustration 2-1 – Constant Voltage Volt-Ampere Curve

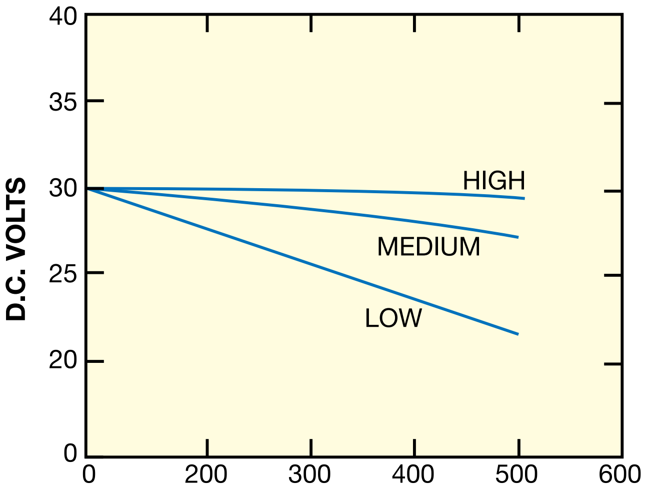


Illustration 2-2 – Different Slope Obtained from a Constant Voltage Power Source

wire and the work. This is not as important in flux cored arc welding as it was in gas metal arc welding because short-circuiting metal transfer is not encountered except with alloy cored, low flux content wires.

A slope control is not required, but may be desirable, when welding with small diameter, alloy cored, low flux content electrodes at low current levels. The short-circuit current determines the amount of pinch force available on the electrode. The pinch force causes the molten electrode droplet to separate from the solid electrode. The flatter the slope of the volt ampere curve, the higher the short-circuit and the pinch force. The steeper the slope, the lower the short-circuit and pinch force. The pinch force is important with these electrodes because it affects the way the droplet detaches from the tip of the electrode wire. When a high short-circuit and pinch force are caused by a flat slope, excessive spatter is created. When a very low short-circuit current and pinch force are caused by a steep slope, the electrode wire tends to freeze in the weld puddle or pile up on the work piece. When the proper amount of short-circuit current is used, very little spatter is created.

The inductance of the power supply also has an effect on the arc stability. When the load on the power supply changes, the current takes time to find its new level. The rate of current change is determined by the inductance of the power supply. Increasing the inductance will reduce the rate of current rise. The rate of the welding current rise increases with the current which is also affected by the inductance in the circuit. Increased arc time or inductance produces a flatter and smoother weld bead as well as a more fluid weld puddle. Too much inductance will cause more difficult arc starting.

The constant current arc system provides a nearly constant welding current to the arc which gives a drooping volt-ampere characteristic, as shown in Illustration 2-3. This arc system is used with the shielded metal arc welding and gas tungsten arc welding processes. The welding current is set by a dial on the machine and the welding voltage is controlled by the arc length held by the welder.

This system is necessary for manual welding because the welder cannot hold a constant arc length which causes only small variations in the welding current. When flux cored arc welding is done with a constant current system, a special voltage sensing wire feeder is used to maintain a constant arc length.

For any power source, the voltage drop across the welding arc is directly dependent on the arc length. An increase in the arc length results in a corresponding increase in the arc voltage and a decrease in the arc length results in a corresponding decrease in the arc voltage. Another important relationship exists between the welding current and the melt off rate of the electrode. With low current, the electrode melts off slower and the metal is deposited slower. This relationship between welding current and wire feed speed is definite, based on the wire size, shielding gas type and type of electrode. A faster wire feed speed will give a higher welding current.

In the constant voltage system, instead of regulating the wire to maintain a constant arc length, the wire is fed into the arc at a fixed speed and the power source is designed to melt off the wire at the same speed. The self-regulating characteristic of a constant voltage power source comes about by the ability of this type of power source to adjust its welding current in order to maintain a fixed voltage across the arc.

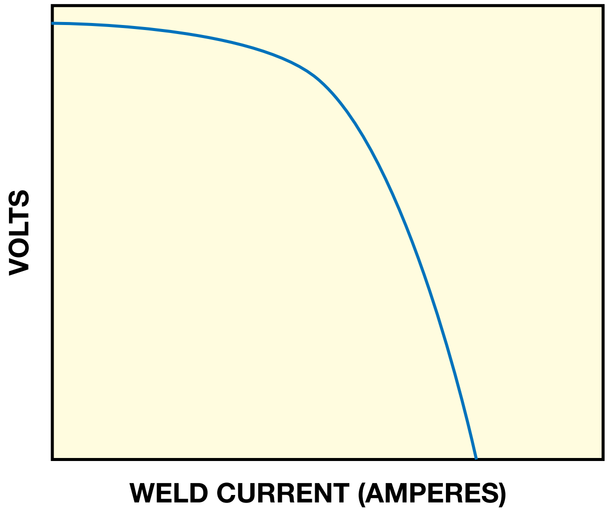


Illustration 2-3 – Constant Current Volt-Ampere Curve

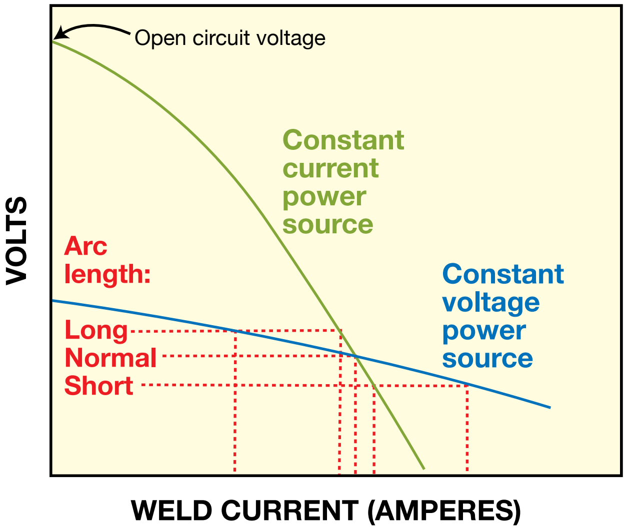


Illustration 2-4 – Volt-Ampere Curves

With the constant current arc system, the welder would change the wire feed speed as the gun is moved toward or away from the weld puddle. Since the welding current remains the same, the burn-off rate of the wire is unable to compensate for the variations in the wire feed speed, which allows stubbing or burning back of the wire into the contact tip to occur. To lessen this problem, a special voltage sensing wire feeder is used, which regulates the wire feed speed to maintain a constant voltage across the arc. The constant voltage system is preferred for most applications, particularly for small diameter wire. With smaller diameter electrodes, the voltage sensing system is often not able to react fast enough to feed at the required burn-off rate, resulting in a higher instance of burn-back into the contact tip of the gun.

Illustration 2-4 shows a comparison of the volt ampere curves for the two arc systems. This shows that for these particular curves, when a normal arc length is used, the current and voltage level is the same for both the constant current and constant voltage systems. For a long arc length, there is a slight drop in the welding current for the constant current machine and large drop in the current for a constant voltage machine. For constant voltage power sources, the volt-ampere curve shows that when the arc length shortens slightly, a large increase in welding current occurs. This results in an increased burn-off rate, which brings the arc length back to the desired level. Under this system, changes in the wire feed speed, caused by the welder, are compensated for electrically by the power source.

METAL TRANSFER

Metal transfer, from consumable electrodes across an arc, has been classified into three general modes of transfer. These are spray transfer, globular transfer, and short-circuiting transfer. The metal transfer of most flux cored electrodes resembles a fine globular transfer, sometimes referred to as small droplet transfer. Some flux cored electrodes have a spray transfer. Only the alloy cored, low flux content wires can produce a short-circuiting metal transfer similar to gas metal arc welding.

On flux cored electrodes, the molten droplets build up around the periphery or outer metal sheath of the electrode. By contrast, the droplets on solid wires tend to form across the entire cross section at the end of the wire. A droplet forms on the cored wire, is transferred, and then a droplet is formed at another location on the metal sheath. The core material appears to transfer independently to the surface of the weld puddle. Illustration 2-5 shows the metal transfer in flux cored arc welding.

At low currents, the droplets tend to be larger than at higher current levels. If the welding current using a 3/32 in. (2.4 mm) electrode wire is increased from 350 to 550 amps, the metal transfer characteristics will change. Transfer is much more frequent and the droplets become smaller as the current is increased. At 550 amperes some of the metal may transfer by the spray mode, although the globular mode prevails. There is no indication that higher currents cause a transition to a spray mode of transfer, unless an argon-oxygen shielding gas mixture is used.

The larger droplets at the lower currents cause a certain amount of "splashing action" when they enter the weld puddle. This action decreases with the smaller droplet size. This explains why there is less visible spatter, the arc appears smoother to the operator, and the deposition efficiency is higher, when a wire is used with a high current density rather than at the low end of its current range.

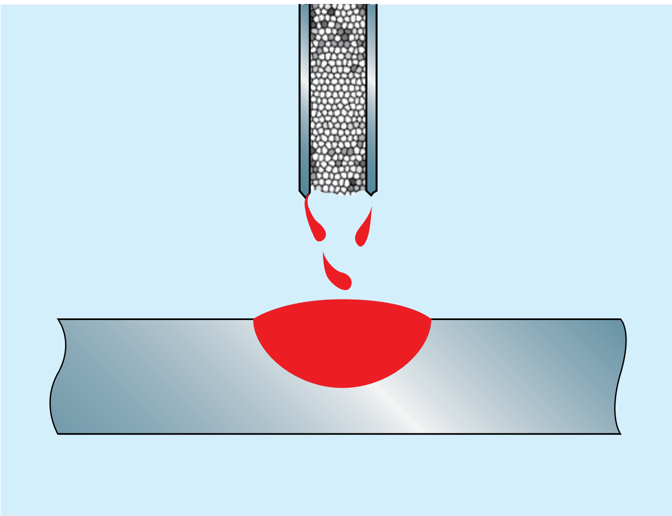


Illustration 2-5 –Metal Transfer in Flux Cored Arc Welding

CHAPTER 3
EQUIPMENT FOR WELDING

The equipment used for flux cored arc welding is very similar to that used for gas metal arc welding. The basic arc welding equipment consists of a power source, controls, wire feeder, welding gun and welding cables. A major difference between the gas-shielded electrodes and self-shielded electrodes is that the gas-shielded wires also require a gas shielding system. This may also have an effect on the type of welding gun used. Fume extractors are often used with this process. For machine and automatic welding, several items, such as seam followers and motion devices, are added to the basic equipment. Illustration 3-1 shows a diagram of the equipment used for semiautomatic flux cored arc welding.

POWER SOURCES

The power source or welding machine provides the electric power of the proper voltage and amperage to maintain a welding arc. Most power sources operate on 230 or 460 volt input power, but machines that operate on 200 or 575 volt input are available as options. Power sources may operate on either single phase or three-phase input with a frequency of 50 to 60 Hz.

Power Source Duty Cycle

The duty cycle of a power source is defined as the ratio of arc time to total time. Most power sources used for flux cored arc welding have a duty cycle of 100%, which indicates that they can be used to weld continuously. Some machines used for this process have duty cycles of 60%, which means that they can be used to weld six of every ten minutes. In general, these lower duty cycle machines are the constant current type, which are used in plants where the same machines are also used for shielded metal arc welding and gas tungsten arc welding. Some of the smaller constant voltage welding machines have a 60% duty cycle.

Types of Current

Flux cored arc welding uses direct current. Direct current can be connected in one of two ways, which are electrode positive (reverse polarity) or electrode negative (straight polarity). The electrically charged particles flow between the tip of the electrode and the work as shown in Illustration 3-2. Flux cored electrode wires are designed to operate on either DCEP or DCEN. The wires designed for use with an external gas shielding system are generally designed for use with DCEP. Some self-shielding flux cored wires are used with DCEP while others are developed for use with DCEN. Electrode positive current gives better penetration into the weld joint. Electrode negative current gives lighter penetration and is used for welding thinner metal or where there is poor fit-up. The weld created by DCEN is wider and shallower than the weld produced by DCEP.

Types of Power Sources

The power sources generally recommended for flux cored arc welding are direct current constant voltage types. Both rotating (generator) and static (single or three-phase transformer-rectifiers) are employed. Any of these types of machines are available to produce constant current or

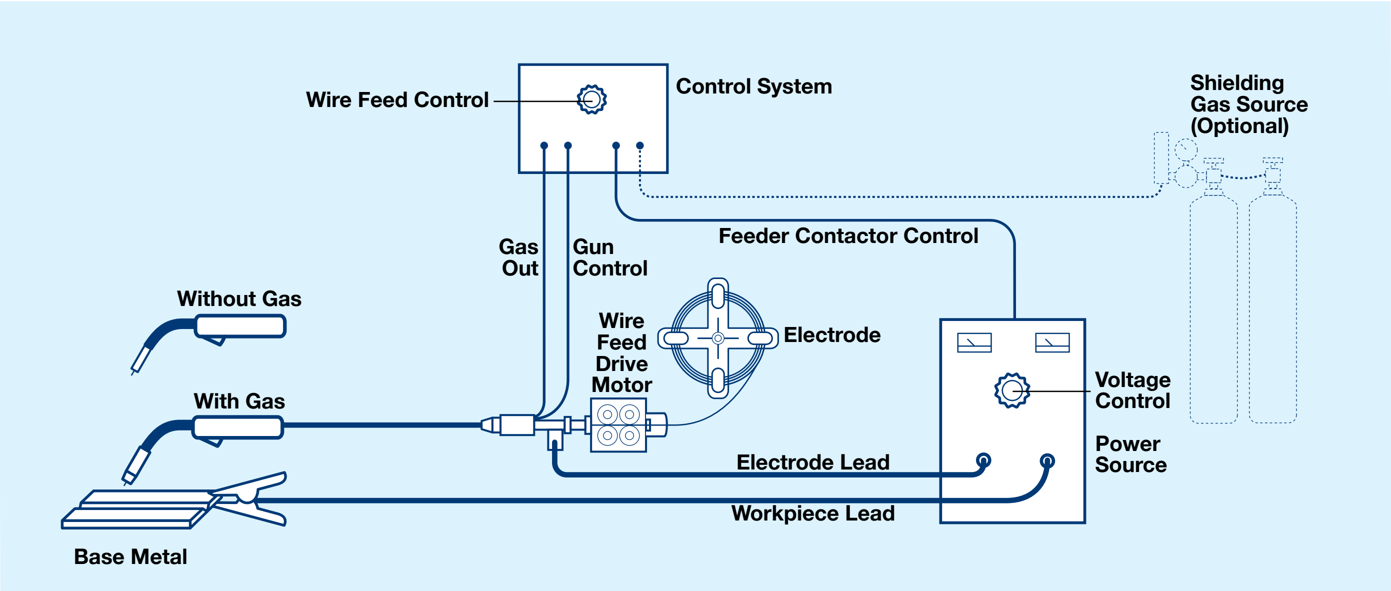


Illustration 3-1 – Equipment for Flux Cored Arc Welding

constant voltage output, or both. The same power sources used with gas metal arc welding are employed with flux cored arc welding. Flux cored arc welding generally uses higher welding currents than gas metal arc welding, which sometimes requires a larger power source. It is important to use a power source that is capable of producing the maximum current level required for an application.

Generator Welding Machines

The generator welding machines used for this process can be powered by an electric motor, for shop use, or an internal combustion engine, for field applications. The gasoline or diesel engine driven welding machines have either liquid or air-cooled engines and many of them provide auxiliary power for emergency lighting, power tools, etc. Many of the engine driven generators used for flux cored arc welding in the field are combination constant current-constant voltage types. These are popular for applications where both shielded metal arc welding and flux cored arc welding can be accomplished using the same power source. Illustration 3-3 shows an engine driven generator machine used for flux cored arc welding. The motor driven generator welding machines are gradually being replaced by transformer-rectifier welding machines. Motor-driven generators produce a very stable arc, but they are noisier, more expensive, consume more power and require more maintenance than transformer-rectifier machines.

Transformer-Rectifier Welding Machines

The most widely used welding machines for flux cored arc welding are the transformer-rectifiers. A method of supplying direct current to the arc, other than the use of a rotating generator, is by adding a rectifier to a basic transformer circuit. A rectifier is an electrical device which changes alternating current into direct current. These machines are more efficient electrically than motor-generator welding machines and they provide quieter operation. There are two basic types of transformer-rectifier welding machines; those that operate on single phase input power and those that operate on three-phase input power.

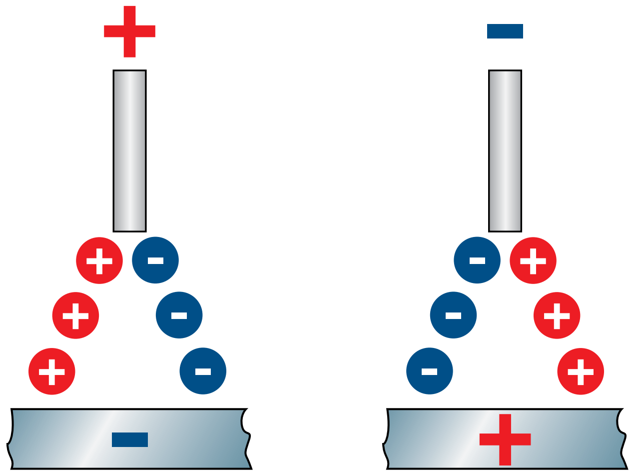


Illustration 3-2 – Particle Flow for DCEP and DCEN

Illustration 3-3 – Gas Powered Welder/Generator
Photo courtesy of Miller Electric Manufacturing Co.

The single phase transformer-rectifier machines provide DC current to the arc and a constant current volt-ampere characteristic. These machines are not as popular as three-phase transformer-rectifier welding machines for flux cored arc welding. When using a constant current power source, a special variable speed or voltage sensing wire feeder must be used to maintain a uniform current level. A limitation of the single phase system is that the power required by the single phase input power may create an unbalance of the power supply lines which is objectionable to most power companies. These machines normally have a duty cycle of 60%.

The most widely used type of power source for this process is the three-phase transformer-rectifier. These machines produce DC current for the arc and, for flux cored arc welding, most have a constant voltage volt ampere characteristic. When using these constant voltage machines, a constant speed wire feeder is employed. This type of wire feeder maintains a constant wire feed speed with slight changes in welding current. The three-phase input power gives these machines a more stable arc than single phase input power and avoids the line unbalance that occurs with the single phase machines. Many of these machines also use solid state controls for the welding. A 650 amp solid state controlled power source is shown in Illustration 3-4. This machine will produce the flattest volt-ampere curve of the different constant voltage power sources. Most three-phase transformer-rectifier power sources are rated at a 100% duty cycle.

CONTROLS

The controls for this process are located on the front of the welding machine, on the welding gun, and on the wire feeder or a control box.

The welding machine controls for a constant voltage machine include an on-off switch, a voltage control, and often a switch to select the polarity of direct current. The voltage control can be a single knob, or it can have a tap switch for setting the voltage range and a fine voltage control knob.

Other controls are sometimes present, such as a switch for selecting CC or CV output on combination machines, or a switch for a remote control. On the constant current welding machines there is an on-off switch, a current level control knob, and sometimes a knob or switch for selecting the polarity of direct current.

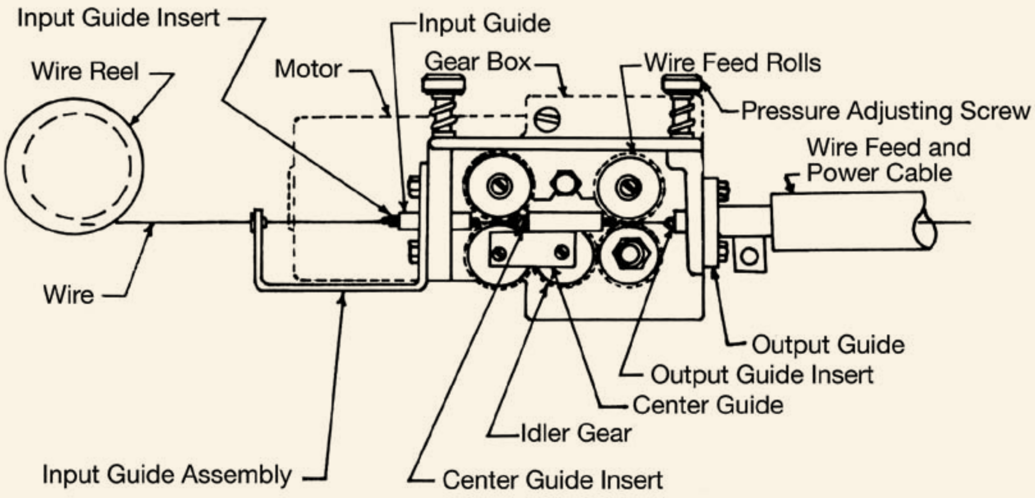
The trigger or switch on the welding gun is a remote control that is used by the welder in semiautomatic welding to stop and start the welding current, wire feed, and shielding gas flow.

For semiautomatic welding, a wire feed speed control is normally part of, or close by, the wire feeder assembly. The wire feed speed sets the welding current level on a constant voltage machine. For machine or automatic

Illustration 3-4 – Three phase Power Source with Multi-Process Capability
Photo courtesy of Miller Electric Manufacturing Co.

welding, a separate control box is often used to control the wire feed speed. On the wire feeder control box, there may also be switches to turn the control on and off and gradually feed the wire up and down.

Other controls for this process are used for special applications, especially when a programmable power source is used. An example is a timer for spot welding. Controls that produce a digital read-out are popular because more concise control is easier.



4-Roll Gear Box
Photo courtesy of Miller Electric Manufacturing Co.

2-Roll Gear Box

Illustration 3-7 – Wire Feeder Assembly

Illustration 3-5
Constant Speed
Wire Feeder
Photo courtesy of Miller Electric Manufacturing Co.

WIRE FEEDERS

The wire feed motor provides the power for driving the electrode through the cable and gun and to the work. There are several different wire feeding systems available. The selection of the best type of system depends on the application. Most of the wire feed systems used for flux cored arc welding are the constant speed type, which are used with constant voltage power sources. This means that the wire feed speed is set before welding. (See Illustration 3.5.) The wire feed speed controls the amount of welding current. Variable speed or voltage sensing wire feeders are used with constant current power sources. With a variable speed wire feeder, a voltage sensing circuit is used to maintain the desired arc length by varying the wire feed speed. Variations in the arc length increase or decrease the wire feed speed. (See Illustration 3.6.)

Illustration 3-6 – Variable Speed (Voltage Sensing) Wire Feeder
Photo courtesy of Miller Electric Manufacturing Co.

A wire feeder consists of an electrical motor connected to a gear box containing drive rolls. The gear box and wire feed motor shown in Illustration 3-7 has four feed rolls in the gear box. Many systems have only two. In a four roll system, the lower two rolls drive the wire. Because of their structure, flux cored wires can be easily flattened. The type of drive roll used is based on the size of the tubular wire being fed. The three basic types of drive rolls are the U-groove, V-knurled and the U-cogged (gear type), as shown in Illustration 3-8. U-groove drive rolls are only used on small diameter wires. These can be used because small diameter tubular wires are less easily flattened. V-knurled drive rolls are most commonly used for wire sizes 1/16 in. (1.6 mm) and greater. These drive rolls are lightly knurled to prevent slipping of the wire. The U-cogged (geared) drive rolls are used for large diameter flux cored wires. A groove is cut into both rolls. Different gear ratios are used, depending on the wire feed speed required. Illustration 3-9 shows the wire feed speeds that can be obtained from different gear ratios.

Wire feed systems may be of the pull, push, or push-pull, type depending on the method of application and the distance between the welding gun and the coil or

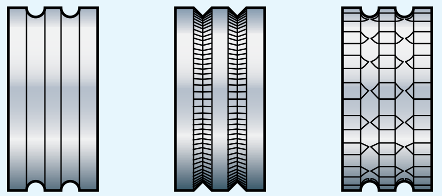


Illustration 3-8
Common Types of Drive Rolls and their Uses

Gear Ratio	Wire Feed Speed	
	in/min	(mm/s)
15:1	500-2000	212-846
37.5:1	60-1000	25-423
46:1	50-825	21-349
75:1	30-500	13-212
90:1	25-400	11-169
150:1	15-250	6-106
300:1	8-125	3-53
600:1	4-63	2-27
1200:1	2-30	1-13

Illustration 3-9 – Wire Feed Speeds obtained from Different Gear Ratios

spool of wire. Pull type wire feeders have the drive rolls attached to the welding gun. Most machine and automatic welding stations use this type of system. Pull type wire feeders are rarely used in semiautomatic welding. Pull wire feeders have the advantage for welding small diameter aluminum and soft nonferrous metals with gas metal arc welding because it reduces wire feeding problems. Since most flux cored wires are steel, this is not an advantage for flux cored arc welding. The push type system, which has the drive rolls mounted near the coil or spool of wire is the most commonly used in semiautomatic welding. The wire is pulled from the coil or spool and then pushed into a flexible conduit and through the gun. The relatively large diameter wires used in flux cored arc welding are well suited to this type of system. The length of the conduit can be up to about 12 feet (3.7 m). Another advantage of this push type system is that the wire feed mechanism is not attached to the gun, which reduces the weight and makes the gun easier to handle.

Some wire feed systems contain a two-gun, two-wire feeder arrangement connected to a single control box, which is connected to a single power source. Both wire feeders may be set up and there is a switch on the control to automatically select which of the two systems will be used. One advantage to this system is that the second wire feeder and gun can provide backup in case of breakdown, gun maintenance or electrode change. Another advantage is that two different electrodes for different applications can be set up. For example, a gas metal arc welding electrode and gun can be set up on one schedule for welding a root pass. The second schedule can be set up with flux cored wire to weld the rest of

Illustration 3-10 – 600 Ampere Air-Cooled Gun for Flux Cored Arc Welding
Photo courtesy of Miller Electric Manufacturing Co.

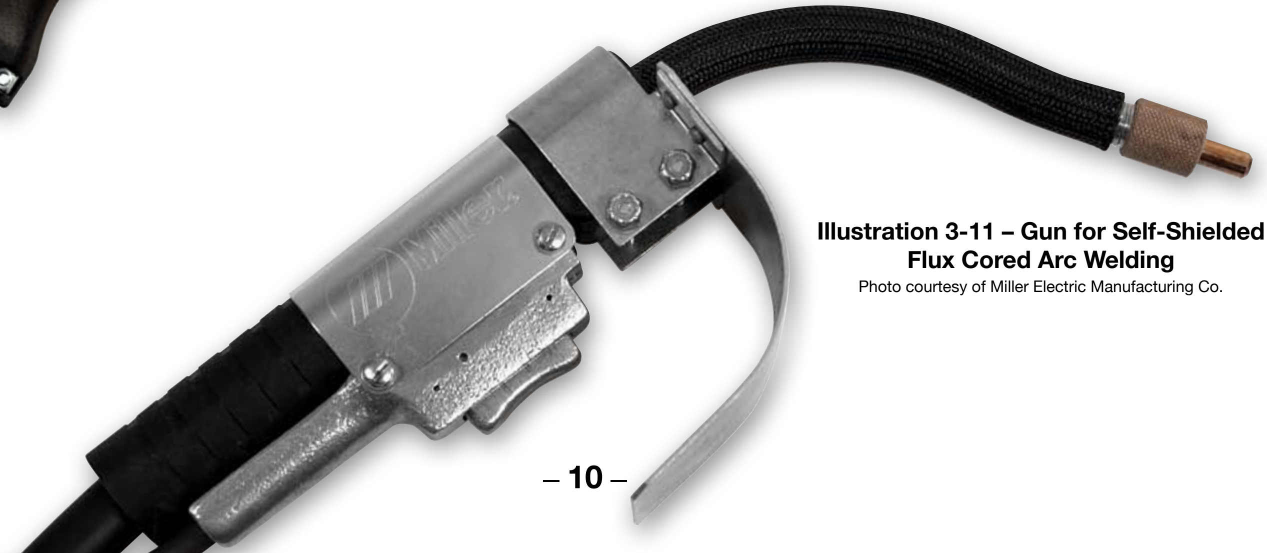


Illustration 3-11 – Gun for Self-Shielded Flux Cored Arc Welding
Photo courtesy of Miller Electric Manufacturing Co.

the joint. This eliminates the need for two power sources or the need to change the electrode wire and gun. The liner is made of flexible metal and is available in sizes compatible with the electrode size. The liner guides the electrode wire from the wire feeder drive rolls through the cable assembly and prevents interruptions in the travel.

Heavy duty welding guns are normally used because of the large size electrode wires used and the high welding current levels required. Because of the intense heat created by this process, heat shields are usually attached to the gun in front of the trigger to protect the welder's hand.

Both air-cooled and water-cooled guns are used for flux cored arc welding. Air-cooled guns are cooled primarily by the surrounding air, but when a shielding gas is used, this will have an additional cooling effect. Air-cooled guns are lighter and easier to manipulate. Illustration 3-10 shows a 600 ampere air-cooled welding gun.

Some self-shielded flux cored wires require a specific minimum electrode extension to develop proper shielding. These welding guns have guide tubes with an insulated extension tube. This guide supports the electrode and insures minimum electrode extension as shown in Illustration 3-12. A gun for self-shielded flux cored wire welding is shown in Illustration 3-11.

Machine Welding Guns

Machine and automatic welding guns use the same basic design principles and features as the semiautomatic welding guns. These guns often have very high current carrying capacities and may also be air-cooled or water-cooled. Large diameter wires up to 1/8 in. (3.2 mm) are commonly used with high amperages. Machine welding guns must be heavy duty because of the high amperages and duty cycles required. The welding gun is mounted directly below the wire feeder. Illustration 3-13 shows a machine welding head with concentric nozzle for flux cored arc welding. Gas can also be supplied to the arc by a side delivery tube. If a gas-shielded wire is to be used, the gas can be supplied by a nozzle that is concentric around the electrode or by a side delivery tube. The side shielding permits the welding gun to be used in deep, narrow grooves and reduces spatter buildup problems in the nozzle. Side shielding is only recommended for welding using carbon dioxide. When using argon-carbon dioxide and argon-oxygen mixtures, a concentric nozzle is preferred. Concentric nozzles provide better shielding and are sometimes recommended for CO_2 at high current levels when a large weld puddle exists.

FUME EXTRACTORS

Fume extractors are often used to help to reduce the smoke levels produced by flux cored electrodes. This

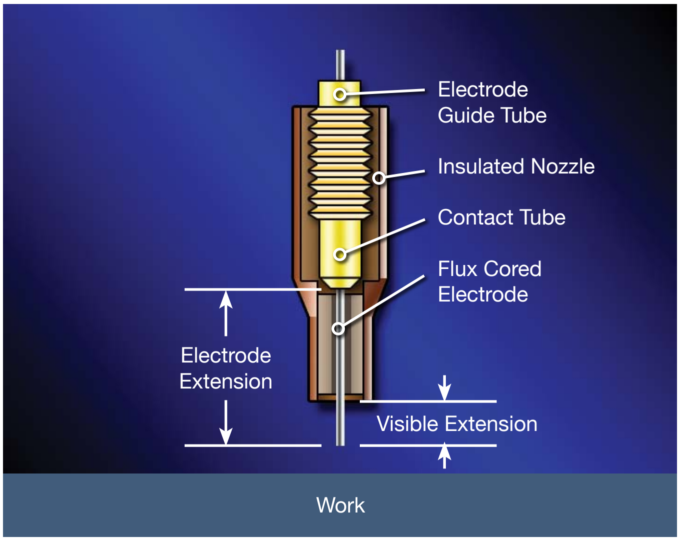


Illustration 3-12 – An Insulated Extension Guide to Ensure a Minimum Electrode Extension for Self-Shielded Electrodes

Illustration 3-13 – Automatic Welding Guns

Photos courtesy of Tregaskiss

Illustration 3-14 –Fume Extractor Nozzle

reduces air pollution and gives better visibility. Welding guns can be equipped with a fume extractor which consists of an exhaust nozzle that encircles the gun nozzle, as shown in Illustration 3-14. The nozzle is connected to a filter and an exhaust pump. The fume extraction nozzle should be located at a distance far enough from the arc to draw in the rising fumes without disturbing the shielding gas flow.

The major advantage of this fume extraction system is that it is always close to the point of welding. A portable fume exhaust fan cannot be positioned as close to the arc and requires repositioning for every change in welding position.

The major disadvantage of the fume extractor is that it makes the gun bulkier and more difficult to manipulate. Fume extractors are generally not necessary in a welding booth that is well ventilated.

SHIELDING GAS EQUIPMENT

The shielding gas equipment used for gas-shielded flux cored wires consists of a gas supply hose, a gas regulator, control valves, and supply hose to the welding gun.

The shielding gases are supplied in liquid form when they are in storage tanks with vaporizers or in a gas form in high pressure cylinders. An exception to this is carbon dioxide. When put in high pressure cylinders, it exists in both the liquid and gas forms. The bulk storage tank system is used when there are large numbers of welding stations using the same type of shielding gas in large quantities. For applications where there are large numbers of welding stations but relatively low gas usage, a manifold system is often used. This consists of several high pressure cylinders connected to a manifold, which then feeds a single line to the welding stations. Individual high pressure cylinders are used when the amount of gas usage is low, when there are few welding stations, or when portability is required.

The purpose of a gas flow regulator is to reduce the pressure from the gas supply source and maintain a constant delivery pressure. The gas flowmeter is then used to control the flow of gas from the regulator to the welding gun. The gas flow rate is adjusted by a valve at the flowmeter outlet. The flowmeter is often attached to the regulator as shown in Illustration 3-15. Regulators and flowmeters are designated for use with specific shielding gases and should only be used with the gas that they were designed for.

The hoses are normally connected to solenoid valves on the wire feeder to turn the gas flow on and off with the welding current. A hose is used to connect the flowmeter to the welding gun. The hose is usually part of the welding gun assembly.

Illustration 3-15 – Flowmeter and Regulator for Argon/CO^2

Photo courtesy of Smith Equipment

WELDING CABLES

The welding cables and connectors are used to connect the power source to the welding gun and to the work. These cables are normally made of copper or aluminum with copper being the most common. The cable consists of hundreds of wires that are enclosed in an insulated casing of natural or synthetic rubber. The cable that connects the power source to the welding gun is called the electrode lead. In semiautomatic welding, this cable is often part of the cable assembly, which also includes the shielding gas hose and the conduit that the electrode wire is fed through. For machine or automatic welding, the electrode lead is normally separate. The cable that connects the work to the power source is called the work lead. The work leads are usually connected to the work by pincher clamps or a bolt.

The size of the welding cables used depends on the output capacity of the welding machine, the duty cycle of the machine, and the distance between the welding ma-

Weld Type	Weld Current	Length of Cable in Feet – Cable Size A.W.G.					
		60'	100'	150'	200'	300'	400'
Manual (Low Duty Cycle)	100	4	4	4	2	1	1/0
	150	2	2	2	1	2/0	3/0
	200	2	2	1	1/0	3/0	4/0
	250	2	2	1/0	2/0		
	300	1	1	2/0	3/0		
	350	1/0	1/0	3/0	4/0		
	400	1/0	1/0	3/0			
	450	2/0	2/0	4/0			
	500	2/0	2/0	4/0			

Note: Length of cable circuit equals total electrode and work cable

Illustration 3-16 – Suggested Copper Welding Cable Sized for Flux Cored Arc Welding

chine and the work. Cable sizes range from the smallest at AWG No. 8 to AWG No. 4/0 with amperage ratings of 75 amperes on up. Illustration 3-16 shows recommended cable sizes for use with different welding currents and cable lengths. A cable that is too small may become too hot during welding

OTHER EQUIPMENT

Water Circulators

When a water-cooled gun is used, a water supply must be included in the system. This can be supplied by a water circulator or directly from a hose connection to a water tap. The water is carried to the welding torch through hoses that may or may not go through a valve in the welding machine. A typical water circulator is shown in Illustration 3-17.

Illustration 3-17 – Water Circulator

Photo courtesy of Smith Equipment

Motion Devices

Motion devices are used for machine and automatic welding. These motion devices can be used to move the welding head, workpiece, or gun, depending on the type and size of work and the preference of the user.

Motor driven carriages that run on tracks or directly on the workpiece are commonly used. Carriages can be used for straight line, contour, vertical, or horizontal welding. Side beam carriages are supported on the vertical face of a flat track and they can be used for straight line welding. Multiple electrode welding heads can be used to obtain higher deposition rates. Welding head manipulators may be used for longitudinal welds and, in conjunction with a rotary weld positioner, for circumferential welds. These welding head manipulators come in many boom sizes and can also be used for semiautomatic welding with mounted welding heads.

Oscillators are optional equipment that are used to oscillate the gun for surfacing, vertical-up welding, and other welding operations that require a wide bead. Oscillators can either be mechanical or electromagnetic devices.

Accessories

Accessory equipment for flux cored arc welding consists of items for cleaning the weld bead and cutting the electrode wire. Because of the slag coating that is formed, chipping hammers and wire brushes are usually required to remove the slag. A grinder is often used for final cleaning and for removing spatter. Wire cutters or pliers are used to cut the end of the electrode wire between stops and starts.

CHAPTER 4
SHIELDING GASES AND ELECTRODES

The electrodes used for flux cored arc welding provide the filler metal to the weld puddle and shielding for the arc. A shielding gas is required for some electrode types. The purpose of the shielding gas is to provide protection, from the atmosphere, to the arc and molten weld puddle. The chemical composition of the electrode wire and flux core in combination with the shielding gas will determine the weld metal composition and mechanical properties of the weld.

SHIELDING GASES

The primary purpose of shielding gas, in any gas-shielded arc welding process, is to protect the arc and weld puddle from contaminating effects of the atmosphere. The nitrogen and oxygen of the atmosphere, if allowed to come in contact with the molten weld metal, cause porosity and brittleness.

In shielded metal arc welding, protection is accomplished by placing an outer coating on the electrode which produces a gaseous shield as the coating disintegrates in the welding arc. In flux cored arc welding, the same effect is accomplished by decomposition of the electrode core or by a combination of this and surrounding the arc area with a shielding gas supplied from an external source.

A shielding gas displaces air in the arc area. Welding is then accomplished under a blanket of shielding gas. Since the molten weld metal is exposed only to the shielding gas, it is not contaminated by the atmosphere.

Oxygen, which makes up 21% of air, is a highly reactive element which, at high temperatures, combines readily with other elements in the steel to form undesirable oxides and gases. Oxygen combines with iron to form compounds which can lead to inclusions in the weld metal and also lower its mechanical properties. On coating, free oxygen in the molten metal combines with the carbon of the steel to form carbon monoxide. If gas is trapped in the weld metal as it cools, it collects in pockets and causes pores in the weld deposit.

Nitrogen, which makes up 78% of air, causes the most serious problems when welding steel. When steel is molten, it can take a relatively large amount of nitrogen into solution. At room temperature, the solubility of nitrogen in steel is very low. Therefore, in cooling, nitrogen precipitates or comes out of the steel as nitrites. These nitrites cause high yield strength, tensile strength, hardness, and a pronounced decrease in the ductility and impact resistance of the steel. The loss of ductility due to the presence of iron nitrites often leads to cracking of the weld metal. Excessive amounts of nitrogen can also lead to extensive porosity in the weld deposit.

Hydrogen may come from water in the atmosphere or from moisture on surfaces welded and is also harmful to welds. Hydrogen is also present in oils, paints, and some protective coverings. Even very small amounts of hydrogen in the atmosphere produce an erratic arc. Of more importance is the effect that hydrogen has on the properties of the weld deposit. As in the case of nitrogen, steel can hold a relatively large amount of hydrogen when it is molten but, upon cooling, it has a low solubility for hydrogen. As the metal starts to solidify, it rejects the hydrogen. The hydrogen entrapped in the solidifying metal collects at small discontinuities and causes pressure stresses to occur. This pressure can lead to minute cracks in the weld metal, which can later develop into larger cracks. Hydrogen also causes defects known as “fish eyes” and underbead cracks. Underbead cracking is caused by excessive hydrogen that collects in the heat affected zone.

Inert and active gases may be used for flux cored arc welding. Active gases such as carbon dioxide, argon-oxygen mixtures and argon-carbon dioxide mixtures are used for almost all applications, with carbon dioxide being the most common. Active gases are not chemically inert and can form compounds with the metals. Since almost all flux cored arc welding is done on ferrous metals, this is not a problem. The choice of the proper shielding gas for a specific application is based on:

1) Type of metal to be welded
2) Arc characteristics and metal transfer
3) Availability
4) Cost of the gas
5) Mechanical property requirements
6) Penetration and weld bead shape

Carbon Dioxide

Carbon dioxide is manufactured from fuel gases which are given off by the burning of natural gas, fuel oil, or coke. It is also obtained as a by-product of calcining operations in lime kilns, from the manufacturing of ammonia, and from the fermentation of alcohol. The carbon dioxide given off by the manufacturing of ammonia and the fermentation of alcohol is almost 100% pure. Carbon dioxide is made available to the user in either cylinder or bulk containers, with the cylinder being more common. With the bulk system, carbon dioxide is usually drawn off as a liquid and

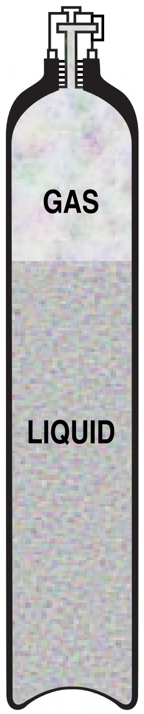


Illustration 4-1
Carbon Dioxide Gas Cylinder

Illustration 4-2 – Manifold System for Carbon Dioxide
Photo courtesy of Rexarc International, Inc.

heated to the gas state before going to the welding torch. The bulk system is normally only used when supplying a large number of welding stations. In the cylinder, the carbon dioxide is in both a liquid and a vapor form, with the liquid carbon dioxide occupying approximately two thirds of the space in the cylinder as shown in illustration 4-1. By weight, this is approximately 90% of the content of the cylinder. Above the liquid, it exists as a vapor gas. As carbon dioxide is drawn from the cylinder, it is replaced with carbon dioxide that vaporizes from the liquid in the cylinder and therefore the overall pressure will be indicated by the pressure gage. When the pressure in the cylinder has dropped to 200 psi (1.4 MPa) the cylinder should be replaced with a new cylinder. A positive pressure should always be left in the cylinder in order to prevent moisture and other contaminants from backing up into the cylinder. The normal discharge rate of the CO_2 cylinder is about 10 to 50 cubic feet per hour (4.7 to 24 liters per minute). However, a maximum discharge rate of 25 cfh (12 L/min.) is recommended when welding using a single cylinder. As the vapor pressure drops from the cylinder pressure to discharge pressure through the CO_2 regulator, it absorbs a great deal of heat. If flow rates are set too high, this absorption of heat can lead to freezing of the regulator and flowmeter which interrupts the shielding gas flow. When flow rates higher than 25 cfh (12 L/min.) are required, normal practice is to manifold two CO_2 cylinders in parallel or to place a heater between the cylinder and gas regulator, pressure regulator and flow meter. Illustration 4-2 shows a manifold system used for connecting several cylinders together. Excessive flow rates can also result in drawing liquid from the cylinder.

Argon only is not used for FCAW, only the mixtures with CO_2. Most active gases cannot be used for shielding, but carbon dioxide provides several advantages for use in welding steel. These are deep penetration and low cost. Carbon dioxide promotes a globular transfer.

The carbon dioxide shielding gas breaks down into components such as carbon monoxide and oxygen. Because carbon dioxide is an oxidizing gas, deoxidizing elements are added to the core of the electrode wire to remove oxygen. The oxides formed by the deoxidizing elements float to the surface of the weld and become part of the slag covering. Some of the carbon dioxide gas will break down to carbon and oxygen. If the carbon content of the weld pool is below about .05%, carbon dioxide shielding will tend to increase the carbon content of the weld metal. Carbon, which can reduce the corrosion resistance of some stainless steels, is a problem for critical corrosion applications. Extra carbon can also reduce the toughness and ductility of some low alloy steels. If the carbon content in the weld metal is greater than about 10%, carbon dioxide shielding will tend to reduce the carbon content. This loss of carbon can be attributed to the formation of carbon monoxide, which can be trapped in the weld as porosity deoxidizing elements in the flux core, reducing the effects of carbon monoxide formation.

Argon-Carbon Dioxide Mixtures

Argon and carbon dioxide are often mixed for use with flux cored arc welding. A high percentage of argon gas in the mixture tends to promote higher deposition efficiency due to the creation of less spatter. This mixture also creates less oxidation and lower fumes. The most commonly used argon-carbon dioxide mixture contains 75% argon and 25% carbon dioxide. This gas mixture produces a fine globular metal transfer that approaches a spray. It also reduces the amount of oxidation that occurs, compared to pure carbon dioxide. The weld deposited in an argon-carbon dioxide shield generally has higher tensile and yield strengths. Argon-carbon dioxide mixtures are often used for out-of-position welding, achieving better arc characteristics and welder appeal. This mixture also improves arc transfer on smaller diameters. Argon/CO_2 is often used on low alloy steels and stainless steels.

Electrodes that are designed for use with CO_2 may cause an excessive build-up of manganese, silicon, and other deoxidizing elements if they are used with shielding gas mixtures containing a high percentage of argon. This will have an effect on the mechanical properties of the weld.

Argon-Oxygen Mixtures

Argon-oxygen mixtures containing 1 or 2% oxygen are used for some applications. Argon-oxygen mixtures tend to promote a spray transfer which reduces the amount of spatter produced. A major application of these mixtures is the welding of stainless steels where carbon dioxide can cause corrosion problems.

ELECTRODES

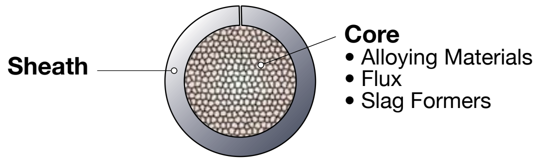


Illustration 4.3 – Cross-Section of a Flux Cored Wire

The electrodes for flux cored arc welding consist of a metal sheath surrounding a core of fluxing and/or alloying compounds as shown in Illustration 4-3. The core of carbon steel and low alloy electrodes contain primarily fluxing compounds. Some of the low alloy steel electrode cores contain high amounts of alloying compounds with a low flux content. Most low alloy steel electrodes require gas shielding. The sheath comprises approximately 75 to 90% of the weight of the electrode. Self-shielded electrodes contain more fluxing compounds than gas-shielded electrodes. The compounds contained in the electrode perform essentially the same functions as the coating of a covered electrode used in shielded metal arc welding. These functions are:

1) To form a slag coating that floats on the surface of the weld metal and protects it during solidification.
2) To provide deoxidizer and scavengers which help purify and produce solid weld metal.
3) To provide arc stabilizers which produce a smooth welding arc and keep spatter to a minimum.
4) To add alloying elements to the weld metal which will increase the strength and improve other properties in the weld metal.
5) To provide shielding gas. Gas-shielded wires require an external supply of shielding gas to supplement that produced by the core of the electrode.

The manufacture of a flux cored electrode is an extremely technical and precise operation requiring specially designed machinery. Illustration 4-4 shows one simplified version of the apparatus for producing tubular type cored electrodes on continuous production. A thin, narrow, flat, low-carbon steel strip passes through forming rolls which form the strip into a U-shaped cross-section. This U-shaped steel passes through a special filling device where a measured amount of the specially formulated granular core material is added. The flux-filled U-shaped strip then flows through special closing rolls which form it into a tube and tightly compress the core materials. This tube is then pulled through draw dies to reduce its diameter and further compress the core materials. Drawing tightly seals the sheath and additionally secures the core materials inside the tube under compression thus avoiding discontinuities in the flux. The electrode may or may not be baked during, or between, drawing operations. This depends on the type of electrode and the type of elements and compounds enclosed in the sheath.

Additional drawing operations are performed on the wire to produce various electrode diameters. Flux cored electrode wires are commonly available in sizes ranging from .035-5/32 inch.

The finished electrode is wound into a continuous coil, spool, reel or drum. These are available as 10 lb., 15 lb., or 50 lb. spools, 60 lb. (27 kg) coils, 250 or 500 lb. (113-225 kg) reels, or a 600 lb. drum. Electrode wires are generally wrapped in plastic to prevent moisture pick-up.

Classification

The classification system used for tubular wire electrodes throughout industry in the United States was devised by the American Welding Society (AWS). There are several different specifications covering flux cored arc welding electrodes for steels which are shown in illustration 4-5.

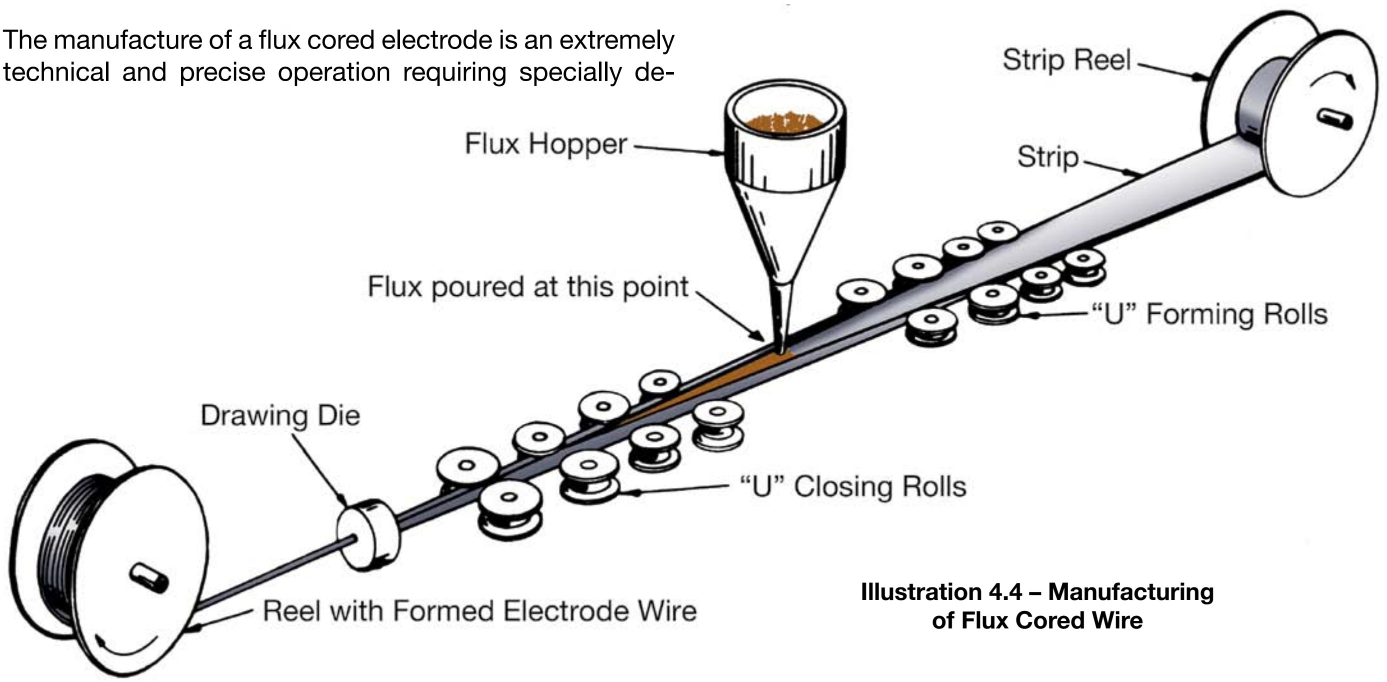


Illustration 4.4 – Manufacturing of Flux Cored Wire

The AWS specification for carbon steel and low-alloy steel electrodes uses two classification systems.

The “fixed classification system” includes electrodes that have gained wide acceptance over the years, and they are classified by their specific mechanical properties. Illustration 4-6 shows the electrodes that are included in the fixed classification system.

AWS Specification	Specification Title / Metal
A5.22	Stainless Steel Flux Cored and Metal Cored Welding Electrode and Rods
A5.36	Carbon and Low Alloy Steel Flux Cored Electrodes for Flux Cored Arc Welding and Metal Cored Electrodes for Gas Metal Arc Welding

Illustration 4-5 – AWS Filler Electrodes Specifications for Flux Cored Arc Welding

Source Specification for Electrode Classification & Requirements	Classification Designation[b,c]	Shielding Gas[d]	Weld Deposit Requirements	
			Mechanical Properties[e]	Weld Deposit[f]
AWS A5.20/A5.20M	E7XT-1C[g]	C1	Tensile Strength: 70-95 ksi Minimum Yield Strength: 58 ksi Min Charpy Impact: 20 ft•lbf @ 0° F Minimum % Elongation: 22% [j]	CS1
	E7XT-1M[g]	M21		
	E7XT-5C[g]	C1	Tensile Strength: 70-95 ksi Minimum Yield Strength: 58 ksi Min Charpy Impact: 20 ft•lbf @ -20° F Minimum % Elongation: 22% [j]	
	E7XT-5M[g]	M21		
	E7XT-6[g]	None		CS3
	E7XT-8[g]			
	E7XT-9C[g]	C1		CS1
	E7XT-9M[g]	M21		
	E7XT-12C[g]	C1	Tensile Strength: 70-90 ksi Minimum Yield Strength: 58 ksi Min Charpy Impact: 20 ft•lbf @ -20° F Minimum % Elongation: 22% [j]	CS2
	E7XT-12M[g]	M21		
	E70T-4[g]	None	Tensile Strength: 70-95 ksi Minimum Yield Strength: 58 ksi Min Charpy Impact: Not Specified Minimum % Elongation: 22% [j]	CS3
	E7XT-7[h]			

a) These multiple pass electrodes are classified according to the fixed classification system utilized in AWS A5.20/A5.20M as applicable, which has been carried over for these specific electrodes as a part of AWS A5.36/A5.36M. The mechanical property and weld deposit requirements are as defined in this table. These same electrodes may also be classified to the same requirements or to different requirements using the open classification system introduced in this specification. In this case, the classification designations are as described in AWS A5.20/A5.20M, Figure 1. See Table A.1 or Table A.3, as applicable, in Annex A for comparisons of the “fixed classification” designations and equivalent “open classification” designations for the above electrodes when both are classified to the requirements listed in this table.

b) Under AWS A5.20/A5.20M, the “E” at the beginning of the classification designates an electrode. The “7” is the tensile strength designator. The “X” indicates the electrode’s position of welding capability. A “0” is used to indicate flat and horizontal only. A “1” is used to indicate all position capability. The “T” identifies the electrode as a flux cored electrode The one or two digit number after the dash indicates the electrode’s usability characteristics as defined in AWS A5.20/A5.20M. For the open classification system introduced in this specification, the “T” identifies the electrode as either a flux cored or a metal cored electrode. The T” is combined with a one or two digit number as a part of the alpha-numeric designator for usability. See Illustration 4-11. Under AWS A5.18/A5.18M for classification E70C-6M, the “E” designates an electrode. The “70” indicates that the weld deposit will have a minimum tensile strength of 70 ksi. The ‘C’” indicates that the electrode is a composite (metal cored) electrode. The “6” indicates the composition of the weld metal the composition produced with this electrode. The “M” indicates the type of shielding gas used.

c) The electrodes shown in the darker blue panels are self-shielded.

d) See Illustration 4-8.

e) Mechanical properties are obtained by testing weld metal from the groove weld shown in Figure 2 of AWS A5.36/A5.36M. Welding and testing shall he done as prescribed in this specification. The requirements for welding and testing are the same as those given in A5.20/A5.20M. All mechanical property testing for the classifications listed in this table shall be done in the as-welded condition.

f) See Illustration 4-12.

g) The “D”, “Q”, and “H” optional designators which are not part of the electrode classification designation, may be added at the end of the designation as established in AWS A5.20/A5.20M, i.e., E7XT-XXD, E7XT-XXQ, E7XT-XXHX, E7XT-XXDHX, or E7XT-XXQHX as applicable. The “J” optional, supplemental designator listed in A5.20/A5.20M is no longer required. The open classification system introduced in this A5.36/A5.36M specification eliminates the need for this designator.

h) The “H” optional, supplemental designator, which is not part of the electrode classification designation, may be added to the end of the designation as established in AWS A5.18/A5.I8M, i.e., E70C-6MHZ. Provisions for the “D” and “Q” optional, supplemental designators have not been established in A5.18/A5.18M and, as a result, may not be used with the E70C-6M designation. However, that does not preclude their use with metal core electrodes classified utilizing the open classification system under the A5.36/A5.36M specification.

i)Yield strength at 0.2% offset.

J Percent elongation in 2 in. (50 mm) gauge length when a 0.500 (12 mm) nominal diameter tensile specimen and nominal gauge length to diameter ratio of 4:1 is used.

Illustration 4-6 – Flux Cored Electrode Classifications with Fixed Requirements[a]
(Source: AWS A5.36)

The "open classification system" is designed to better define the performance capabilities of advanced electrodes that are being developed.

An example is E80T5-M21P6-Ni2 where:

1) The "E" indicates an electrode.

2) The number "8" designates the minimum tensile strength in units of 10,000 ksi (69 MPa). Illustration 4-7 shows the tension test requirements.

3) The third digit indicates the welding position. A "0" indicates flat and horizontal positions only, and a "1" indicates all positions.

4) The "T" stands for a tubular (flux cored) wire classification and the "5" designates the usability characteristics of the electrode. See Illustration 4-11.

Tensile Strength Designator		Single Pass Electrodes	For A5.36 Multiple Pass Electrodes U.S. Customary Units			For A5.36 Multiple Pass Electrodes International System of Units (SI)		
U.S. Customary Units	International System of Units (SI)	Min. Tensile Strength ksi (MPa)	Tensile Strength (ksi)	Min. Yield Strength[a] (ksi)	Minimum Percent Elongation[b]	Tensile Strength (MPa)	Min. Yield Strength[a] (MPa)	Minimum Percent Elongation[b]
6	43	60 (430)	60-80	48	22	430-550	330	22
7	49	70 (490)	70-95	58	22	490-660	400	22
8	55	80 (550)	80-100	68	19	550-690	470	19
9	62	90 (620)	90-110	78	17	620-760	540	17
10	69	100 (690)	100-120	88	16	690-830	610	16
11	76	110 (760)	110-130	98	15	760-900	680	15
12	83	120 (830)	120-140	108	14	830-970	740	14
13	90	130 (900)	130-150	118	14	900-1040	810	14

a) Yield strength at 0.2% offset.
b) In 2 in (50 mm]) gauge length when a 0.500 in. (12.5 mm) nominal diameter tensile specimen and nominal gauge length to diameter ratio of 4:1 (as specified in the Tension Test section of AWS B4.0) is used. In 1 in. (25 mm) gauge length when a 0.250 in (6.5 mm) nominal tensile specimen is used as permitted for 0.045 in. (1.2 mm) and smaller sizes of the E7XT11-AZ-CS3 (E49XT11-AZ-CS3).
c) Elongation requirement may be reduced by one percentage point if the tensile strength of the weld metal is in the upper 25% of the tensile strength range.

Illustration 4-7 – Tension Test Requirements for Carbon and Low Alloy Steel Flux Cored Electrodes
(Source: AWS A5.36)

AWS A5.36 Shielding Gas Designator[a]	AWS A5.36/5.36M Composition Ranges for Indicated Main/Sub Group[b]		Nominal Composition of Shielding Gases to be Used for Classification of Gas Shielded Electrodes to AWS A5.36/5.36M		
	Oxidizing Components[c]		ISO 14175 Designation	Oxidizing Components[c,e]	
	% CO_2	% O_2		% CO_2	% O_2
C1	100	–	C1	100	–
M12	$0.5 \le CO_2 \le 5$	–	M12-ArC-3	3	–
M13	–	$0.5 \le O_2 \le 3$	M13-ArO-2	–	2
M14	$0.5 \le CO_2 \le 5$	$0.5 \le O_2 \le 3$	M14-ArCO-3/2	3	2
M20	$5 < CO_2 \le 15$	–	M20-ArC-10	10	–
M21	$15 < CO_2 \le 25$	–	M21-ArC-20	20	–
M22	–	$3 < O_2 \le 10$	M22-ArO-7	–	7
M23	$.05 \le CO_2 \le 5$	$3 < O_2 \le 10$	M23-ArO-7/3	3	7
M24	$5 < CO_2 \le 15$	$0.5 \le O_2 \le 3$	M24-ArCO-10/2	10	2
M25	$5 < CO_2 \le 15$	$3 < O_2 \le 10$	M25-ArCO-10/7	10	7
M26	$15 < CO_2 \le 25$	$0.5 \le O_2 \le 3$	M26-ArCO-20/2	20	2
M27	$15 < CO_2 \le 25$	$3 < O_2 \le 10$	M27-ArCO-20/7	20	7
M31	$25 < CO_2 \le 50$	–	M31-ArC-38	38	–
M32	–	$10 < O_2 \le 15$	M32-ArO-12.5	–	12.5
M33	$25 < CO_2 \le 50$	$2 < O_2 \le 10$	M33-ArCO-38/6	38	6
M34	$5 < CO_2 \le 25$	$10 < O_2 \le 15$	M34-ArCO-15/12.5	15	12.5
M35	$25 < CO_2 \le 25$	$10 < O_2 \le 15$	M35-ArCO-38/12.5	38	12.5
Z	The designator "Z" indicates that the shielding gas used for electrode classification is not one of the shielding gases specified in this table but is a different composition as agreed upon between the supplier and purchaser.				

a) The Shielding Gas Designators are identical to the Main group/Sub-group designators used in AWS A5.32M/A5.32:2011 (ISO 14175:2008 MOD), *Welding Consumables – Gases and Gas Mixtures for Fusion Welding and Allied Processes*, for these same shielding gases.
b) Under AWS A5.32M/A5.32:2011, the inert gas used for the balance of the gas mixture may be either argon, helium, or some mixture thereof.
c) The mixture tolerances are:
For a component gas with a nominal concentration of >5%, ±10% of nominal.
For a component gas with a nominal concentration of 1-5%, ±0.5% absolute.
For a component gas with a nominal concentration of <1%, not specified in this standard.
d) AWS A5.32M/A5.32:2011 shielding gas designators begin with "AWS A5.32 (ISO 14175)." That part of the designation has been omitted from the Shielding Gas Designator brevity.
e) The inert gas to be used for the balance of the gas mixtures specified for the classification of gas-shielded flux cored electrodes shall be argon.

Illustration 4-8 – Composition Requirements for Shielding Gases
(Source: AWS A5.36)

5) The "M21" designates the shielding gas. The absence of a designator in this position would indicate a self-shielding electrode. See Illustration 4-8.

6) The "P" indicates the tested weld was Postweld Treated. A letter "A" in this position would indicate as welded, and a letter "G" would indicate as agreed between supplier and purchaser. Illustration 4-9 shows the heat treatment test specifications.

7) The number "6" indicates impact test requirements as shown in Illustration 4-10.

8) The "Ni2" indicates the chemical composition of the weld metal as shown in Illustration 4-12.

Optional supplementary designators pertaining to diffusible hydrogen and temperature variables can also be added at the end of the electrode classification.

AWS Weld Metal Designation	Preheat and Interpass Temperature[a]		Postweld Heat Treatment (PWHT) Temperature[a,b,c]	
	For A5.36 U.S. Customary Units	For A5.36 International System of Units (SI)	For A5.36 U.S. Customary Units	For A5.36 International System of Units (SI)
CS1, CS2, CS3	60° F preheat min. 300° F ±25° F Interpass	15° C preheat min. 150° C ±15° C Interpass	1150° F ±25° F	620° C ±15° C
A1, Ni1, Ni2, Ni3, D2	300° F ±25° F	150° C ±15° C	1150° F ±25° F	620° C ±15° C
B1, B1L, B2, B2L, B2H, B3, B3L, B3H	350° F ±25° F	275° C ±15° C	1275° F ±25° F	690° C ±15° C
B6, B6L, B8, B8L	400° F ±100° F	200° C ±50° C	1375° F ±25° F	745° C ±15° C
B91, B92	500° F ±100° F	260° C ±50° C	1400° F ±25° F	760° C ±15° C
D1, D3, K1, K2, K3, K4, K5, K6, K7, K8, K9, K10, K11, W2	300° F ±25° F	150° C ±15° C	As agreed upon between supplier and purchaser.	
EXXTX-XGX-X, EXXTG-XGX-X, EXXTX-XGX-G	As agreed upon between supplier and purchaser.		As agreed upon between supplier and purchaser.	

a) These temperatures are specified for testing under this specification and are not to be considered as recommendations for preheat and postweld heat treatment (PWHT) in production welding. The requirements for production welding must be determined by the user.
b) Postweld heal treatment is required only for those classifications with the "P" designator for condition of heat treatment.
c) The PWHT schedule is as described in 9.2.1.2 of AWS A5.20/A5.20M.
d) PWHT temperature in excess of 1150° F (620° C) will decrease Charpy V-Notch impact strength.
e) Held at temperature for 2 hours -0 +15 minutes.

Illustration 4-9 – Preheat, Interpass, and PWHT Temperatures
(Source: AWS A5.36)

For A5.36 Multiple Pass Electrodes U.S. Customary Units			For A5.36 Multiple Pass Electrodes International System of Units (SI)		
Impact Designator[a,b]	Maximum Test Temperature[c,d] (°F)	Minimum Average Energy Level	Impact Designator[a,b]	Maximum Test Temperature[c,d] (°C)	Minimum Average Energy Level
Y	+68	20 ft•lbf	Y	+20	27 J
0	0		0	0	
2	-20		2	-20	
4	-40		3	-30	
5	-50		4	-40	
6	-60		5	-50	
8	-80		6	-60	
10	-100		7	-70	
15	-150		10	-100	
Z	No Impact Requirements.		Z	No Impact Requirements.	
G	As agreed between supplier and purchaser.				

a) Based on the results of the impact tests of the weld metal, the manufacturer shall insert in the classification the appropriate designator from this table.
b) When classifying an electrode to A5.36 using U.S. Customary Units, the Impact Designator indicates the maximum impact lest temperature in degrees Fahrenheit. When classifying to A5.36M using the International System of Units (SI), the Impact Designator indicates the maximum impact test temperature in degrees Celsius. With the exception of the Impact Designator "4", a given Impact Designator will indicate different temperatures depending upon whether classification is according to A5.36 in U.S. Customary Units or according to A5.36M in the International System of Units (SI). For example, a "2" Impact Designator when classifying to A5.36 indicates a lest temperature of -20° F. When classifying to A5.36M, the "2" Impact Designator indicates a test temperature of -20° C, which is -4° F.
c) Weld metal from an electrode that meets the impact requirements at a given temperature also meets the requirements at all higher temperatures in this table. For example, weld metal meeting the A5.36 requirements for designator "5" also meets the requirements for designators 4, 2, 0, and Y. (Weld metal meeting the A5.36M requirements for designator "5" also meets the requirements for designators 4, 3, 2, 0, and Y.)
d) Filler metal classification testing to demonstrate conformance to a specified minimum acceptable level for impact testing, i.e., minimum energy at specific temperature, can be met by testing and meeting the minimum energy requirement at any lower temperature. In these cases, the actual temperature used for testing shall be listed on the certification documentation when issued.

Illustration 4-10 – Impact Test Requirements for Carbon and Low Alloy Steel Flux Cored Electrodes (Source: AWS A5.36)

Usability Designator[a]	Process	General Description of Electrode Type[b,c]	Position of Welding[a, b]	Polarity[f]
T1	FCAW-G	Flux cored electrodes of this type are gas-shielded and have a rutile base slag. They are characterized by a spray transfer, low spatter loss, and a moderate volume of slag which completely covers the weld.	H, F, VU, OH	DCEP
T1S	FCAW-G	Flux cored electrodes of this type are similar to the "T1" type of electrode but with higher manganese or silicon, or both. They are designed primarily for single pass welding in the flat and horizontal positions. The higher levels of deoxidizers in this electrode type allow single pass welding of heavily oxidized or rimmed steel.	H, F, VU, OH	DCEP
T3S	FCAW-S	Flux cored electrodes of this type are self-shielded and are intended for single pass welding and are characterized by a spray type transfer. The titanium-based slag system is designed to make very high welding speeds possible.	H, F	DCEP
T4	FCAW-S	Flux cored electrodes of this type are self-shielded and are characterized by a globular type transfer. Its flouride-based basic slag system is designed to make very high deposition rates possible and to make low sulfur welds for improved resistance to hot cracking.	H, F	DCEP
T5	FCAW-G	Flux cored electrodes of this type are gas-shielded and are characterized by a globular transfer, slightly convex bead contour, and a thin slag that may not completely cover the weld bead. They have a lime-flouride slag system and develop improved impact properties and better cold cracking resistance than typically exhibited by the "T1" type electrodes.	H, F, VU, OH	DCEP or DCEN
T6	FCAW-S	Flux cored electrodes of this type are self-shielded and are characterized by a spray type transfer. Its oxide-based slag system is designed to produce good low temperature impacts, good penetration into the root of the weld, and excellent slag removal.	H, F	DCEP
T7	FCAW-S	Flux cored electrodes of this type are self-shielded and are characterized by a small droplet to spray type transfer. The flouride-based slag system is designed to provide high deposition rates in the downhand positions with the larger diameters and out of position capabilities with the smaller diameters.	H, F, VU, OH	DCEN
T8	FCAW-S	Flux cored electrodes of this type are self-shielded and are characterized by a small droplet to spray type transfer. The flouride-based slag system is designed to provide improved out-of-position control. The weld metal produced typically exhibits very good low temperature notch toughness and crack resistance.	H, F, VD, VU, OH	DCEN

Continued on next page.

Illustration 4-11 – Usability Characteristics for Carbon and Low Alloy Steel Flux Cored Electrodes
(Source: AWS A5.36)

Usability Designator[a]	Process	General Description of Electrode Type[b,c]	Position of Welding[a, b]	Polarity[f]
T9	FCAW-G	Flux cored electrodes of this type are similar in design and application to the "T1" types but with improved weld metal notch toughness capabilities.	H, F, VU, OH	DCEP
T10S	FCAW-S	Flux cored electrodes of this type are self-shielded and are characterized by a small droplet transfer. The flouride-based slag system is designed to make single pass welds at high travel speeds on steel of any thickness.	H, F	DCEN
T11	FCAW-S	Flux cored electrodes of this type are self-shielded and are characterized by a smooth spray type transfer, limited slag coverage, and are generally not recommended for the welding of materials over 3/4 in. (20 mm) thick.	H, F, VD, OH	DCEN
T12	FCAW-G	Flux cored electrodes of this type are similar in design and application to the "T1" types, however, they have been modified for improved impact toughness and to meet the lower manganese requirements of the A-No. 1 Analysis Group in the ASME *Boiler and Pressure Vessel Code*, Section IX.	H, F, VU, OH	DCEP
T14S	FCAW-S	Flux cored electrodes of this type are self-shielded and are characterized by a smooth spray type transfer. The slag system is designed for single pass welds in all positions and at high travel speeds.	H, F, VD, OH	DCEN
T17	FCAW-S	This flux cored electrode type is a self-shielded electrode specifically designed for use with AC power sources with or without modified waveforms.	H, F, VD, VU, OH	AC[h]
G	–	As agreed upon between supplier and purchaser.	Not Specified	Not Specified

a) An "S" is added to the end of the Usability Designator when the electrode being classified is recommended for single pass applications only.
b) For more information refer to AWS A5.36/A5.36M, A7, Description and Intended Use, in Annex A.
c) Properties of weld metal from electrodes that are used with external shielding gas will vary according to the shielding gas used. Electrodes classified with a specific shielding gas should not be used with other shielding gases without first consulting the manufacturer of the electrode.
d) H = horizontal position, F = flat position, OH = overhead position, VU = vertical position with upward progression, VD - vertical position with downward progression.
e) Electrode sizes suitable for out-of-position welding, i.e., welding positions other that flat and horizontal, are usually those sizes that are smaller than the 3/32 in. (2.4 mm) size or or the nearest size called for in Clause 9 for the groove weld. For that reason, electrodes meeting the requirements for the groove weld test may be classified as EX1TX-XXX-X (where X represents the tensile strength, usability, shielding gas, if any, condition of heat treatment, impact test temperature, and weld metal composition designators) regardless of their size.
f) The term "DCEP" refers to direct current electrode positive (dc, reverse polarity). The term "DCEN" refers to direct current electrode negative (dc, straight polarity).
g) Some EX1T5-XXX-X electrodes may be recommended for use on DCEN for improved out-of-position welding. Consult the manufacturer for the recommended polarity.
h) For this electrode type the welding current can be conventional sinusoidal alternating current, a modified AC waveform alternating between positive and negative, an alternating DCEP waveform, or an alternating DCEN waveform.

Illustration 4-11 – Usability Characteristics for Carbon and Low Alloy Steel Flux Cored Electrodes
(Source: AWS A5.36)

Weld Metal Designation	UNS Number[b]	Weight Percent[c]											
		C	Mn	Si	S	P	Ni	Cr	Mo	V	Al	Cu	Other[d]
Carbon Steel Electrodes													
CS1[e]	–	0.12	1.75	0.90	0.030	0.030	0.50[f]	0.20[f]	0.30[f]	0.08	–	0.35	–
CS2[e,g]	–	0.12	1.60	0.90	0.030	0.030	0.50[f]	0.20[f]	0.30[f]	0.08	–	0.35	–
CS3[e]	–	0.30	1.75	0.60	0.030	0.030	0.50[f]	0.20[f]	0.30[f]	0.08	1.8[f,h]	0.35	–
Molybdenum Steel Electrodes													
A1	W1703X	0.12	1.25	0.030	0.030	0.30	–	–	0.40 to 0.65	–	–	–	–
Chromium-Molybdenum Steel Electrodes													
B1	W5103X	0.05 to 0.12	1.25	0.80	0.030	0.030	–	0.40 to 0.65	0.40 to 0.65	–	–	–	–
B1L	W5113X	0.05	1.25	0.80	0.030	0.030	–	0.40 to 0.65	0.40 to 0.65	–	–	–	–
B2	W5203X	0.05 to 0.12	1.25	0.80	0.030	0.030	–	1.00 to 1.50	0.40 to 0.65	–	–	–	–
B2L	W5213X	0.05	1.25	0.80	0.030	0.030	–	1.00 to 1.50	0.40 to 0.65	–	–	–	–
B2H	W5223X	0.10 to 0.15	1.25	0.080	0.030	0.030	–	1.00 to 1.50	0.40 to 0.65	–	–	–	–
B3	W5303X	0.05 to 0.12	1.25	0.80	0.030	0.030	–	2.00 to 2.50	0.90 to 1.20	–	–	–	–
B3L	W5313X	0.05	1.25	0.80	0.030	0.030	–	2.00 to 2.50	0.90 to 1.20	–	–	–	–
B3H	W5323X	0.10 to 0.15	1.25	0.80	0.030	0.030	–	2.00 to 2.50	0.90 to 1.20	–	–	–	–
B6	W50231	0.05 to 0.12	1.25	1.00	0.030	0.025	0.40	4.0 to 6.0	0.45 to 0.65	–	–	0.50	–
B6L	W50230	0.05	1.25	1.00	0.030	0.025	0.40	4.0 to 6.0	0.45 to 0.65	–	–	0.50	–
B8	W50431	0.05 to 0.12	1.25	1.00	0.030	0.040	0.40	8.0 to 10.5	0.85 to 1.20	–	–	0.50	–
B8L	W50430	0.05	1.25	1.00	0.030	0.040	0.40	8.0 to 10.5	0.85 to 1.20	–	–	0.50	–
B91[i]	W50531	0.08 to 0.13	1.20[j]	0.50	0.015	0.020	0.80[j]	8.0 to 10.5	0.85 to 1.20	0.15 to 0.30	0.04	0.25	Nb: 0.02-0.10 N: 0.02-0.07
B92	–	0.08 to 0.15	1.20[j]	0.50	0.015	0.020	0.80[j]	8.0 to 10.0	.0.30 to 0.70	0.15 to 0.30	0.04	0.25	Nb: 0.02-0.08 W: 1.5-2.0 N: 0.02-0.08 Co[k]
Nickel Steel Electrodes													
Ni1	W2103X	0.12	1.75	0.80	0.030	0.030	0.80 to 1.10	0.15	0.35	0.05	1.8[h]	–	–
Ni2	W2203X	0.12	1.50	0.80	0.030	0.030	1.75 to 2.75	–	–	–	1.8[h]	–	–
Ni3	W2303X	0.12	1.50	0.80	0.030	0.030	2.75 to 3.75	–	–	–	1.8[h]	–	–

Continued on next page.

Illustration 4-12 – Chemical Composition Requirements for Carbon and Low Alloy Steel Flux Cored Electrodes[a]
(Source: AWS A5.36)

Weld Metal Designation	UNS Number[b]	Weight Percent[c]										
		C	Mn	Si	S	P	Ni	Cr	Mo	V	Al	Cu	Other[d]
Manganese-Molybdenum Steel Electrodes													
D1	W1913X	0.12	1.25 to 2.00	0.80	0.030	0.030	–	–	0.25 to 0.55	–	–	–	–
D2	W1923X	0.15	1.65 to 2.25	0.80	0.030	0.030	–	–	0.25 to 0.55	–	–	–	–
D3	W1933X	0.12	1.00 to 1.75	0.80	0.030	0.030	–	–	0.40 to 0.65	–	–	–	–
Other Low-Alloy Steel Electrodes													
K1	W2113X	0.15	0.80 to 1.40	0.80	0.030	0.030	0.80 to 1.10	0.15	0.20 to 0.65	0.05	–	–	–
K2	W2123X	0.15	0.50 to 1.75	0.80	0.030	0.030	1.00 to 2.00	0.15	0.35	0.05	1.8[h]	–	–
K3	W2133X	0.15	0.75 to 2.25	0.80	0.030	0.030	1.25 to 2.60	0.15	0.20 to 0.65	0.05	–	–	–
K4	W2223X	0.15	1.25 to 2.25	0.80	0.030	0.030	1.75 to 2.60	0.20 to 0.60	0.20 to 0.65	0.05	–	–	–
K5	W2162X	0.10 to 0.25	0.60 to 1.60	0.80	0.030	0.030	0.75 to 2.00	0.20 to 0.60	0.15 to 0.55	0.05	–	–	–
K6	W2104X	0.15	0.50 to 1.50	0.80	0.030	0.030	0.40 to 1.00	0.20	0.15	0.05	1.8[h]	–	–
K7	W2105X	0.15	1.00 to 1.75	0.80	0.030	0.030	2.00 to 2.75	–	–	–	–	–	–
K8	W2143X	0.15	1.00 to 2.00	0.40	0.030	0.030	0.50 to 1.50	0.20	0.20	0.05	1.8[h]	–	–
K9	W2323X	0.07	0.50 to 1.50	0.60	0.015	0.015	1.30 to 3.75	0.20	0.50	0.05	–	0.06	–
K10	–	0.12	1.25 to 2.25	0.80	0.030	0.030	1.75 to 2.75	0.20	0.50	–	–	0.50	–
K11	–	0.15	1.00 to 2.00	0.80	0.030	0.030	0.40 to 1.00	0.20	0.50	0.05	1.8[h]	–	–
W2	W2013X	0.12	0.50 to 1.30	0.030	0.030	0.35 to 0.80	0.40 to 0.80	0.45 to 0.70	–	–	–	0.30 to 0.75	–
G	–	[m]	As agreed upon between supplier and purchaser.										
GS[n]	–	As agreed upon between supplier and purchaser.											

a) The weld metal shall be analyzed for the specific elements for which values are shown in this table.
b) Refer to ASTM DS-56/SAE HS-1086, *Metals and Alloys in the Unified Numbering System*. An "X", when present in the last position, represents the usability designator for the electrode type used to deposit the weld metal. An exception to this applies to the "11" electrode type where a "9" is used instead of an "11".
c) Single values arc maximums.
d) An analysis of the weld deposit for for boron is required and shall be reported if this element is intentionally added or if it is known to be present at levels in excess of 0.0010%.
e) The total of all the elements listed in this classification shall not exceed 5%.
f) The analysis of these elements shall be reported only if intentionally added.
g) Meets the lower Mn requirements of the A-No. 1 Analysis Group in the ASME Boiler and Pressure Vessel Code, Section DC, Welding and Brazing Qualifications, QW-422.
h) Applicable to self-shielded electrodes only. Electrodes intended for use with gas shielding normally do not have significant additions of aluminum.
i) The "B91" designation is a new designation, replacving the "B9" designation previously used for this alloy type.
j) Mn+Ni = 1.40% maximum. See AWS A5.36/A.536M, A7.17.2 in Annex A.
k) Analysis for Co is required to be reported if intentionally added, or if it is known to be present at levels greater than 0.20%.
m) The limit for gas-shielded electrodes is 0.18% maximum. The limit for self-shielded electrodes is 0.30% maximum.
n) The composition of weld metal is not particulalry meaningful since electrodes in this category are intended only for single pass welds. Dilution from the base metal in such weld is usually quite high. See AWS A5.36/A.536M, A7.2 in Annex A.

Illustration 4-12 – Chemical Composition Requirements for Carbon and Low Alloy Steel Flux Cored Electrodes[a]
(Source: AWS A5.36)

AWS[d] Classification	UNS Number[c]	Weight Percent[b,c]											
		C	Cr	Ni	Mo	Nb + Ta	Mn	Si	P	S	N	Cu	Other
E307TX-X	W30731	0.13	18.0 to 20.5	9.0 to 10.5	0.5 to 1.5	–	3.30 to 4.75	1.0	0.04	0.03	–	0.75	–
E308TX-X	W30831	0.08	18.0 to 21.0	9.0 to 11.0	0.75	–	0.5 to 2.5	1.0	0.04	0.03	–	0.75	–
E308HTX-X	W30831	0.04 to 0.08	18.0 to 21.0	9.0 to 11.0	0.75	–	0.5 to 2.5	1.0	0.04	0.03	–	0.75	–
E308LTX-X	W30835	0.04	18.0 to 21.0	9.0 to 11.0	0.75	–	0.5 to 2.5	1.0	0.04	0.03	–	0.75	–
E308HMoTX-X	W30832	0.08	18.0 to 21.0	9.0 to 11.0	2.0 to 3.0	–	0.5 to 2.5	1.0	0.04	0.03	–	0.75	–
E308LMoTX-X	W30838	0.04	18.0 to 21.0	9.0 to 12.0	2.0 to 3.0	–	0.5 to 2.5	1.0	0.04	0.03	–	0.75	–
E309TX-X	W30931	0.10	22.0 to 25.0	12.0 to 14.0	0.75	–	0.5 to 2.5	1.0	0.04	0.03	–	0.75	–
E309HTX-X	W30931	0.04 to 0.10	22.0 to 25.0	12.0 to 14.0	0.50	–	0.5 to 2.5	1.0	0.04	0.03	–	0.75	–
E309LTX-X	W30935	0.04	22.0 to 25.0	12.0 to 14.0	0.75	–	0.5 to 2.5	1.0	0.04	0.03	–	0.75	–
E309LMoTX-X	W30939	0.12	21.0 to 25.0	12.0 to 16.0	2.0 to 3.0	–	0.5 to 2.5	1.0	0.04	0.03	–	0.75	–
E309LNiMoTX-X	W30938	0.04	21.0 to 25.0	12.0 to 16.0	2.0 to 3.0	–	0.5 to 2.5	1.0	0.04	0.03	–	0.75	–
E309NiMoTX-X	W30936	0.04	20.5 to 23.5	15.0 to 17.0	2.5 to 3.5	–	0.5 to 2.5	1.0	0.04	0.03	–	0.75	–
E309LNbTX-X	W30932	0.04	22.0 to 25.0	12.0 to 14.0	0.75	0.70 to 1.00	0.5 to 2.5	1.0	0.04	0.03	–	0.75	–
E310TX-X	W31031	0.20	25.0 to 28.0	20.0 to 22.5	0.75	–	1.0 to 2.5	1.0	0.03	0.03	–	0.75	–
E312TX-X	W31331	0.15	28.0 to 32.0	8.0 to 10.5	0.75	–	0.5 to 2.5	1.0	0.04	0.03	–	0.75	–
E316TX-X	W31631	0.08	17.0 to 20.0	11.0 to 14.0	2.0 to 3.0	–	0.5 to 2.5	1.0	0.04	0.03	–	0.75	–
E316HTX-X	W31631	0.04 to 0.08	17.0 to 20.0	11.0 to 14.0	2.0 to 3.0	–	0.5 to 2.5	1.0	0.04	0.03	–	0.75	–
E316LTX-X	W31635	0.04	17.0 to 20.0	11.0 to 14.0	2.0 to 3.0	–	0.5 to 2.5	1.0	0.04	0.03	–	0.75	–
E317LTX-X	W31735	0.04	18.0 to 21.0	12.0 to 14.0	3.0 to 4.0	–	0.5 to 2.5	1.0	0.04	0.03	–	0.75	–
E347TX-X	W34731	0.08	18.0 to 21.0	19.0 to 11.0	0.75	8xC min to 1.0 max	0.5 to 2.5	1.0	0.04	0.03	–	0.75	–
E347HTX-X	W34731	0.04 to 0.08	18.0 to 21.0	9.0 to 11.0	0.75	8xC min to 1.0 max	0.5 to 2.5	1.0	0.04	0.03	–	0.75	–
E409TX-X	W40931	0.10	18.0 to 21.0	0.60	0.75	–	0.80	1.0	0.04	0.03	–	0.75	Ti=10xC min to 1.5 max
E409NbTX-X	W40957	0.10	10.5 to 13.5	0.6	0.5	8xC min to 1.0 max	1.2	1.0	0.04	0.03	–	0.75	–
E410TX-X	W41031	0.12	11.0 to 13.5	0.60	0.75	–	1.2	1.0	0.04	0.03	–	0.75	–
E410NiMoTX-X	W41036	0.06	11.0 to 12.5	4.0 to 5.0	0.40 to 0.70	–	1.0	1.0	0.04	0.03	–	0.75	–
E430TX-X	W43031	0.10	15.0 to 18.0	0.60	0.75	–	1.2	1.0	0.04	0.03	–	0.75	–
E430NbTX-X	W43057	0.10	15.0 to 18.0	0.6	0.5	0.5 to 1.5	1.2	1.0	0.04	0.03	–	0.75	–
E2209TX-X	W39239	0.04	21.0 to 24.0	7.5 to 10.0	2.5 to 4.0	–	0.5 to 2.0	1.0	0.04	0.03	0.08 to 0.20	0.75	–
E2553TX-X	W39533	0.04	24.0 to 27.0	8.5 to 10.5	2.9 to 3.9	–	0.5 to 1.5	0.75	0.04	0.03	0.10 to 0.25	1.5 to 2.5	–
E2594TX-X	W39594	0.04	24.0 to 27.0	8.0 to 10.5	2.5 to 4.5	–	0.5 to 2.5	1.0	0.04	0.03	0.20 to 0.30	0.75	W = 10
EGTX-X[g]	Not Specified												
E307T0-3	W30733	0.13	19.5 to 22.0	9.0 to 10.5	0.5 to 1.5	–	3.30 to 4.75	1.0	0.04	0.03	–	0.75	–
E308T0-3	W30833	0.08	19.5 to 22.0	9.0 to 11.0	0.75	–	0.5 to 2.5	1.0	0.04	0.03	–	0.75	–

Illustration 4-13 – Chemical Composition Requirements for Stainless Steel Flux Cored Electrodes
(Source: AWS A5.22)

AWS[d] Classification	UNS Number[e]	Weight Percent[b,c]											
		C	Cr	Ni	Mo	Nb + Ta	Mn	Si	P	S	N	Cu	Other
E308HT0-3	W30833	0.08	19.5 to 22.0	9.0 to 11.0	0.75	–	0.5 to 2.5	1.0	0.04	0.03	–	0.75	–
E308LT0-3	W30837	0.04	19.5 to 22.0	9.0 to 11.0	0.75	–	0.5 to 2.5	1.0	0.04	0.03	–	0.75	–
E308MoT0-3	W30839	0.08	18.0 to 21.0	9.0 to 11.0	2.0 to 3.0	–	0.5 to 2.5	1.0	0.04	0.03	–	0.75	–
E308HMoT0-3	W30830	0.07 to 0.12	19.0 to 21.5	9.0 to 10.7	1.8 to 2.4	–	1.25 to 2.25	0.25 to 0.80	0.04	0.03	–	0.75	–
E308LMoT0-3	W30838	0.4	18.0 to 21.0	9.0 to 12.0	2.0 to 3.0	–	0.5 to 2.5	1.0	0.04	0.03	–	0.75	–
E309T0-3	W30933	0.10	23.0 to 25.5	12.0 to 14.0	0.75	–	0.5 to 2.5	1.0	0.04	0.03	–	0.75	–
E309LT0-3	W30937	0.4	23.0 to 25.5	12.0 to 14.0	0.75	–	0.5 to 2.5	1.0	0.04	0.03	–	0.75	–
E309MoT0-3	W30939	0.12	21.0 to 25.0	12.0 to 16.0	2.0 to 3.0	–	0.5 to 2.5	1.0	0.04	0.03	–	0.75	–
E309LMoT0-3	W30938	0.4	21.0 to 25.0	12.0 to 16.0	2.0 to 3.0	–	0.5 to 2.5	1.0	0.04	0.03	–	0.75	–
E309LNbT0-3	W30934	0.4	23.0 to 25.5	12.0 to 14.0	0.75	0.70 to 1.00	0.5 to 2.5	1.0	0.04	0.03	–	0.75	–
E310T0-3	W31031	0.20	25.0 to 28.0	20.0 to 22.5	0.75	–	1.0 to 2.5	1.0	0.04	0.03	–	0.75	–
E312T0-3	W31231	0.15	28.0 to 32.0	8.0 to 10.5	0.75	–	0.5 to 2.5	1.0	0.04	0.03	–	0.75	–
E316T0-3	W31633	0.08	18.0 to 20.5	11.0 to 14.0	2.0 to 3.0	–	0.5 to 2.5	1.0	0.03	0.03	–	0.75	–
E316LT0-3	W31637	0.04	18.0 to 20.5	11.0 to 14.0	2.0 to 3.0	–	0.5 to 2.5	1.0	0.04	0.03	–	0.75	–
E316LKT0-3[f]	W31630	0.04	17.0 to 20.0	11.0 to 14.0	2.0 to 3.0	–	0.5 to 2.5	1.0	0.04	0.03	–	0.75	–
E317LT0-3	W31737	0.04	18.5 to 21.0	13.0 to 15.0	3.0 to 4.0	–	0.5 to 2.5	1.0	0.04	0.03	–	0.75	–
E347LT0-3	W34733	0.08	19.0 to 21.5	9.0 to 11.0	0.75	8XC min to 1.0 max	0.5 to 2.5	1.0	0.04	0.03	–	0.75	–
E409LT0-3	W40931	0.10	10.5 to 12.5	0.60	0.75	–	0.80	1.0	0.04	0.03	–	0.75	Ti=10xC min to 1.5 max
E410LT0-3	W41031	0.12	11.0 to 13.5	0.60	0.75	–	1.0	1.0	0.04	0.03	–	0.75	–
E410NiMoT0-3	W41036	0.06	11.0 to 12.5	4.0 to 5.0	0.40 to 0.70	–	1.0	1.0	0.04	0.03	–	0.75	–
E430T0-3	W43031	0.10	15.0 to 18.0	0.60	0.75	–	1.0	1.0	0.04	0.03	0.08 to 0.20	0.75	–
E2209T0-3	W39239	0.04	21.0 to 24.0	7.5 to 10.0	2.5 to 4.0	–	0.5 to 2.0	1.0	0.04	0.03	0.10 to 0.25	0.75	–
E2553T0-3	W39533	0.04	24.0 to 27.0	8.5 to 10.5	2.9 to 3.9	–	0.5 to 1.5	0.75	0.04	0.03	0.20 to 0.30	1.5 to 2.5	–
E2594T0-3	W39594	0.04	24.0 to 27.0	8.0 to 10.5	2.5 to 4.5	–	0.5 to 2.5	1.0	0.04	0.03	–	1.5	W = 10
EGTX-3[g]	Not Specified												
R308LT1-5	W30835	0.03	18.0 to 21.0	9.0 to 11.0	0.75	–	0.5 to 2.5	1.2	0.04	0.03	–	0.75	–
R309LT1-5	W30935	0.03	22.0 to 25.0	12.0 to 14.0	0.75	–	0.5 to 2.5	1.2	0.04	0.03	–	0.75	–
R316LT1-5	W31635	0.03	17.0 to 20.0	11.0 to 14.0	2.0 to 3.0	–	0.5 to 2.5	1.2	0.04	0.03	–	0.75	–
R347T1-5	W34731	0.08	18.0 to 21.0	9.0 to 11.0	0.75	8XC min to 1.0 max	0.5 to 2.5	1.2	0.04	0.03	–	0.75	–
RGT1-5[g]	Not Specified												

a) The weld metal shall be analyzed for the specific elements in this table. If the presence of other elements is indicated in the course of this work, the amount of those elements shall be determined to ensure that their total (excluding iron) does not exceed 0.50%.
b) Single values shown are maximum.
c) For flux cored electrodes and rods intended for elevated temperature service (above approximately 750º F [400º C] and for post weld heat treatment above 900º F [500º C], bismuth (Bi) should be restricted to 0.002 wt % (20 ppm) maximum. See AWS A7.24 for more information.
d) In this table, the "X" following the "T" refers to the position of welding (1 for all-position or 0 for flat or horizontal operation) and the "X" following the dash refers to the shielding medium (-1 or -4) as shown in the AWS Classification column in Table 2.
e) SAE HS-1086 / ASTM DS-56, *Metals & Metal Alloys in the Unified Numbering System*.
f) This alloy is designed for cryogenic applications.
g) See AWS A2.2.7 and A2.2.8.

Illustration 4-13 – Chemical Composition Requirements for Stainless Steel Flux Cored Electrodes
(Source: AWS A5.22)

AWS[a] Classification	External Shielding Gas[b]	Welding Polarity
EXXXTX-1	CO_2	DCEP
EXXXTX-3	None (self-shielded)	DCEP
EXXXTX-4	75-85% Ar / remainder CO_2	DCEP
EXXXTX-G	Not Specified	Not Specified

a) The letters "XXX" stand for the designation of the chemical composition (see AWS A5.22, Table 1). The "X" after the "T" designates the position of operation. A "0" indicates flat or horizontal operation; a "1" indicates all-position operation. Refer to AWS A5.22, Figure A and Clause A2 for a complete description of this classification system.
b) The requirements for the use of a specified external shielding gas shall not be construed to restrict the use of any other media, for which the electrodes are found suitable, for any application other than the classification tests.
c) See AWS A2.2.7 to A2.2.9 for additional information.
d) AWS A5.32/A5.32M class SG-C.
e) AWS A5.32/A5.32M class SG-AC-25 or SG-AC-20.
f) AWS A5.32/A5.32M class SG-A.
g) AWS A5.32/A5.32M class SG-A, SG-AO-1 or SG-AO-2.

Illustration 4-14 – Required Shielding Gas and Polarity for Stainless Steel Flux Cored Electrodes
(Source: AWS A5.22)

The classification system for stainless steel electrodes is based on the chemical composition of the weld metal and the type of shielding to be employed during welding. An example of a stainless steel electrode classification is E308T1-1 where:

1) The "E" indicates an electrode.

2) The digits between the "E" and the "T" indicate the chemical composition of the weld as shown in illustration 4-13.

3) The "T" stands for a tubular (flux cored) wire classification.

4) The next digit indicates the welding position. A "0" indicates flat and horizontal positions only, and a "1" indicates all positions.

5) The suffix indicates the type of shielding to be used as shown in illustration 4-14.

Electrode Selection

The selection of the proper electrode for an application is based on the type of metal to be welded and the specific chemical and mechanical properties required of the joint. Identification of the base metal is required to select an electrode. If the type of metal is not known, tests must be made based on visual, magnetic, chisel, flame, fracture, spark or chemistry tests.

The selection of the proper filler metal for a specific job application is quite involved but may be based on the following factors.

1) Base Metal Strength Properties – This is done by choosing an electrode wire to match the tensile or yield strength of a metal. This is usually one of the most important criteria for selecting a filler metal to be used on low carbon and many low alloy steels.

2) Base Metal Composition – The chemical composition of the metal to be welded should be known. Closely matching the filler and base metal compositions is important when corrosion resistance and creep resistance are needed. The filler metals for welding stainless steels and alloy steels are usually chosen on the basis of matching chemical compositions.

3) Welding Position – Flux cored electrodes are designed to be used in specific positions. Wire diameter is the major factor limiting the position in which an electrode can be used. All position electrodes are available only in the smaller sizes. Flat and horizontal position only electrodes may have very similar compositions but are available in all sizes or the larger sizes which cannot be easily used for vertical and overhead welding. Electrodes should be selected to match the welding position.

4) Welding Current – Flux cored electrodes are designed to operate on either direct current electrode negative or direct current electrode positive. Electrodes operating on DCEN generally give lighter penetration and higher deposition rates. Electrodes operating on DCEP generally provide deeper penetration.

5) Joint Design and Fit-up – Electrodes should be chosen according to their penetration characteristics. Gas-shielded flux cored wires produce deeper penetration than self-shielding wires. This can have an effect on the joint design used.

6) Thickness and Shape of Base Metal – Weldments may include thick sections or complex shapes which may require maximum ductility to avoid weld cracking. Electrodes that give the best ductility should be used for these applications.

7) Service Conditions and/or Specifications – For weldments subject to severe conditions such as low temperature, high temperature, or shock loading, an electrode that matches the ductility and impact strength of the steel should be selected.

8) Production Efficiency and Job Conditions – Large diameter electrodes should be used, if possible, to give higher deposition rates.

Flux cored electrodes for carbon and low alloy steels are each designed for specific applications based on the composition of the flux core of the wire. Each suffix used indicates a general grouping of electrodes that have similar flux components and usability characteristics.

A T-1 electrode is a single or multiple pass electrode. It operates on DCEP and requires gas shielding. It produces a flat to slightly convex weld bead with a moderate slag coating. T-1 electrodes produce a fine globular transfer and low spatter levels. Welds produced with T-1 electrodes have good mechanical properties.

A T-2 electrode operates on DCEP and also requires gas shielding. These electrodes are similar to T-1 types, but are designed to weld over rust and scale. They are for single-pass welding only because of their high silicon and manganese contents.

T-3 electrodes are self-shielding wires using DCEP for single-pass welding operations. These electrodes produce a fine globular transfer and are designed for welding sheet metal at high welding speeds.

T-4 electrodes are self-shielding wires using DCEP for single or multiple-pass operation. These electrodes produce a globular metal transfer and light penetration for joints with poor fit-up. Desulfurizing elements are contained in the flux core to help prevent weld cracking.

T-5 electrodes can be used to weld higher carbon steels, or for joining low alloy steels to carbon steels because of cleaner welds and lower hydrogen levels.

T-6 electrodes are self-shielded electrodes for single or multiple pass welding using DCEP. These electrodes are characterized by a fine globular transfer and deep penetration. The slag coating has good deep-groove removal characteristics and produces good low temperature impact properties.

T-7 electrodes are self-shielded electrodes that operate on DCEN for single or multiple pass welding. The larger sizes of this type of electrode are designed to produce high deposition rates. The smaller sizes are used for all-position welding. The slag coating desulfurizes the weld metal to a very low level which helps prevent cracking.

T-8 electrodes are self-shielding electrodes for single or multiple pass welding that operate on DCEN. The slag system is designed to allow all-position welding. The slag also desulfurizes the weld metal and produces good low temperature impact properties.

T-10 electrodes are self-shielded, single-pass electrodes that operate on DCEN. These electrodes are used for making welds in the flat and horizontal positions at high travel speeds.

T-11 electrodes are self-shielded electrodes that operate on DCEN for single and multiple pass welding. These are general purpose electrodes for all position welding at moderate travel speeds. They produce a fine globular transfer.

T-G electrodes are for multiple pass welding which are not covered by another classification.

T-GS electrodes are single pass electrodes which are not covered by another classification. The operating conditions and characteristics are not defined for the T-G and the T-GS electrodes.

Electrode selection will be discussed in more detail in Chapter 7.

Conformances and Approvals

Flux cored arc welding electrodes must conform to specifications, or be approved by code-making organizations for many FCAW applications. Some of the code-making organizations that issue specifications or approvals are the American Welding Society (AWS), the American Bureau of Shipping (ABS), and other state and federal highway and military organizations. The American Welding Society provides specifications or flux cored wire electrodes. Electrodes must meet specific requirements in order to conform to a particular electrode classification. Many code-making organizations such as the American Society of Mechanical Engineers (ASME) and the American Petroleum Institute (API) recognize and use the AWS specifications.

Some of the code-making organizations such as the American Bureau of Shipping (ABS) and the military, must directly approve the electrodes before they can be used for welding on a project that is covered by that code. These organizations send inspectors to witness the welding and testing, as well as to approve the classification of the flux cored electrodes. To conform to the AWS specifications for carbon and low alloy steel filler metals, the electrodes must produce a weld deposit that meets the specific mechanical and chemical requirements. For the stainless steel filler metal, the electrodes must produce a weld deposit with a specific chemical composition. The requirements will vary depending on the class of the electrodes.

CHAPTER 5
WELDING APPLICATIONS

Flux cored arc welding has gained popularity for a wide variety of applications. Flux cored arc welding has replaced shielded metal arc welding for some applications. One of the major advantages of the process is the high deposition rates obtained when compared to manual arc welding processes. Flux cored arc welding deposition rates are also generally higher than those obtained from gas metal arc welding. Because flux cored arc welding is a semiautomatic process, higher productivity can be obtained compared to shielded metal arc welding. This process also lends itself easily to machine and automatic welding. Because of the versatility of flux cored arc welding, it has obtained wide application in shop fabrication, maintenance and field erection work.

Each of the two variations of flux cored arc welding has its advantages, but the areas of application of the two variations often overlap. The method of welding used depends on the joint design, fit-up, availability of electrodes, and mechanical property requirements of the welded joints. The self-shielding electrode wire variation can often be used for applications that can be done by shielded metal arc welding. This is especially true when welding in locations where compressed gas cylinders are difficult to handle. Gas-shielded flux cored wires are used for many applications that compete with gas metal arc welding. There are many different applications possible but the most common ones are discussed in this chapter.

Illustration 5-5
Flux Cored Arc Welding
Photo courtesy of Bernard

INDUSTRIES

Structures

One of the most important applications of flux cored arc welding is in the structural fabrication industry. A wide variety of low carbon and low alloy steels in many different thicknesses are used in this industry. Welding is done in the shop and the field and flux cored arc welding is readily adaptable to both types of wires. The major advantages of this process in the structural industry are the high deposition rates, high production rates, deep penetrating characteristics and the adaptability of the process for field erection welding. Because a large percentage of the welds made in structural work are fillets, flux cored arc welding is widely used for making large single-pass fillet welds. Many of these welds would require multiple passes using gas metal arc welding and shielded metal arc welding.

Gas-shielded flux cored wires have replaced shielded metal arc welding and gas metal arc welding for many shop applications. Flux cored arc welding is widely employed for welding of the thicker structural members where the higher deposition rates provide more advantage.

For field welding, the self-shielding flux cored wires are commonly used. These flux cored wires are preferred over the gas-shielded types because a supply of shielding gas is not required, which makes the equipment more portable.

Another advantage of the self-shielding electrodes for field construction is that they can be used in windier conditions. This is because the decomposition of the flux core which provides the shielding is less sensitive to wind than an external gas shielding supply.

Another application of self-shielding electrodes is for the welding of galvanized steel roof decking. Single-pass electrodes using DCEN are preferred for most applications because of the lighter penetration produced which reduces the chances of burning through the decking.

Ships

Flux cored arc welding is employed in the shipbuilding industry because of the wide variety of low carbon and low alloy steels and metal thicknesses being welded. Because this process can be used in the vertical and overhead positions, it is employed in places where submerged arc welding cannot be used. The process is also useful for vertical welding on metal thicknesses too thin for electroslag welding to be economical. Most flux cored arc welding is done semiautomatically but some automatic welding applications are employed.

Industrial Piping

Flux cored arc welding is used to some extent in the industrial piping industry. This process is employed for welding pipe in both the shop and the field for use in steam generating plants, refineries, distilleries and chemical processing plants. Flux cored arc welding competes

Illustration 5-5 – Flux Cored Arc Welding
Photo courtesy of Bernard

with submerged arc welding, shielded metal arc welding, and gas metal arc welding.

This process may be used to deposit all passes or it may be used to deposit the fill and cover passes over a root pass welded by another process. Flat position roll welding, (1G position) is often used for both semiautomatic and automatic welding applications. This allows higher welding currents with larger diameter wires and requires fewer weld passes. Roll welding is often employed, especially on large diameter piping. Copper backing strips are sometimes used to allow higher current levels and insure full penetration to the root of the joint. When welding fixed position pipe, smaller diameter electrodes are used. These electrodes operate at lower current levels and require more passes. In these positions, the root pass is often welded using gas metal arc welding and sometimes gas tungsten arc welding. In the 5G or horizontal fixed position, welding the root pass by flux cored arc welding is done using a downhill technique. The remaining passes are then welded using an uphill technique.

Flux cored arc welding is used for welding both carbon steel and alloy steel pipe. A major application of the process is for welding chromium-molybdenum steel pipe. This is the major type of alloy steel used for pipe. Flux cored electrodes are preferred over the solid wire when matching chemical compositions. This is because porosity is hard to avoid. Also, with the solid wire electrodes the operating characteristics of solid wires are not as good, which makes them more difficult to use. Most of the electrodes used for flux cored arc welding of pipe are gas-shielded because of the better penetration produced and the generally better mechanical properties produced.

Railroads

Flux cored arc welding is used extensively in the railroad industry. Other processes such as shielded metal arc welding, gas metal arc welding and submerged arc welding are also widely employed, so the choice of the welding process is based on the weld size, joint accessibility, joint length and welding position. The longest welds on the heavier metal thicknesses in the flat position are generally welded using submerged arc welding. Flux cored arc welding is usually used on the heavier metal thicknesses where submerged arc welding is not practical. Examples would be for joints in other positions, shorter joints and where accessibility is more limited. Flux cored arc welding is preferred over shielded metal arc welding and gas metal arc welding for many uses because of the higher deposition rates obtained.

Many different components on the engines and the rail cars are commonly welded.

Most manufacturers of railroad engines and cars primarily use the gas-shielded electrode wires. Self shielding electrodes are sometimes used where lighter penetration is desirable. Flux cored wires that have good weld-

Illustration 5-5 – Flux Cored Arc Welding
Photo courtesy of Bernard

Illustration 5-5 – Flux Cored Arc Welding
Photo courtesy of Hobart Brothers Company

ing characteristics when welding over rust and scale are also popular in this industry because the amount of joint cleaning time is reduced.

Automotive Products

Flux cored arc welding has gained popularity for use in the automobile and truck manufacturing industries. This process is used because of the high production rates that can be obtained. Both the self-shielding and the gas-shielded electrode wires have been used. The gas-shielded wires are generally used when deeper penetration is required. Flux cored arc welding is also popular because it can be easily automated. Components such as frames, truck wheels, trailers and axle housings are common applications. Flux cored arc welding is more popular for trucks because of the larger thicknesses of metal generally employed.

The use of flux cored arc welding has increased over gas metal arc welding for many frame welding applications because joint fit-up is less important, better appearing weld beads can be produced, and flux cored arc welding has better welder appeal.

Many flux cored electrodes have been developed for welding over some rust and scale which reduces the metal preparation time.

Flux cored arc welding is often employed for the welding of axle housings and attachments.

A special application of flux cored arc welding is for the welding of catalytic converters. These are made of type 409 stainless steel which is welded with an equivalent filler metal using gas shielding.

Heavy Equipment

The heavy equipment manufacturing industry includes mining, agricultural and earth moving equipment, as well as, other items such as fork lift trucks and armored vehicles. Flux cored arc welding is popular in these industries because of the high deposition rates obtained. Fillet welds are often encountered in these industries. Large single pass fillet welds can often be welded by flux cored arc welding which eliminates interpass cleaning time and increases productivity.

The mining equipment manufacturing industry is a major user of flux cored arc welding for welding a wide variety of low carbon and low alloy steels.

Maintenance and Repair

The flux cored arc welding process is very useful for maintenance and surfacing operations. Maintenance operations range from repairing and modifying plant and building facilities to repairing pipe, production equipment and castings. Surfacing and salvaging operations include the repair of mismachined parts, foundry defects, accommodating engineering changes, rebuilding worn parts, especially shafting and rollers, and overlaying parts with special materials. Reclamation includes the disassembly and rewelding of defective items manufactured in the factory and in the field. It has been used for maintaining and repairing items too expensive to repair with oxyacetylene welding and other arc welding processes. Self shielding flux cored electrodes are popular for field repairs and maintenance because the equipment is more portable.

A metal overlay can be used to extend the usable life of new parts which lack some of the wear-resistant qualities required for certain applications. Overlays are used mostly to replace metal which has been worn away by abrasion, corrosion, and impacts. An overlay provides toughness and resistance to corrosion, abrasion and wear at the exact location on the part where it is needed most. The primary reason for weld overlaying of parts is to prepare them for certain applications and to extend their service life. Flux cored arc welding is widely employed because of its characteristic high deposition rate and good weld bead appearance.

FLUX CORED ARC SPOT WELDING

Flux cored arc spot welding is a variation of the process where a fusion weld is made through one sheet into an adjacent sheet of a lap joint while the welding gun is held stationary. The equipment used for arc spot welding is the same as for normal welding, except that a timer and a special gun nozzle is required. Flux cored arc spot welding is used on low carbon and low alloy steels and is generally preferred for welding thicker sheet metal and thin plate sections. This is because of the greater penetrating capability of the process as compared to gas tungsten or gas metal arc spot welding. The flux cored arc welding process also provides a wider penetration spot weld at the interface between the plates to be joined. This produces a larger diameter spot weld with greater strength. Flux cored arc spot welding is identical to gas metal arc spot welding except that a flux cored electrode wire is used. Carbon dioxide shielding is generally used but argon-CO_2 mixtures are sometimes used to reduce the amount of penetration. When welding thinner metals, a backup bar is used under the sheet metal.

The advantages of flux cored arc spot welding over resistance spot welding are:

1) Access is only required from the top of the joint

2) Flux cored arc spot welding can be done in all positions more easily

3) The gun is light and portable and can be taken to the weldment

4) Weld joint fit-up is not as critical

5) Faster production rates can be obtained, particularly on thicker metal

The main disadvantage of flux cored arc spot welding is the consistency of weld size and strength is not as good.

Either the gas-shielded or self-shielded flux cored electrodes may be used. The weld is made by depressing the trigger which starts the shielding gas, if used, and, after a preflow interval, starts the arc and the wire feed. The arc melts through the top sheet of the lap joint and fuses into the bottom sheet. When the preset weld time is finished, the arc and wire feed are stopped, followed by the gas flow, if used. Metals of the same or different thicknesses can be made. If dissimilar thicknesses are being welded, the thinner member should always be placed on top. The length of the spot weld cycle affects the penetration and the amount of reinforcement on the surface of the weld bead. Flux cored arc spot welding generally produces larger, stronger weld nuggets on the same metal thicknesses as compared to gas metal arc spot welding. The rest of the welding variables affect the weld in the same way as normal weld.

CHAPTER 6
COST OF FLUX CORED ARC WELDING

The cost of welding is an important factor to consider when selecting a welding process for an application. Flux cored arc welding has advantages over other processes which make it the most economical welding method for many different applications. Factors such as deposition rates, welding speeds, joint preparation time, operator factors, and welding material costs must be compared to properly choose a welding process.

The initial investment for the equipment can vary considerably depending on the size and complexity of the equipment used. The equipment used is often basically the same as for gas metal arc welding. Because of the higher current levels used in flux cored arc welding, larger power sources may be needed. With the self-shielding electrode wires, a gas shielding system is not needed, which simplifies and reduces the overall cost of the equipment. In some cases where gas metal arc welding equipment is available, a change to flux cored arc welding would require almost no new equipment. The equipment for semiautomatic welding is much less expensive than equipment for automatic welding.

An advantage of flux cored arc welding over the manual welding processes is that a lower degree of welder skill is needed. A welder skilled in gas metal arc welding would have very little trouble learning the flux cored arc welding process that generally has good welder appeal. This is particularly true when compared to gas metal arc welding at the higher current levels. Another example is the comparison to semiautomatic submerged arc welding where it is more difficult to weld because the weld puddle is not visible. Semiautomatic flux cored arc welding usually competes with shielded metal arc welding, gas metal arc welding and submerged arc welding. Automatic flux cored arc welding usually competes with automatic gas metal arc welding and submerged arc welding. In flux cored arc welding, the costs of materials will vary depending on the electrode and whether or not shielding gas is required. The electric power cost will depend on the machine and the welding parameters.

The cost of this process consists of four major items which are the labor and overhead, electrodes, shielding gas and electric power. The cost calculation methods used in this chapter can be used to compare the cost of flux cored arc welding to the other processes.

LABOR COST

The labor cost is usually the largest cost factor of a process. Labor and overhead costs are generally combined in cost calculations, which is common practice in many plants. The overhead normally includes items such as taxes, services, facilities maintenance and depreciation of the equipment. The hourly labor and overhead rates will vary considerably, so the actual rates for each plant should be used in the cost calculations.

There are several items that are used in labor cost calculations. One of the most important is the operator factor, which is the percentage of the total welding time that the arc is in operation. Because this process is applied semiautomatically and automatically, the operator factor can vary widely. Operator factors for semiautomatic welding usually range from 25% to as high as 60%. When compared to gas metal arc welding, operator factors are usually slightly lower with flux cored arc welding because more time is spent removing slag. Since flux cored arc welding uses a continuously fed electrode wire, operator factors are much higher than those obtained in shielded metal arc welding, where much time is spent changing electrodes. Operator factors for machine and automatic welding can range up to as high as 80% or more, depending on the application. Another factor used in many cost calculations is the deposition rate. This is the rate at which the electrode wire is deposited in the weld joint. The deposition rate and travel speed affect the labor and overhead costs because the rate at which the electrode is deposited and the speed of welding affect the productivity. The deposition rate and travel speeds used are determined by the size of the electrode, the welding current, the base metal thickness and the position of welding.

The equation for determining the labor and overhead cost is:

$$\textbf{Labor Cost} = \frac{\text{Labor + Overhead Cost/hr} \times \text{Pounds of Weld Deposit/Weld}}{\text{Deposition Rate} \times \text{Operator Factor}}$$

Or...

$$\textbf{Labor Cost} = \text{Total Welding Time} \times \text{Labor} + \text{Overhead}$$

ELECTRODE COST

The cost of the electrode wire per weld is determined by several factors. The first is the weight of the weld deposited, which is dependent on the size and shape of the weld to be made. A second factor is the cost per pound of electrode wire, which is dependent on the type and size of the electrode wire. Some types of mild steel electrodes are substantially less expensive than other types. Small diameter flux cored electrodes cost more per pound than larger diameter flux cored electrodes because of the additional wire drawing operations required. Electrode wire is less expensive per pound when supplied in a reel or large coil, as compared to a small coil. The total amount of wire purchased also affects the cost. Large shipments of wire will generally cost less per pound than small shipments. In relation to covered electrodes and solid wire electrodes, flux cored electrodes tend to be more expensive. This factor can usually be offset by the higher deposition rates obtained from flux cored arc welding. A third factor is the deposition efficiency of the electrode. The deposition efficiency is the actual percentage of the total weight of the electrode wire purchased that is actually deposited in the weld. The deposition efficiency of flux cored wire is lower than that of solid wires because the flux core provides shielding gas and a slag covering. Self-shielding flux cored wires typically have a deposition efficiency of about 75-80%, which is much higher than obtained from covered electrodes. Gas-shielded electrode wires have deposition efficiencies ranging from 80-90%. These are higher than those obtained from self-shielding wires because less of the core becomes shielding gas and slag. With both types of flux cored wires, some wire is lost to spatter and vaporization. Spatter is generally higher with self-shielding electrodes which also contributes to the lower deposition efficiencies. The type of shielding gas used will have an effect on the deposition efficiency. Carbon dioxide will produce higher spatter levels than argon-carbon dioxide and argon-oxygen mixtures.

The equations used for determining the cost of an electrode wire are:

$$\textbf{Electrode Cost} = \text{Arc Time} \times \text{Wire Feed Rate} \times \frac{\text{Wire Weight}}{\text{Unit of Length}} \times \text{Wire Cost Per Pound}$$

Or...

$$\textbf{Electrode Cost} = \frac{\text{Weight of Deposit} \times \text{Wire Cost Per Pound}}{\text{Deposition Efficiency}}$$

For the first equation, the wire weight per unit of length is needed. This figure will vary depending on the type of electrode wire used. Some flux cored electrodes contain more core elements than others. This is true of the self-shielding wires when compared to gas-shielded wires. A good approximation of the percent fill or amount of flux in a tubular wire for cost calculations is about 16% by weight. This gives the inches of wire per pound as shown in Illustration 6-1.

Wire Diameter	Inches of Wire Per Pound
.035"	3704
.045"	2375
1/16"	1230
5/64"	996
3/32"	640
7/64"	469
1/8"	346
3/32"	225

Illustration 6-1 – Inches of Wire Per Pound of Wire

SHIELDING GAS COST

The cost of the shielding gas depends on the flow rate, arc time, and type of shielding gas. This factor is not included in a cost calculation for a self-shielding electrode. Carbon dioxide is the least expensive and most commonly used shielding gas. Using an argon-carbon dioxide or argon-oxygen gas mixture will increase the costs of welding.

The equation for determining the shielding gas cost is:

$$\textbf{Shielding Gas Cost} = \text{Arc Time} \times \text{Gas Flow} \times \text{Cost of Gas per Cubic Ft.}$$

ELECTRIC POWER COST

The cost of the electric power is a relatively minor cost factor, but it can become important when large amounts of welding are required on an application. The electric power cost is determined by the welding current, welding voltage, power source efficiency and the cost per kilowatt-hour. The power consumption of the power source when idling will not be calculated because it is a very small percentage of the total power consumption of the power source. The power source efficiency will be assumed for the calculations in this chapter.

The equation for electric power cost is:

$$\textbf{Electric Power Cost} = \frac{\text{Welding Current} \times \text{Welding Voltage}}{\text{Power Source Efficiency}} \times \text{Arc Time} \times \frac{\text{Power Cost per kW-hr}}{1000}$$

	SMAW Manual	GMAW Semiautomatic	FCAW Semiautomatic		SAW Semiautomatic
	E7024	E70S-3	E70T-4	E70T-1	EM 12K
Electrode Diameter	1/4"	1/16"	3/32"	3/32"	3/32"
Welding Current (amps)	380	350	375	475	550
Welding Voltage (volts)	33	25	28	29	33
Travel Speed (IPM)	11	18	12	15	12
Gas Flow (ft^3/hr)	–	45	–	35	–
Total Welding Time (hr)	.0995	.0654	.0587	.0556	.0605
Arc Time (hr/ft)	.0348	.0327	.0264	.0250	.0272
Wire Feed Speed (in/min)	–	270	215	200	120
Labor + Overhead Costs ($/hr)	30.00	30.00	30.00	30.00	30.00
Operator Factor (%)	35	50	45	45	45
Weight of Deposit (lbs)	.425	.425	.425	.425	.425
Electrode Cost ($/lb)	1.00	1.60	3.00	3.00	1.60
Deposition Efficiency (%)	67	93	80	90	100*
Deposition Rate (lbs/hr)	12.2	13.0	16.1	17.0	15.6
Gas Cost ($/$ft^3$)	–	.13	–	.13	–
Gas Used ($/$ft^3$)	–	.33	–	.33	–
Flux Cost ($/lb)	–	–	–	–	.50
Flux Used (lbs)	–	–	–	–	.53
Electric Power Cost ($/kW-hr)	.06	.06	.06	.06	.06
Power Source Efficiency (%)	50	80	80	80	80
Labor Cost ($/ft)	2.99	1.96	1.76	1.66	1.82
Filler Wire Cost ($/Ft)	.634	.731	1.594	1.417	.680
Flux Cost ($/Ft)	–	–	–	–	.265
Shielding Gas Cost ($/Ft)	–	.114	–	.114	–
Electric Power Cost ($/Ft)	.052	.022	.021	.025	.037
Total Cost ($/Ft)	**3.676**	**2.827**	**3.375**	**3.216**	**2.802**

Illustration 6-2 – Cost Comparison of SMAW, GMAW, FCAW and SAW on a 1/2" (12.7 mm) Fillet Weld in the Horizontal Position

Examples

Illustration 6-2 shows the figures used for a cost calculation comparison of shielded metal arc welding, gas metal arc welding, flux cored arc welding using a self-shielding wire, flux cored arc welding using a gas-shielded wire and submerged arc welding. The examples given are fairly typical but the exact data should be obtained from the manufacturers data sheets and the actual welding conditions.

In equations where arc time is necessary, it can be determined from the following equation:

$$\textbf{Arc Time} = \frac{\text{Length of Weld } \mathbf{X} \text{ Number Passes}}{\text{Travel Speed}}$$

Or...

$$\frac{\text{Weight of Deposit}}{\text{Deposition Rate}}$$

The total welding time can then be determined by the equation:

$$\textbf{Total Welding Time} = \frac{\text{Arc Time}}{\text{Operator Factor}}$$

The following is a sample cost per foot of weld calculation for making a 1/2 in. (12.7 mm) fillet weld in the horizontal position using semiautomatic flux cored arc welding with a gas-shielded electrode. Figures for calculation are taken from Illustration 6-1 and 6-2.

$$\textbf{Labor Cost} = \frac{\text{Labor + Overhead Cost/hr} \ \mathbf{X} \ \text{Pounds of Weld Deposit/Weld}}{\text{Deposition Rate} \ \mathbf{X} \ \text{Operator Factor}} = \frac{30 \text{ \$/hr} \ \mathbf{X} \ .425 \text{ lbs/ft}}{17 \text{ lbs/hr} \ \mathbf{X} \ 45\ \%} = \mathbf{\$1.66}$$

$$\textbf{Electrode Cost} = \text{Arc Time} \ \mathbf{X} \ \text{Wire Feed Rate} \ \mathbf{X} \ \frac{\text{Wire Weight}}{\text{Unit of Length}} \ \mathbf{X} \ \text{Wire Cost Per Pound} = .0250 \text{ hr/ft} \ \mathbf{X} \ \underset{\text{(200 IPM x 60 min)}}{12000 \text{ in/hr}} \ \mathbf{X} \ \frac{1 \text{ lb}}{640 \text{ in.}} \ \mathbf{X} \ 3.00 \text{ \$/lb}$$

Or,

$$\textbf{Electrode Cost} = \frac{\text{Weight of Deposit} \ \mathbf{X} \ \text{Wire Cost Per Pound}}{\text{Deposition Efficiency}} = \frac{.425 \text{ lbs/ft} \ \mathbf{X} \ 3.00 \text{ \$/lb}}{90\ \%}$$

$$= \mathbf{\$1.417}$$

$$\textbf{Shielding Gas Cost} = \text{Arc Time} \ \mathbf{X} \ \text{Gas Flow} \ \mathbf{X} \ \text{Cost of Gas per Cubic Ft.} = .025 \text{ hr/ft} \ \mathbf{X} \ 35 \text{ ft}^3\text{/hr} \ \mathbf{X} \ .13 \text{ \$/ft}^3 = \mathbf{\$.114}$$

$$\textbf{Electric Power Cost} = \frac{\text{Welding Current} \ \mathbf{X} \ \text{Welding Voltage}}{\text{Power Source Efficiency}} \ \mathbf{X} \ \text{Arc Time} \ \mathbf{X} \ \frac{\text{Power Cost per kW-hr}}{1000} = \frac{475 \text{ amps} \ \mathbf{X} \ 29 \text{ volts}}{80\ \%} \ \mathbf{X} \ .025 \text{ hr/ft} \ \mathbf{X} \ \frac{.06 \text{ \$/kW-hr}}{1000} = \mathbf{\$.025}$$

TOTAL WELD COST PER FOOT = $3.216

CHAPTER 7
WELDING METALLURGY

PROPERTIES OF THE WELD

The properties of a weld include the chemical composition, mechanical strength, ductility, toughness, and the microstructure. These items will relate to the weldability of the metal. The weldability of a metal is the quality obtained and the ease of welding for the intended service conditions. The chemical, physical and mechanical properties of the weld are affected by the types of materials used. The mechanical properties and microstructure are determined by the heat input as well as the chemical composition and physical properties of the weld.

CHEMICAL COMPOSITION

The chemical composition of the base and filler metal have a great influence on the weldability of a metal. This property has an influence of the preheating and postheating used, as well as the welding parameters. For the welding of stainless steels, the chemical composition of the weld is often the most important property. The chemical composition of the weld must match the composition of the base metal when corrosion resistance, thermal and electrical conductivity, and appearance are major considerations. The chemical composition can also affect the high and low temperature strength, as well as the microstructure and mechanical properties of the weld.

Preheating reduces the cooling rate of the weld after welding to prevent cracking. The amount of preheat needed depends on the type of metal being welded, the metal thickness, and the amount of joint restraint. In steels, those with higher carbon contents need higher preheat than those with lower carbon equivalents. Illustration 7-1 shows typical preheat values for different metals welded by flux cored arc welding.

Another major factor that determines the amount of preheat needed is the thickness of the base metal. Thicker base metals usually need higher preheat temperatures than thinner base metals. Thick metal draws the heat away from the welding zone quicker because there is a large mass of metal to absorb the heat. This would cause a quicker cooling of the weld if the same preheat temperature was used, as on thinner base metals. The third major factor for determining the amount of preheat needed is the amount of joint restraint. Joint restraint is the resistance of a joint configuration to moving or relieving the stresses due to welding during the heating and cooling of the weld zone. Where there is high resistance to moving or high joint restraint, large amounts of internal stresses build up. Higher preheat temperatures are needed as the amount of joint restraint increases. Slower cooling rates reduce the amount of internal stresses that are building up as the weld cools.

MECHANICAL PROPERTIES

The mechanical properties that are the most important in the weld are the tensile strength, yield strength, elongation, reduction of area, and the impact strength. The first two are measures of the strength of the material, the next two are measures of the ductility of the material, and the last is a measure of the toughness of the material. These properties are often important in flux cored arc welding of steels designed to give maximum strength, ductility, and toughness. Flux cored arc welding can produce good properties in the weld and heat affected zone. The slag coating in flux cored arc welding slows the cooling rate of the weld metal which reduces the tendency to become brittle.

Flux cored arc welding produces a higher heat input which will also tend to produce a slower cooling rate. A disadvantage of the higher heat input is that distortion is more of a problem than with gas metal arc welding. The mechanical properties of the weld will vary depending on whether a self-shielded or gas-shielded flux cored wire is used. Some self-shielded electrodes contain high amounts of deoxidizers, which may produce weld metal with relatively low impact toughness. Most of the gas-shielded flux cored wires produce welds that have better impact toughness.

The yield strength, ultimate tensile strength, elongation, and reduction of area are all measured from a 505 in. (12.8 mm) diameter machined tensile bar. The metal is tested by pulling it in a tensile testing machine. Illustration 7-2 shows a tensile bar before and after testing.

The yield strength of the metal is the stress at which the material is pulled beyond the point where it will return to its original length. The ultimate tensile strength is the maximum stress or load that can be carried by the material without breaking. Two points are marked on the tensile bar before testing. After testing, the distance between the two points is measured again by putting the two pieces of the tensile bar back together and measuring the change in the distance between them in percent. Reduction of area is another method of measuring ductility. The original area of the cross section of the testing bar is .20 sq. in. (128 sq. mm). During the testing, the diameter of the bar reduces as it elongates. When the bar finally breaks, the diameter of the bar at the breaking point is measured, which is then used to determine the area. The percent reduction of this cross sectional area is called the reduction of area.

Impact tests are used to measure the toughness of a metal. The toughness of a metal is the ability to absorb mechanical energy by deforming before breaking. The

Type of Metal		Preheat
Low Carbon Steel		Room Temperature or up to 200° F (93° C)
Medium Carbon Steel		400-500° F (205-260° C)
High Carbon Steel		500-600° F (260-315° C)
Low Alloy Nickel Steel	Less than 1/4” (6.4 mm) thick	Room Temperature
	More than 1/4” (6.4 mm) thick	500° F (260° C)
Low Alloy Nickel Chrome Steel	Carbon less than .20%	200-300° F (93-150° C)
	Carbon .20%-.35%	600-800° F (315-425° C)
	Carbon above .35%	900-1100° F (480-595° C)
Low Alloy Manganese Steel		400-500° F (205-260° C)
Low Alloy Chrome Steel		Up to 750° F (400° C)
Low Alloy Molybdenum Steel	Carbon less than .15%	Room Temperature
	Carbon more than .15%	400-650° F (205-345° C)
Low Alloy High Tensile Steel		150-300° F (66-150° C)
Austenitic Stainless Steel		Room Temperature
Ferritic Stainless Steels		300-350° F (150-260° C)
Martensitic Stainless Steels		400-600° F (205-315° C)
Cast Irons		700-900° F (370-480° C)
Copper		500-800° F (260-425° C)
Nickel		200-300° F (93-150° C)
Aluminum		Room Temperature or up to 300° F (150° C)

Illustration 7-1 – Preheats for Various Metals

Charpy V-notch test is the most commonly used method of determining impact toughness. Illustration 7-3 shows a typical Charpy V-notch bar.

These bars are usually 10 mm square and have a v-shaped notch ground or machined in them. The bars are then put into a machine where they are struck by a hammer attached to a pendulum. The energy that it takes to break these bars is known as the impact strength and is measured in foot-pounds (Joules).

MICROSTRUCTURE

There are three basic microstructural areas within a weldment. These are the weld metal, heat affected zone, and the base metal. The weld metal is the area that was molten during welding. This is bounded by the fusion line which is the maximum limit of melting. The heat affected zone is the area where the heat from welding had an effect on the microstructure of the base metal. The limit of visible heat affect is the outer limit of this area. The base metal zone is the area that was not affected by the welding. Illustration 7-4 shows a cross section of a weld showing the different areas. The extent of change of the microstructure is dependent on four factors:

1) The maximum temperature that the weld metal reached.

2) The time that the weld spent at that temperature.

3) The chemical composition of the base metal.

4) The cooling rate of the weld.

Illustration 7-2 – Tensile Strength Testing Bar

Illustration 7-3 – Charpy V-Notch Bar

The weld metal zone, which is the area that is melted, generally has the coarsest grain structure of the three areas. Usually a fairly fine grain size is produced on cooling in most metals. Large grain size is undesirable because it gives the weld poor toughness and poor cracking resistance. The solidification of the weld metal starts at the edge of the weld puddle next to the base metal. The grains that form at the edge, called dendrites, grow toward the molten center of the weld. Illustration 7-5 shows the solidification pattern of a weld.

These dendrites give the weld metal its characteristic columnar grain structure. The grains that form in the weld zone are similar to the grains that form in castings. Deoxidizers and scavengers are often added to filler metal to help refine the grain size in the weld. The greater the heat input to the weld and the longer that it is held at high temperature, the larger the grain size. A faster cooling rate will produce a smaller grain size than a slower cooling rate. Preheating will give larger grain sizes, but is often necessary to prevent the formation of a hard, brittle microstructure.

The heat affected zone is an area of change in the microstructure of the base metal. The area that is closest to the weld metal usually undergoes grain growth. Other parts of the heat affected zone will go through grain refinement. Other areas may be annealed and considerably softened. Because of the changes due to the heat input and cooling rate, areas of the heat affected zone can become embrittled and become the source of cracking. A large heat input during welding will cause a larger heat affected zone. This is often not desirable, so the welding parameters used can help influence the size of the heat affected zone.

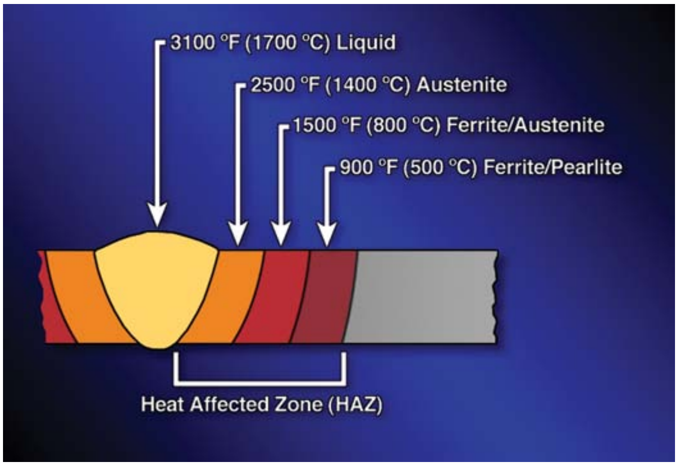


Illustration 7-4 – Cross-Section of a Weld showing the Different Zones and Lines in the Weld Area

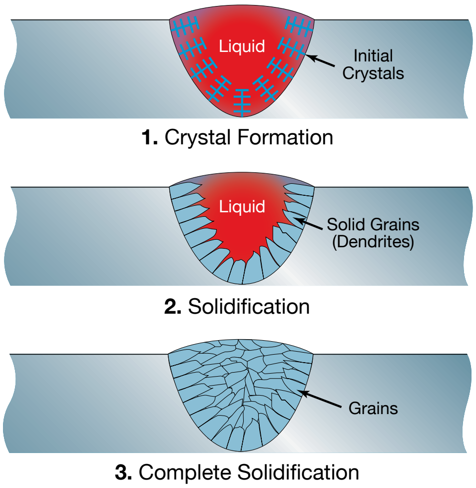


Illustration 7-5 – The Solidification Pattern of the Weld Area

WELDABLE METALS

Flux cored arc welding is commonly used to weld most steels and stainless steels. Some nickel alloys are also welded by this process. Most nonferrous metals are not welded by this process because of the high heat input and because suitable electrode wires have not been developed.

Steels

Flux cored arc welding is widely used for welding steels. In general, steel is classified according to the carbon content, such as low carbon, mild, medium carbon, and high carbon steels. In addition, steel is also classified according to the alloys used. For the purpose of discussion in this chapter, the different steels will be grouped according to their welding characteristics.

When welding steel, the carbon and other alloy content influences the hardness and hardenability of the weld metal which, in turn, influences the amount of preheat needed. The two terms, hardness and hardenability, are not the same. The maximum hardness of a steel is primarily a function of the amount of carbon in the steel. Hardenability is a measure of how easily a martensitic structure is formed when the steel is quenched. Martensite is the phase or metallurgical structure in steel where the maximum hardness of the steel can be obtained. Steels with low hardenability must have very high cooling rates after welding to form martensite, where steels with high hardenability will form martensite even when they are slow cooled. The hardenability will determine to what extent a steel will harden during welding. The carbon equivalent formula is one of the best methods of determining the weldability of steels. This value is determined by the amounts of the alloying elements use. There are several different formulas used. One of the most popular is as follows:

$$\text{Carbon Equivalent} = \%C + \frac{\%Cr}{10} + \frac{\%Mn}{6} + \frac{\%Mo}{10} + \frac{\%Ni}{20} + \frac{\%Cu}{40}$$

Steels with lower carbon equivalents generally are more readily weldable and require fewer precautions such as the use of preheat and postheat. Steels with higher carbon equivalents are generally more difficult to weld. When welding some of the steels, it is more important to match the mechanical properties than the chemical composition of the filler metal to the base metal. Often, filler metal with a lower carbon content than the base metal is used because the weld metal absorbs carbon from the base metal. This is done to minimize the tendency for weld cracking.

Low Carbon and Mild Steel

Low carbon and mild steels are those that have low carbon contents and are the most readily weldable. This group of steels is the most widely used in industrial fabrication. This group also includes the high strength structural steels.

Low carbon steels have a carbon content up to .14%. Mild steel has a carbon content ranging from .15 to .29%. For many applications, preheating is not required except on thick sections, highly restrained joints, or where codes require preheating. Other precautions such as interpass temperature control and postheating are sometimes used. With thicker sections and highly restrained joints, preheating, interpass temperature control and postheating are usually required to prevent cracking. When welding these steels, electrodes of the E70-T class are employed with carbon dioxide. Self-shielding wires are also widely used. The filler metal should be chosen so that it matches the tensile strength of the base metal. When welding rimmed steels which have silicon contents less than .05%, filler metal with sufficient amounts of deoxidizers must be chosen to prevent porosity. This precaution is not necessary for welding steels containing more than .05% silicon.

The high strength structural steels are steels whose yield strength falls between 45,000 psi (310 MPa) and 70,000 psi (485 MPa) and their carbon content is generally below .25%. These steels have relatively small amounts of alloying elements. Some common examples of these steels are the ASTM designations of A242, A441 A572, A588, A553 and A537.

Some low carbon and mild steel electrodes are designed for welding over some rust and mill scale. The flux core helps to reduce the bad effects of rust and mill scale but some reduction in weld quality may occur. These flux cored arc welding electrodes are preferred for many applications because cleaning of the base metal is less important. For applications where the maximum mechanical properties are not as important as higher deposition rates and travel speeds, high welding currents can be used.

Low Alloy Steels

The low alloy steels discussed here will be those steels that are low carbon and have alloy additions less than 5%. This includes the quenched and tempered steels, heat treated low alloy steels, and the low nickel alloy steels. Elements such as nickel, chromium, manganese, and molybdenum are the main alloying elements used. These steels have a higher hardenability than mild steels and it is this factor that is the principal complication in welding. Low alloy steels have good weldability but are not as easily weldable as the mild steels. This higher hardenability permits martensite to form at lower cooling rates. As the alloy content and the carbon content increases, the hardenability also increases. In general, the weldability of the steel decreases as the hardenability increases. One of the best methods for determining the weldability of a low alloy steel is the use of the carbon equivalent formula. Steels that have carbon equivalents below about .40% usually do not require the use of preheating and postheating in the welding procedure and generally have the best weldability. Steels with carbon equivalents higher than .40% require more precautions for welding. Generally, the higher the carbon equivalent, the more difficult the steel is to weld.

The selection of electrodes for the welding of steels is usually based on the strength and mechanical properties desired of the weld, rather than matching chemical compositions. Low alloy steels are often welded using the gas-shielded EXXT-1 and EXXT-5 electrodes. These wires produce good, low temperature toughness and are preferred for most applications. EXXT-4 and EXXT-8 self-shielded wires often contain nickel for good strength, and aluminum as a deoxidizer to help give good mechanical properties. In other cases, such as for the welding of low nickel steels, the electrode wires are chosen to match the chemical composition of the base metal.

The quenched and tempered heat treated steels have yield strengths ranging from 50,000 psi (345 MPa) to very high yield strengths and have carbon contents ranging up to .25%. Some common examples of these types of steel are the ASTM designations A533 Grade B, A514, A517, A543 and A553. The 25% carbon limit is used to provide fairly good weldability. These steels provide high tensile and yield strength along with good ductility, notch toughness, corrosion resistance, fatigue strength and weldability. The presence of hydrogen is always bad in steel, but it is even more critical in these types of steels compared to mild steels. Preheat is generally not used on thinner sections, but it is used on thicker or highly restrained sections. Postweld heat treatment is usually not used because the flux cored arc welds made in these have a good toughness. The steels are generally used in the welded or stress relieved conditions.

The nickel alloy steels included in these low alloy steel groups are those with less than 5% nickel contents. The 2-1/4% and 3-1/2% nickel steels are usually welded with electrodes that have the same general chemical compositions as the base metal. Preheating is required with highly restrained joints. Most self-shielding wires for low alloy steels have been developed for welding the low nickel steels.

Heat Treatable Steels

The heat treatable steels are the medium and high carbon steels and medium carbon steels that have been alloyed. This group includes quenched and tempered steels after welding, normalized or annealed steels, and medium and high carbon steels. These steels are more difficult to weld than other types of steels already mentioned in this chapter. The most important factor for selecting the type of electrode to be used is matching the chemical compositions of the base metal and the filler metal.

Medium carbon steels are those that have carbon contents ranging from .30% to .59% and high carbon steels have carbon contents ranging from .60% to about 1.0%. When medium and high carbon steels are welded, precautions should be included in the welding procedure because of the hardness that can occur in the weld joint. As the carbon content increases up to .60%, the hardness of the fully hardened structure (or martensite) increases to a maximum value. When the carbon content is above .60%, the hardness of the fully hardened structure does not increase, so these steels can be welded using about the same welding procedures as the medium carbon steels. Martensite, which is the phase that steel is in at its fullest hardness, is harder and more brittle in high carbon steel than it is in low carbon steel. A high carbon, martensitic structure can have a tendency to crack in the weld metal and heat affected zone during cooling. Welding procedures that lower the hardness of the heat affected zone and the weld metal reduce the cracking tendency. This can be done by using a procedure that requires lower carbon content in the filler metal, and by slowing the cooling rate. The procedure would include preheat, interpass temperature control, and postheat. The procedures used for welding medium carbon steels can be simpler than the one just mentioned, but that depends on the specific applications.

Medium carbon steels can be welded with the E70T-E90T classifications. High carbon steels should be welded with the E80T-El20T using the electrode of the proper tensile strength to match the tensile strength of the base metal. Generally, very high carbon steels are not used in welded production work. These steels are usually only welded in repair work.

Mild steel electrodes may also be used, but the deposited weld metal absorbs carbon from the base metal and thus loses a considerable amount of ductility. Stainless steel electrodes of the austenitic type are sometimes used, but the fusion zone may still be hard and brittle. A preheat and/or postheat will help reduce the brittle structure.

The quenched and tempered steels, after welding, have carbon contents ranging from about .25% to .45%, which distinguishes them from the steels that are quenched and tempered before welding. These steels also have small additions of alloying elements. Some common examples of these steels are the AISI designations 4130, 4140 and 4340. Because of the higher carbon contents, the steels in this group can be heat treated to extremely high levels of strength and hardness. Some of these steels have enough alloy content to give them high hardenability. Because of this combination of carbon and alloy content, the steels must be preheated before welding. The weldability of these steels is also influenced by the purity of the steels. High amounts of sulfur and phosphorous in the steel increase the sensitivity to cracking and reduce the ductility. Flux cored arc welding is often used for welding these steels. Filler metal of the same chemical composition as the base metal is required to obtain the maximum strength. The composition of the weld metal is usually similar to that of the base metal.

Chromium-Molybdenum Steels

The low chromium-molybdenum steels in this section are those with alloy contents of about 6% or less. These steels are in the low carbon range, generally up to .15%, and are readily weldable. The chromium and molybdenum alloying elements provide these steels with good oxidation resistance and high temperature strength. The chromium is mainly responsible for the high oxidation resistance and the molybdenum is mainly responsible for the high temperature strength.

The higher chrome-moly steels contain about 6-10% chromium and .5-1% molybdenum. These steels are limited to a maximum carbon content of about .10% to limit the hardness, because these steels are very sensitive to air hardening. For the welding of these steels, preheating, interpass temperature control, slow cooling, and postweld heat treatment are required to make a weld with good mechanical properties. These steels generally do not require preheating except when welding thick sections or highly restrained joints. Postheating is usually not required on chromium molybdenum steels that contain less than 2-1/4% Cr and 1% Mo.

Flux cored arc welding is one of the most common methods of welding the chromium-molybdenum steels. The steels with less than 6% chromium are welded with a carbon dioxide or argon-carbon dioxide mixture. For the steels with 6% chromium or more, argon with small additions of carbon dioxide is often used. The filler metal is chosen to match the chemical composition of the base metal as closely as possible to give good corrosion resistance.

Free Machining Steels

Free machining steels are steels that have additions of sulfur, phosphorous, selenium, or lead in them to make these steels easier to machine. Except for the high sulfur, lead, selenium, or phosphorous, these steels have chemical compositions similar to mild, low alloy, and stainless steels. The addition of these elements makes these steels difficult to weld. The reason for this is that the elements, lead, phosphorous, selenium and sulfur, have melting points that are much lower than the melting point of the steel. As the weld solidifies, these elements retain liquid much longer than the steel so that they coat the grain boundaries, which cause hot cracking in the weld. Hot cracking is cracking that occurs before the weld has had a chance to cool. Because of this hot cracking problem, free machining steels cannot be welded easily. High manganese filler metal and low base metal dilution will help give the best results possible.

Stainless Steels

Most types of stainless steels can be welded by this process. The types that are very difficult to weld are types such as 303, 416, 416 Se, 430 F, and 430 FSe, which have high sulfur and selenium contents and Type 440, which has a high carbon content. The major alloying element which distinguishes stainless steels from the other types of steel is the chromium. Steels that have chromium contents greater than 11% are considered stainless steels. The high chromium content gives these very good corrosion and oxidation resistance. The three major groups of stainless steels that are welded are the austenitic, martensitic and ferritic types.

The austenitic types of stainless steels are generally the easiest to weld. In addition to the high chromium content of about 16-26%, these types have high nickel contents ranging from 6-22%. These steels are designated by the AISI as the 300 series. The 200 series, which have high manganese contents to replace some of the nickel, are also austenitic. Nickel and manganese are strong austenite formers and maintain an austenitic structure at all temperatures. This structure gives these steels good toughness and ductility but also makes them non-hardenable. A major problem when welding these types of steels is carbide precipitation or sensitization, which only occurs in the austenitic structure. This occurs when the temperature of the steel is between approximately 1000-1600° F (540-870° C) and can greatly reduce the resistance to corrosion. There are several methods for preventing this problem:

1) A fast cooling rate after welding through this temperature range. This is a major reason why preheating is usually not used and why these steels require a relatively low maximum interpass temperature on multiple pass welds.
2) The use of extra low carbon base and filler metal (.03% C max.). Examples are 304L and 316L.
3) The use of a stabilized base and filler metal alloy containing columbium, tantalum, or titanium. Examples are 347 and 321.
4) The use of a solution heat treatment to resolve the carbides after welding.

Martensitic stainless steels are not as easy to weld as the austenitic stainless steels. These stainless steels have approximately 11-18% chromium, which is the major alloying element, and are designated by the AISI as the 400 series. Some examples are 403, 410, 420, and 440. These types of stainless steels are heat treatable because they generally contain higher carbon contents and a martensitic structure. Stainless steels with higher carbon contents are more susceptible to cracking and some, such as Type 440, have carbon contents so high that they are often considered unweldable. A stainless steel with carbon content greater than .10% will often need preheating. Preheating is usually done in the range of from 400-600° F (205-315° C) to avoid cracking. For steels containing carbon contents greater than .20%, a postweld heat treatment such as annealing is often required to improve the toughness of the weld produced.

Ferritic stainless steels are also more difficult to weld than austentic stainless steels because they produce welds having lower toughness than the base metal. These stainless steels form a ferritic grain structure and are also designated by the AISI as the 400 series. Some examples are Types 405, 430, 442, and 446. These types are generally less corrosion resistant than austenitic stainless steel. To avoid a brittle structure in the weld, preheating and postheating are often required. Typical preheat temperatures range from 300-500° F (150-260° C). Annealing is often used after heat treatment welding to increase the toughness of the weld.

The flux cored arc welding process can produce stainless steel weld deposits with a quality similar to those produced by gas metal arc welding. Lower current levels may be desirable for welding stainless steel compared to welding mild steel because of the higher thermal expansion, lower thermal conductivity and lower melting point of stainless steel. The lower thermal conductivity and higher thermal expansion causes more distortion and warpage for a given heat input. Carbon dioxide, argon-carbon dioxide, and argon-oxygen mixtures are used. Carbon dioxide causes a loss of silicon and manganese and an increase in carbon in the low carbon stainless steels. The use of carbon dioxide or EXXT-1 electrodes is restricted for welding many of the stainless steels, especially austenitic grades, because the corrosion resistance may be reduced, due to carbon added to the weld by gas. When good corrosion resistance is required, argon-carbon dioxide or argon-oxygen mixtures are used. The argon-oxygen mixtures containing 1 or 2% oxygen are used to improve the arc stability and weld puddle wetting, as well as to eliminate carbon pickup from the shielding gas. When the self-shielding EXXXT-3 electrodes are used, there is greater pickup of nitrogen from the atmosphere into the weld metal. Nitrogen is an austenite stabilizer and when excessive nitrogen is absorbed by the weld, there is a greater chance for micro-cracking to occur. The welding position and arc length have a large influence on this problem. An excessive arc length will usually cause excessive nitrogen pickup in the weld. For this reason, procedures for out-of-position welding with self-shielding wires should be carefully controlled to produce a sound weld deposit.

The filler metal used for welding stainless steel is generally chosen to match the chemical composition of the base metal. In the 200 series austenitic stainless steels, 300 series austenitic filler metal is usually used, due to a lack of availability of 200 series filler metal. This weld joint will generally be weaker than the surrounding base metal. 300 series filler metal is used on 300 series base metal. The Type 410 and 420 electrodes are the only martensitic stainless steel types recognized by the AWS. This limitation is often the reason why austenitic stainless steel filler metal is used for welding martensitic stainless steel. Austenitic filler metal provides a weld with lower strength but higher toughness and eliminates the need for preheating and postheating. For the welding of ferritic stainless steels, both ferritic and austenitic filler metal may be used. Ferritic filler metal is used when higher strength and annealing postheat are required. Austenitic filler metal is used when higher ductility is required. Illustration 7-6 shows filler metal selection for stainless steels.

AISI Number	Chemical Analyses of Stainless Steels (percent)					
	Carbon	Manganese	Silicon	Chromium	Nickel	Other Elements
Chromium-Nickel-Magnesium-Austenitic-Nonhardenable						
201	0.15 max.	5.5-7.5	1.0	16.0-18.0	3.5-5.5	N_2 0.25 max.
202	0.15 max.	7.5-10.	1.0	17.0-19.0	4.0-6.0	N_2 0.25 max.
Chromium-Austenitic-Nonhardenable						
301	0.15 max.	2.0	1.0	16.0-18.0	6.0-8.0	–
302	0.15 max.	2.0	1.0	17.0-19.0	8.0-10.0	–
302B	0.15 max.	2.0	2.0-3.0	17.0-19.0	8.0-10.0	–
303	0.15 max.	2.0	1.0	17.0-19.0	8.0-10.0	S 0.15 min.
303Se	0.15 max.	2.0	1.0	17.0-19.0	8.0-10.0	Se 0.15 min.
304	0.08 max.	2.0	1.0	18.0-20.0	8.0-10.0	–
304L	0.03 max.	2.0	1.0	18.0-20.0	8.0-10.0	–
305	0.12 max.	2.0	1.0	17.0-19.0	10.0-13.0	–
308	0.08 max.	2.0	1.0	19.0-21.0	10.0-12.0	–
309	0.20 max.	2.0	1.0	22.0-24.0	12.0-15.0	–
309S	0.08 max.	2.0	1.0	22.0-24.0	12.0-15.0	–
310	0.25 max.	2.0	1.0	24.0-26.0	19.0-22.0	–
310S	0.08 max.	2.0	1.50	24.0-26.0	19.0-22.0	–
314	0.25 max.	2.0	1.50	23.0-26.0	19.0-22.0	–
316	0.08 max.	2.0	1.5-3.0	16.0-18.0	10.0-14.0	Mo 2.0-3.0
316L	0.03 max.	2.0	1.0	16.0-18.0	10.0-14.0	Mo 2.0-3.0
317	0.08 max.	2.0	1.0	18.0-20.0	11.0-15.0	Mo 3.0-4.0
321	0.08 max.	2.0	1.0	17.0-19.0	9.0-12.0	Ti 5xC min.
347	0.08 max.	2.0	1.0	17.0-19.0	9.0-13.0	Cb + Ta 10xC min.
348	0.08 max.	2.0	1.0	17.0-19.0	9.0-13.0	Ta 0.10 max.
Chromium-Martensitic-Hardenable						
403	0.15 max.	1.0	.05	11.5-13.0	–	–
410	0.15 max.	1.0	1.0	11.5-13.5	–	–
414	0.15 max.	1.0	1.0	11.5-13.5	1.25-2.5	–
416	0.15 max.	1.25	1.0	12.0-14.0	–	S 0.15 min.
416Se	0.15 max.	1.25	1.0	12.0-14.0	–	Se 0.15 min.
420	Over 0.15	1.0	1.0	12.0-14.0	–	–
431	0.20 max.	1.0	1.0	15.0-17.0	1.25-2.5	–
440A	0.60-0.85	1.0	1.0	16.0-18.0	–	Mo 0.75 max.
440B	0.75-0.95	1.0	1.0	16.0-18.0	–	Mo 0.75 max.
440C	0.95-1.2	1.0	1.0	16.0-18.0	–	Mo 0.75 max.
Chromium-Ferritic-Nonhardenable						
405	0.08 max.	1.0	1.0	11.5-14.5	–	Al 1.1-0.3
430	0.12 max.	1.0	1.0	14.0-18.0	–	–
430F	0.12 max.	1.25	1.0	14.0-18.0	–	S 0.15 min
430Se	0.12 max.	1.25	1.0	14.0-18.0	–	Se 0.15 min.
446	0.20 max.	1.50	1.0	23.0-27.0	–	N 0.25 max.
Martensitic						
501	Over 0.10	1.0	1.0	4.0-6.0	–	Mo 0.40-0.65
502	0.10 max.	1.0	1.0	4.0-6.0	–	Mo 0.40-0.65

Illustration 7-6 – AISI Stainless Steel Classification System (Courtesy of the American Iron and Steel Institute)

CHAPTER 8
WELD AND JOINT DESIGN

The weld joint designs used in flux cored arc welding are determined by the design of the weldment, metallurgical considerations, and codes or specifications. Another factor to consider is the method of flux cored arc welding to be used. A properly selected joint design should allow the highest quality weld to be made at the lowest possible cost. A weld joint consists of a specific weld being made in a specific joint. A joint is defined as the junction of members that are to be, or have been, joined. Illustration 8-1 shows the five basic joint types.

Each joint type may be joined by many different types of welds, the most common of which are shown in Illustration 8-2.

The type of weld made is governed by the joint configuration. Each of the different types of welds has their own specific advantages. The nomenclature used for the various parts of groove and fillet welds is given in Illustration 8-3.

There are several factors that influence the joint design to be used:

1) Process Method
2) Strength Required
3) Welding Position
4) Joint Accessibility
5) Metal Thickness
6) Type of Metal

The edge and joint preparation are important because they affect both the quality and cost of welding. The cost items to be considered are the amount of filler metal required, the method of joint preparation, the amount of labor required and the quality level required. Joints that are more difficult to weld will often have more repair work necessary than those that are easier to weld. This can lead to significant increases in cost, since repair welding sometimes requires more time and expense than the original weld.

All of the five basic joint types are applicable to flux cored arc welding, although the butt and T-joints are the most widely used. Lap joints have the advantage of not requiring much preparation other than squaring off the edges and making sure the members are in close contact. Edge joints are widely used on thin metal. Corner joints generally use similar edge preparations to those used on T-joints.

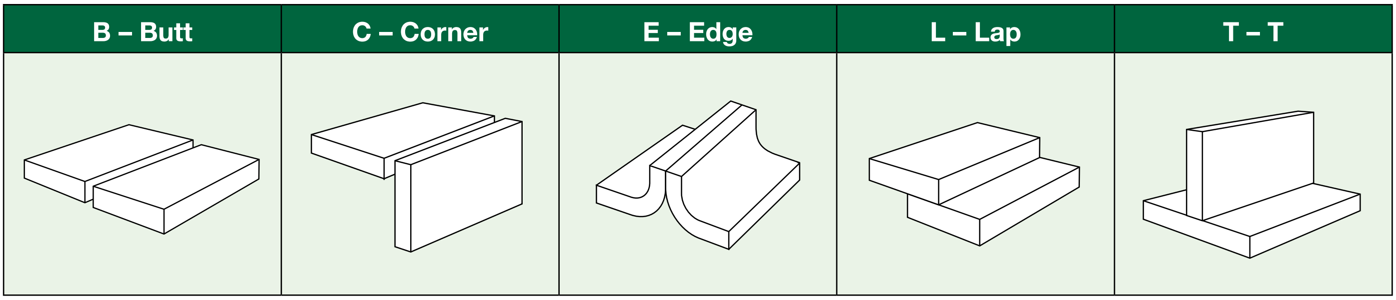


Illustration 8-1 – There are only five basic joints. They can, however, be used in combinations.

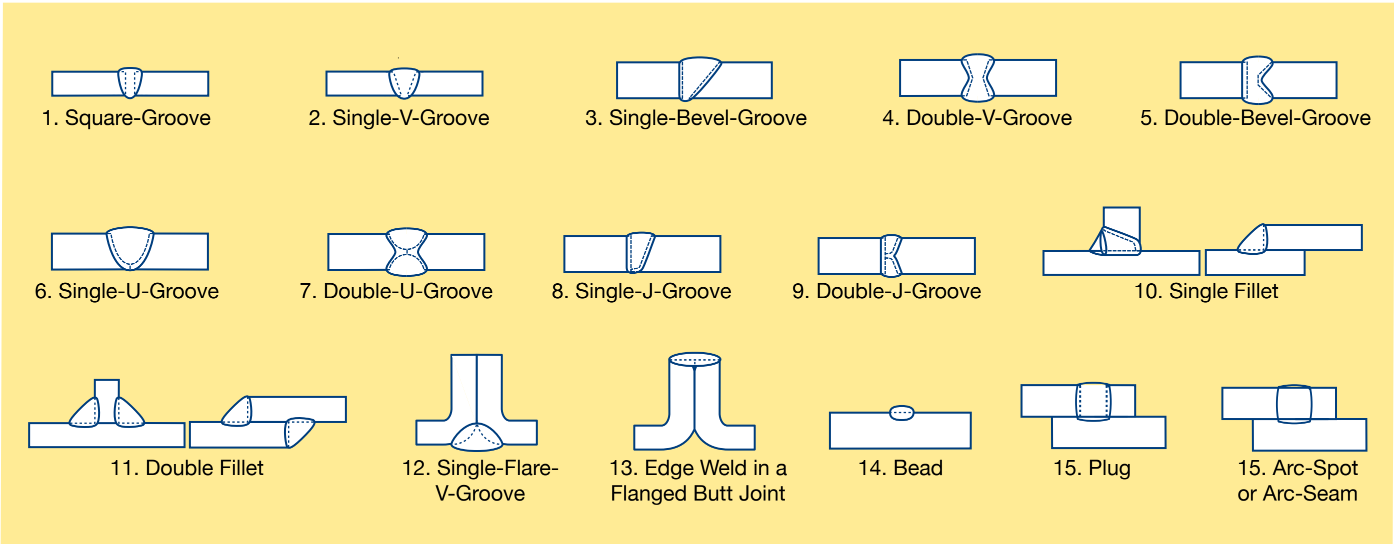
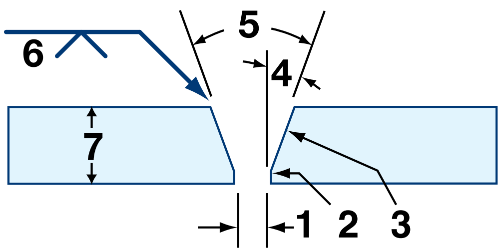
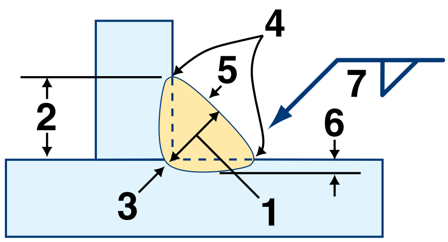


Illustration 8-2 – Common Types of Welds (Many other variations of welds are possible)

Groove Weld



Fillet Weld



1. **ROOT OPENING (RO):** the separation between the members to be joined at the root of the joint.
2. **ROOT FACE (RF):** Groove face adjacent to the root of the joint.
3. **GROOVE FACE:** The surface of a member included in the groove.
4. **BEVEL ANGLE (A):** the angle formed between the prepared edge of a member and a plane perpendicular to the surface of the member.
5. **GROOVE ANGLE (A):** the total included angle of the groove between parts to be joined by a groove weld.
6. **SIZE OF WELD (S):** the joint penetration (depth of bevel plus the root penetration when specified).
7. **PLATE THICKNESS (T):** Thickness of plate welded.

1. **ACTUAL THROAT OF A FILLET WELD:** The shortest distance from the root of the fillet weld to its face.
2. **LEG OF A FILLET WELD:** The distance from the root of the joint to the toe of the fillet weld.
3. **ROOT OF A WELD:** The points at which the weld intersects the base metal and extends furthest into the weld joint.
4. **TOE OF A WELD:** The junction between the face of the weld and the base metal.
5. **FACE OF WELD:** The exposed surface of a weld on the side from which the welding was done.
6. **DEPTH OF FUSION:** The distance that fusion extends into the base metal or previous pass from the surface melted during welding.
7. **SIZE OF WELD (S):** Leg length of the fillet.

Illustration 8-3 – Weld Nomenclature

Many of the joint designs used for flux cored arc welding are similar to those used in gas metal arc welding or shielded metal arc welding. Flux cored arc welding has some characteristics which may affect the joint design. The joint should be designed so the welder has good access to the joint and is able to properly manipulate the electrode. Joints must be located so that an adequate distance between the joint and nozzle of the welding gun is created. The proper distance will vary depending on the type of flux cored electrode being used.

PROCESS METHOD

The joint design, as well as the welding procedure, will vary depending on whether the welding is done using gas-shielded or self-shielded electrodes. Both methods of flux cored arc welding achieve deeper penetration than shielded metal arc welding. This permits the use of narrower grooves with smaller groove angles, larger root faces and narrower root openings. Differences also exist between the two flux cored arc welding methods because of the deeper penetration that is produced by the gas-shielded electrode wires. Illustration 8-4 shows a comparison of a flat position, V-groove weld on a backing strip for each of the two methods.

The joint design for the self-shielding wire requires a larger root opening to allow better access to the root of the joint. The joint design for the gas-shielded wire does not need such a wide root opening because complete penetration is easier to obtain. This weld would be less expensive to make using the gas-shielded electrode because less filler metal is required. This difference in joint design usually only applies when a backing strip is employed. For joints not requiring a backing strip, gas-shielded and self-shielded wires use the same joint designs.

STRENGTH

The strength required of a weld joint is a major factor governing weld joint design. Weld joints may be either full or partial penetration, depending on the strength required of the joint. Full or complete penetrating welds are those that have weld metal through the full cross section of the joint. Partial penetrating welds are those where weld metal only extends partially through the joint thickness. Welds that are subject to cyclic, impact, or static loading require complete penetration. This is even more important for applications that require low temperature service. Partial penetration welds may be adequate for joints where loading is static only. This type of joint is easier to prepare and requires less filler metal than full penetration joints. Fillet welds of the same leg size made by this process are stronger than those made by shielded metal arc welding. This is because of the deeper penetration obtained from flux cored arc welding, as shown

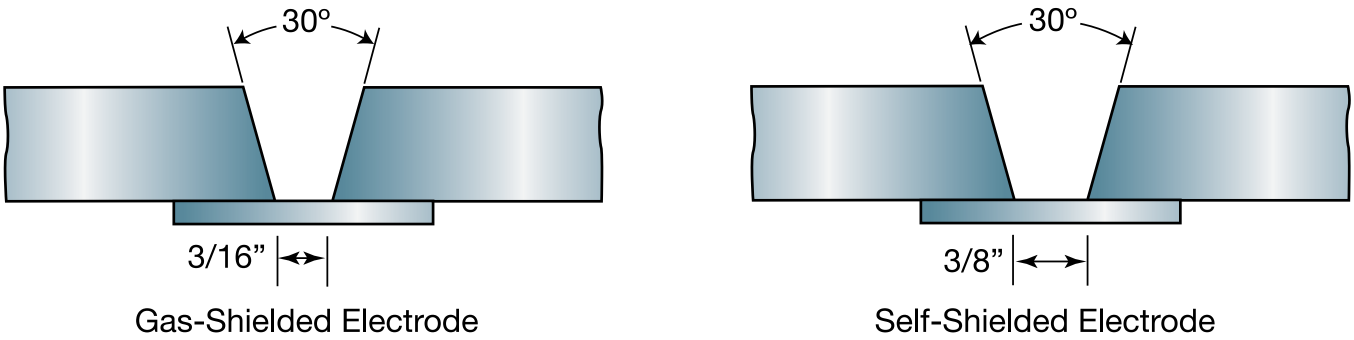


Illustration 8-4 – Comparison between Gas-Shielded and Self-Shielded Wire Joint Designs for the Flat Position

in Illustration 8-5. For some applications, the size of the weld can be reduced which decreases the amount of filler metal required. This can reduce the total cost also.

The amount of penetration obtained will be affected by the root opening and root face used. A root opening is used to allow good access to the root of the joint and is usually used in full penetrating weld joints. A root opening is usually not used in partial penetration weld joints because access to the root is not necessary and parts are easier to fit together without a root opening. The size of the root face is also affected. A larger root face is used for partial penetration welds than for complete penetration welds because less penetration is required. Because of the deep penetrating characteristics of flux cored arc welding process, larger root faces are used for this process compared to shielded metal arc welding and gas metal arc welding using short circuiting metal transfer. This is to prevent burning through the back of the joint being welded, which can be a problem in flux cored arc welding because of the high welding currents used. When compared to shielded metal arc welding, smaller groove

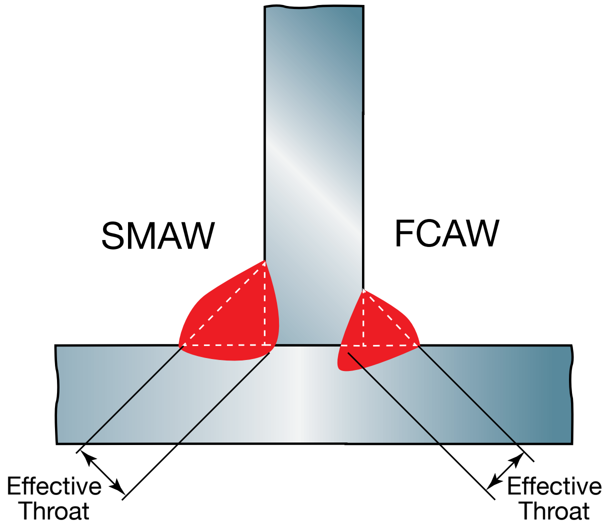


Illustration 8-5 – Comparison between the penetrating Characteristics of SMAW and FCAW

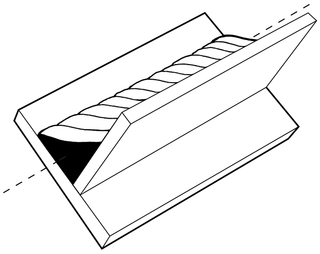
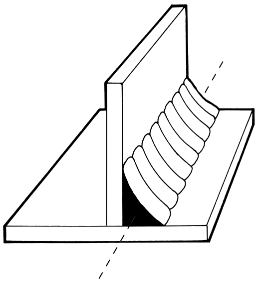
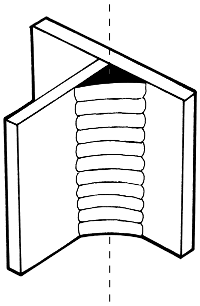
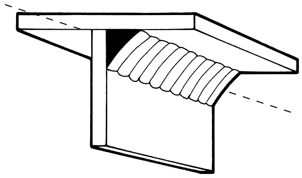
angles are used because the flux cored wire is smaller than a covered electrode and operates with a higher current density. Because of the smaller electrode, access to the root of the joint is better.

POSITION

Flux cored arc welding may be used in all welding positions based on the size and type of electrode wire used. A diagram of the welding position capabilities is shown in Illustration 8-6.

Welding positions are classified by a set of numbers and letters. The four basic welding positions are designated by the numbers 1 for flat, 2 for horizontal, 3 for vertical and 4 for overhead. A G designation indicates a groove weld and an F designation indicates a fillet weld. The 2G, 5G and 6G positions are used in pipe welding. The large diameter wires which are over 1/16 in. (1.6 mm) in diameter are limited to the flat and horizontal positions only because the weld puddle becomes too large to control. The smaller diameter electrodes, which are 1/16 in. (1.6 mm) and less can generally be used easily in all positions.

The joint configuration will vary depending on the position of welding. One example of this is that wider groove angles are needed for vertical position welding. This is done to provide enough room to manipulate the electrode wire in the joint. Weaving of the electrode is usually required in vertical position welding to prevent excessive reinforcement or dropping the weld metal out of the puddle. Joint designs for overhead welding are generally the same as for flat position welding. Joints that are welded in the horizontal position often have an unsymmetrical joint configuration. This usually consists of a groove angle that has a horizontal lower groove face as shown in Illustration 8-7. The upper groove face is raised accordingly to provide a groove angle that is large enough to provide good access. The horizontal lower groove face is used as a shelf to support the molten weld metal. This joint configuration is less expensive to prepare because the bevel is only made in one plate.

Fillet Welds			
FLAT POSITION 1F	**HORIZONTAL POSITION 2F**	**VERTICAL POSITION 3F**	**OVERHEAD POSITION 4F**
			
Axis of Weld Horizontal	Axis of Weld Horizontal	Axis of Weld Vertical	Axis of Weld Horizontal

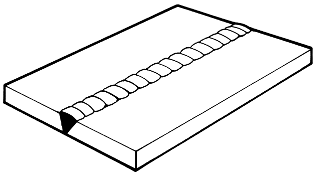
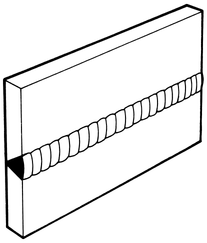
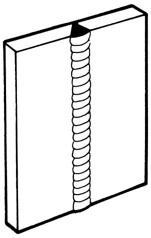
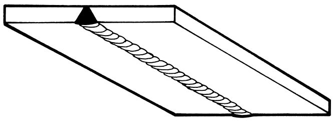
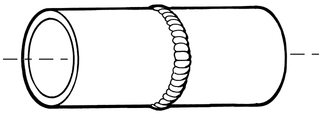
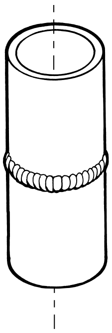
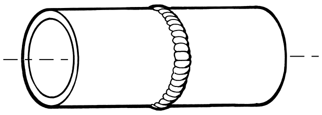
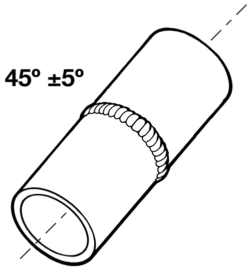
Groove Welds			
FLAT POSITION 1G	**HORIZONTAL POSITION 2G**	**VERTICAL POSITION 3G**	**OVERHEAD POSITION 4G**
			
Plates, Axis of Weld Horizontal	Plates vertical, Axis of Weld Horizontal	Plates vertical, Axis of Weld Vertical	Plates Overhead, Axis of Weld Horizontal
FLAT 1G	**HORIZONTAL 2G**	**HORIZONTAL FIXED 5G**	**45º FIXED 6G**
		"Bell Hole" 	"Arkansas Bell Hole" 
Pipe *shall be turned or rolled* while welding axis of pipe horizontal	Axis of Pipe Vertical	Pipe *shall not be turned or rolled* while welding axis of pipe horizontal	Pipe stationary with axis approximately 45º

Illustration 8-6 – Welding Test Positions

THICKNESS

The thickness of the base metal has a large influence on the joint preparation required to produce the best quality weld joint. Flux cored arc welding is used to weld thicknesses down to 18 gauge (1.2 mm). The process is also suitable for welding thick metal. Because of this, a wide variety of joint designs are used. The most common groove preparations used on butt joints are the square-V, J, U-bevel, and combination-grooves. The square-J, bevel, and combination-groove preparations are also used on T-joints. The different preparations are employed on different thicknesses to make it possible to get complete or adequate penetration.

Square-groove welds are used on the thinnest metal thicknesses. The square-groove joint design is the easiest to prepare and requires the least filler metal. Thicknesses up to 3/8 in. (9.5 mm) thick can be welded with full penetration from both sides. This is thicker than the square-groove joints that can be welded with full penetration by shielded metal arc welding or gas tungsten arc welding, because of the hotter arc and deeper penetration produced by this process. Root openings are used to allow complete penetration through the joint. Many square-groove welds are made in one pass. A backing strip may be used so that the root can be opened enough to provide better accessibility and insure adequate penetration.

V-grooves for butt joints and bevel-grooves for T-joints are commonly used for thicker metal up to about 3/4 in. (19.1 mm). These joints are more difficult to prepare and require more filler metal than square groove welds. The included angle for a V-groove is usually up to 75° with smaller groove angles such as 45° or 60° being more commonly employed. The smaller groove angles become even more economical as the thickness of the metal increases. The wider groove angles are used to provide better accessibility to the root of the joint. Because of the deeper penetrating characteristics of this process, single V-groove or single-bevel-groove welds are often welded with little or no root opening. Larger root faces and smaller groove angles are often used compared to those employed for shielded metal arc welding and gas tungsten arc welding. This helps to minimize the amount of distortion and reduce the amount of filler metal required. For complete penetration welds, root faces usually are close to 1/8 in. (3.2 mm).

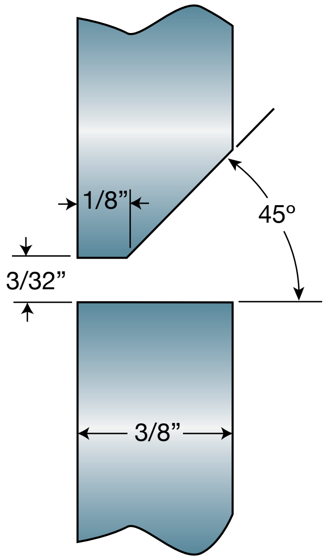


Illustration 8-7 – V-Groove Joint in the Horizontal Position

U- and J-grooves are generally used on thicknesses greater than 5/8 in. (14.3 mm). These joint preparations are the most difficult and expensive to prepare but the radius at the root of the joint allows better access to the root of the joint. Another advantage is that smaller groove angles may be used compared to those used in V-grooves. On thicker metal, this reduces the amount of filler metal required and on very thick metals, the savings become very substantial.

ACCESSIBILITY

The accessibility of the weld joint is another important factor in determining the weld joint design. Welds can be made from one or both sides of the weld joint. Single-V, J, U, bevel, and combination grooves are used when accessibility is from one side only and on thinner metal. Double-V, J, U, bevel, and combination grooves are used on thicker metal where the joint can be welded from both sides. Double-groove welds have three major advantages over single-groove welds where accessibility is only from one side. The first is that distortion is more easily controlled through alternate weld bead sequencing. Weld beads are alternated from one side to the other to keep the distortion from building up in the one direction. The weld roots are nearer the center of the plate. A second advantage is that less filler metal is required to fill a double groove joint than a single-groove joint. This tends to make double-groove welds more economical on metal 1 in. (25 mm) thick or greater. The third advantage is that complete penetration can be more easily insured. The root of the first pass on the plate can be gouged or chipped out before the root pass on the second side is welded, to make sure there is complete fusion at the root. The disadvantages of joints welded from both sides are that more joint preparation is required and gouging or chipping is usually required to remove the root of the first pass. Savings in the amount of filler metal needed for a double-groove weld may more than compensate for the extra joint preparation costs. Both of these add to the labor time required. Welding on both sides of a square-groove weld joint provides fuller penetration in thicker metal than metal welded from one side only. This would also save joint preparation time.

Backing Strips

When backing strips are used, joints are accessible from one side only. Backing strips allow better access to the root of the joint and support the molten weld metal. These strips are available in two forms, which are fusible or nonfusible. Fusible backing strips are made of the metal being welded and remain part of the weldment after welding. These may be cut or machined off. Non-fusible backing strips are made of copper, carbon, flux or ceramic backing in tape or composite form. These forms of backing do not become part of the weld. Backing strips on square-groove joints make a full penetration weld from one side easier. For this application, using a backing strip is more expensive because of the cost of a backing strip and the larger amount of filler metal required. This is not always the case. On V-groove joints, the backing strip allows wider root openings and removes the need for a root face, which reduces the groove preparation costs.

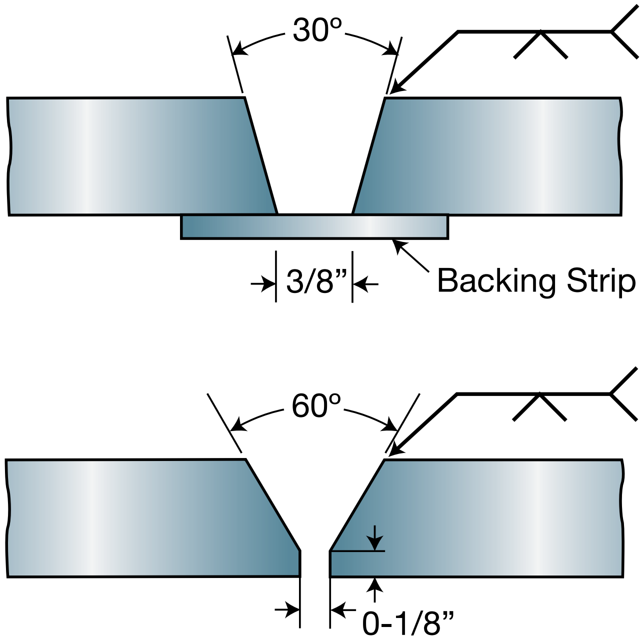


Illustration 8-8 – Single-V-Groove Joints with and without Backing Strip in the Same Thickness of Metal

Another advantage is that because the root may be opened up, the groove angle may be reduced, which will reduce the amount of filler metal required in thicker metal. These effects are shown in Illustration 8-8 where single V-groove joints are shown with and without a backing strip.

As discussed earlier in this chapter, the use of a backing strip will have an effect on the joint designs used for gas-shielded and self-shielded electrodes. The deeper penetrating characteristics of the gas-shielded electrode allow the joint designs to be adjusted to take advantage of this.

TYPE OF METAL

The flux cored arc welding process is used to weld steels, some stainless steels and some nickels. The influence of the type of metal on the joint design is based primarily on the physical properties of the metal to be welded and whether or not the metal has an oxide coating. For example, stainless steels have a lower thermal conductivity than carbon steels. This causes the heat from welding to remain in the weld zone longer, which enables slightly greater thicknesses of stainless steel to be welded using a square groove joint design. Stainless steels also have an oxide coating which tends to reduce the depth of fusion of the weld. Consequently, stainless steels normally employ larger groove angles and root openings than carbon steels. This allows the welder to direct the arc on the base metal surfaces to obtain complete fusion.

WELD JOINT DESIGNS

The weld joint designs shown in the rest of this chapter are those typically used for flux cored arc welding. All of the partial penetration weld joint designs covered may be welded using either the self-shielded or gas-shielded electrode wires. The joint dimensions will vary for full penetration welds using backing strips, depending on which method of flux cored arc welding is being used. The joint designs that should be used only by the gas-shielded method are indicated on these joints. All other full penetration welds may be made by either of the two methods.

Ranges are given on many of the joint dimensions to account for varying fit-up and types of electrode wires. The thickness ranges given are those typically recommended for use with the joint designs. Minimum weld sizes are commonly used for partial penetration welds. Recommended minimum weld sizes are given in Illustration 8-9.

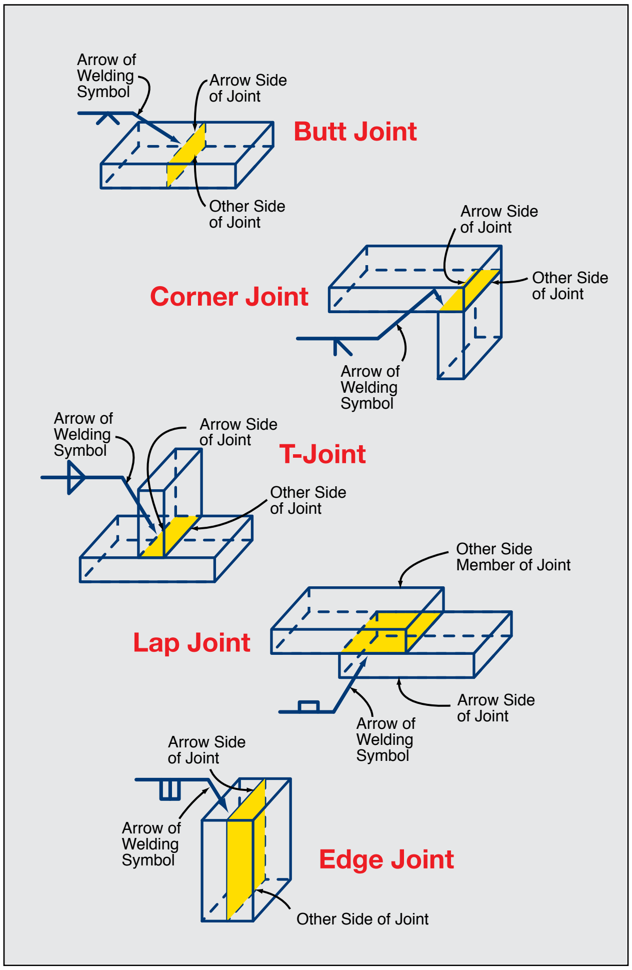
Base Metal Thickness of Thicker Part Joined	Minimum Weld Size
To 1/4" (6.5mm) inclusive	1/8" (3mm)
Over 1/4" to 1/2" (6.4-12.7m) inclusive	3/16" (5mm)
Over 1/2" to 3/4" (12.7-19.0mm) inclusive	1/4" (6mm)
Over 3/4" to 1-1/2" (19.0-38.1mm) inclusive	5/16" (8mm)
Over 1-1/2" to 2-1/4" (38.1-57.1mm) inclusive	3/8" (10mm)
Over 2-1/4" to 6" (57.1-152mm) inclusive	1/2" (13mm)
Over 6" (152mm) inclusive	5/8" (16mm)

Illustration 8-9 – Minimum Weld Sizes for Partial Joint Penetration Groove Welds

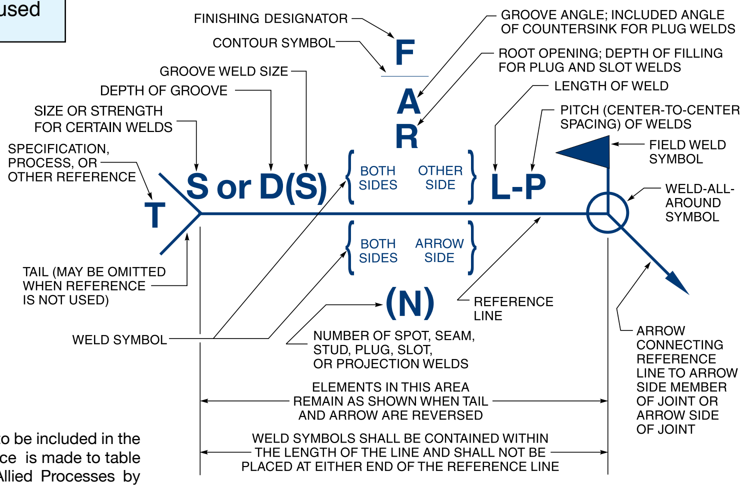
Basic Welding Symbols and their Location Significance

Type of Weld		Arrow Side	Other Side	Both Sides	No Arrow Side or Other Side Significance
Fillet					not used
Slot				not used	not used
Plug				not used	not used
Spot or Projection				not used	
Stud			not used	not used	not used
Seam				not used	
Back or Backing				not used	not used
Surfacing			not used	not used	not used
Edge					not used
GROOVE WELDS	Square				not used
	V				not used
	Bevel				not used
	U				not used
	J				not used
	Flare-V				not used
	Flare Bevel				not used
Scarf for Brazed Joint					not used

Basic Joints Identification of Arrow Side and Other Side Joint



Location of Elements of a Welding Symbol



Supplementary Symbols

Weld Around	Field Weld	Melt-thru	Consumable Insert	Backing Spacer

Contour		
Flush or Flat	Convex	Concave

Process abbreviations
Where process abbreviations are to be included in the tail of the welding symbol, reference is made to table 1, Designation of Welding and Allied Processes by Letters of AWS A2.4:2012
American Welding Society
550 N.W. LeJeune Road, Miami, Florida 33126

Illustration 8-10 – Welding Symbols

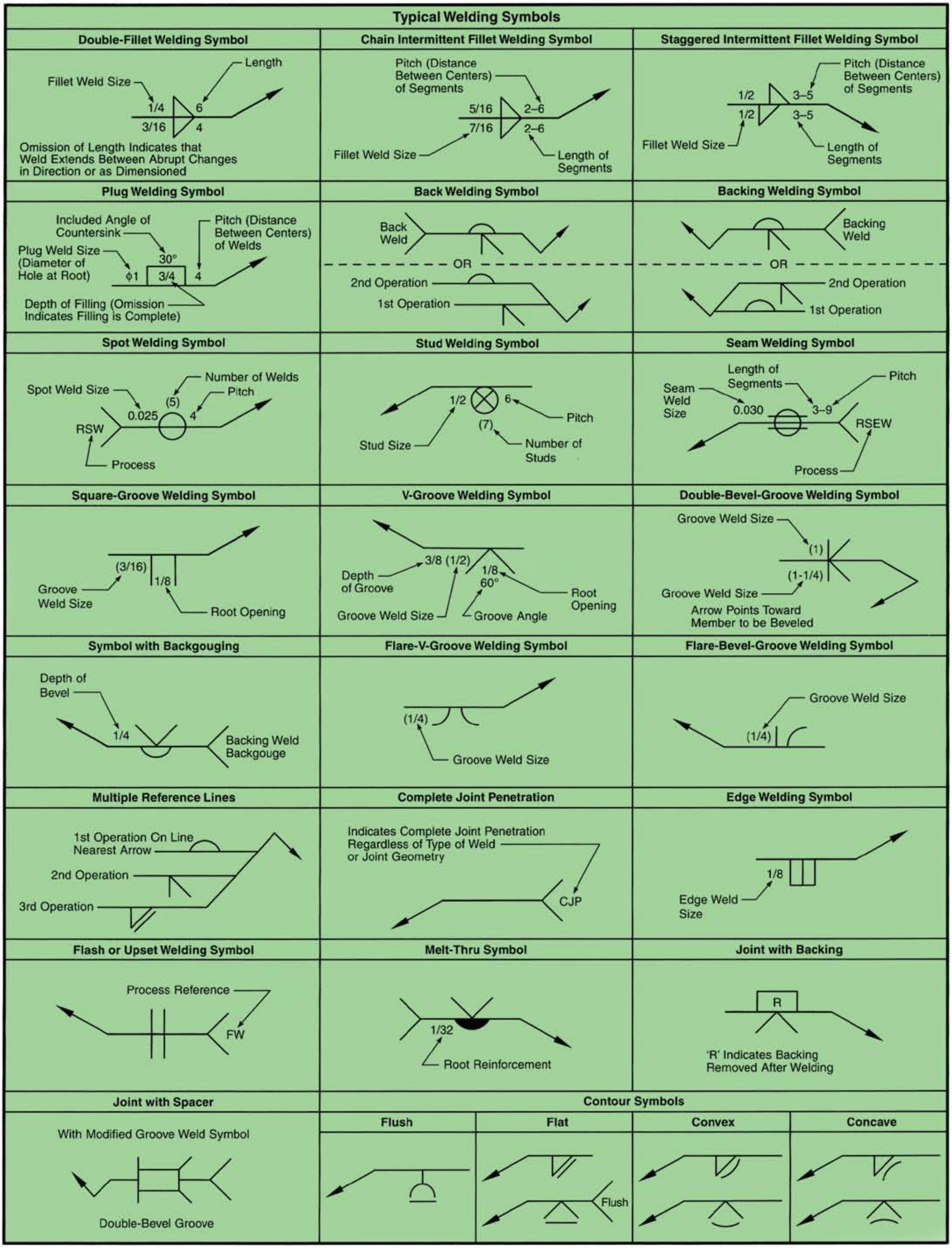
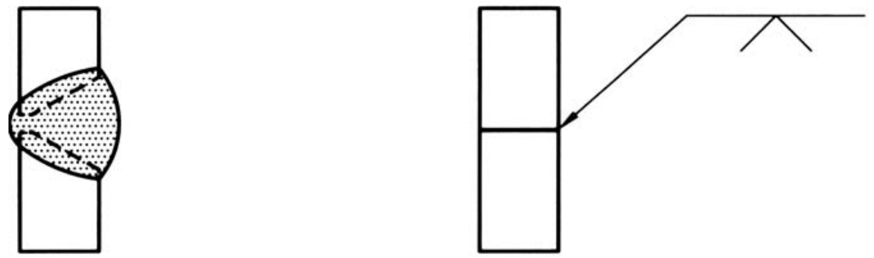


Illustration 8-10 – Welding Symbols (continued)

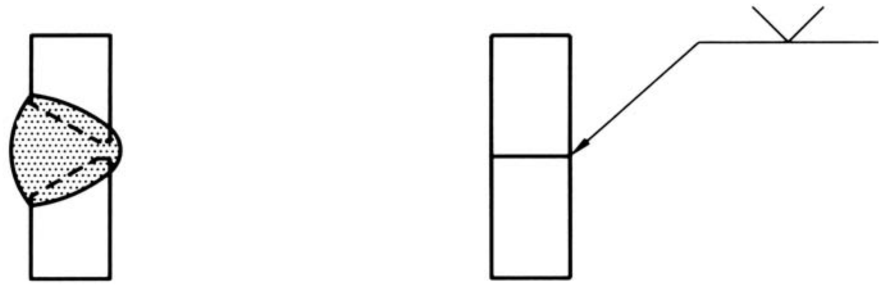
Application of Arrow and Other Side Convention

(A) Arrow side V-groove weld symbol



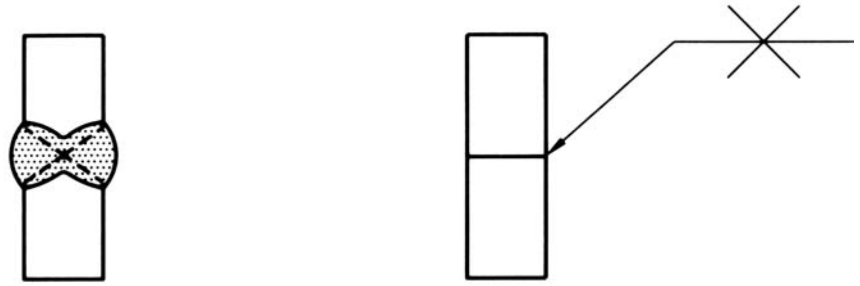
Weld Cross Section *Symbol*

(B) Other side V-groove weld symbol



Weld Cross Section *Symbol*

(C) Both sides V-groove weld symbol

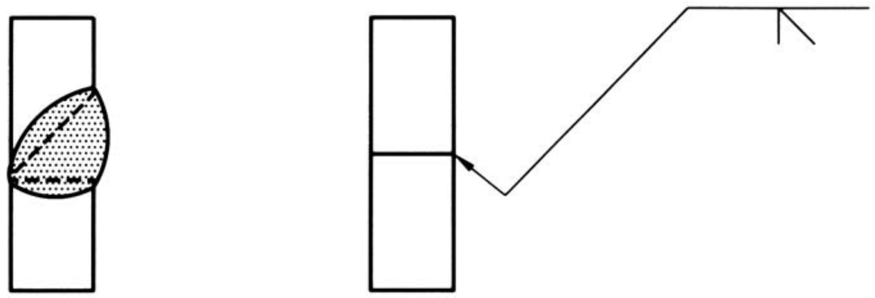


Weld Cross Section *Symbol*

Illustration 8-11 – Weld Joint Designs

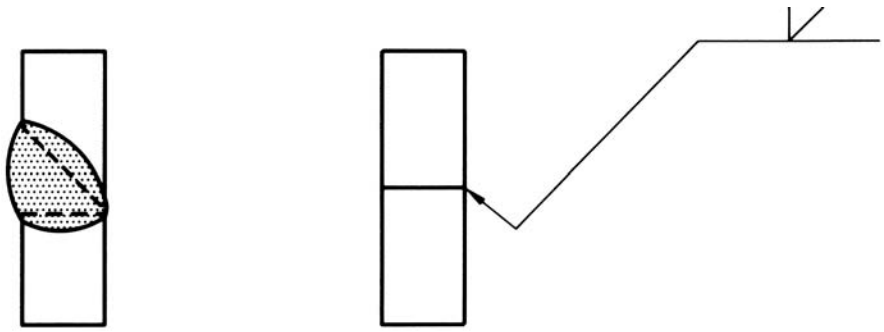
Application of Break in Arrow of Welding Symbol

(A) Arrow side



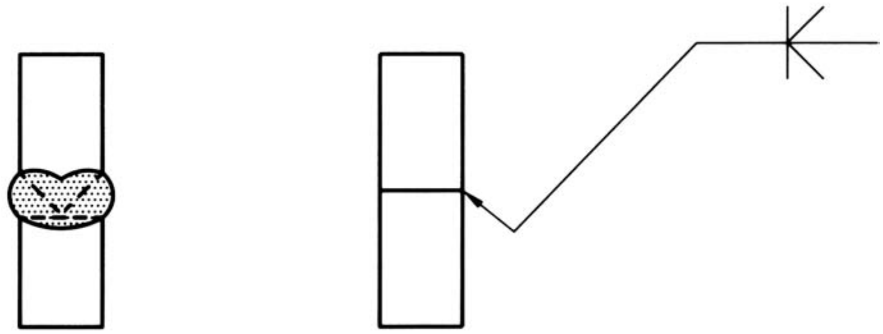
Weld Cross Section *Symbol*

(B) Other side



Weld Cross Section *Symbol*

(C) Both sides

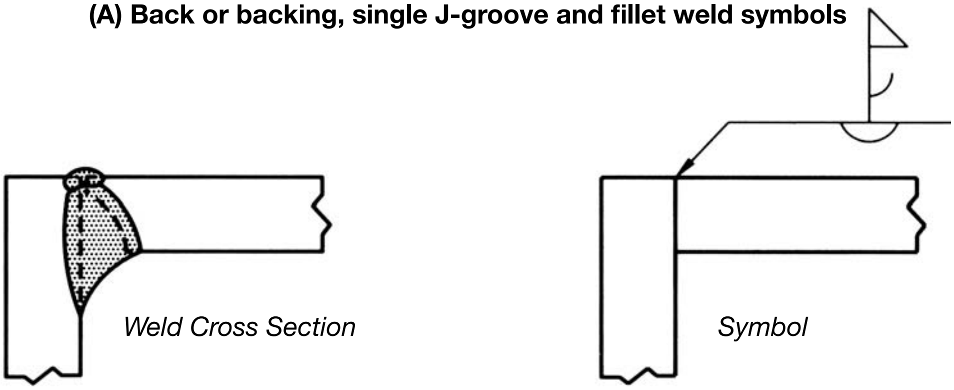


Weld Cross Section *Symbol*

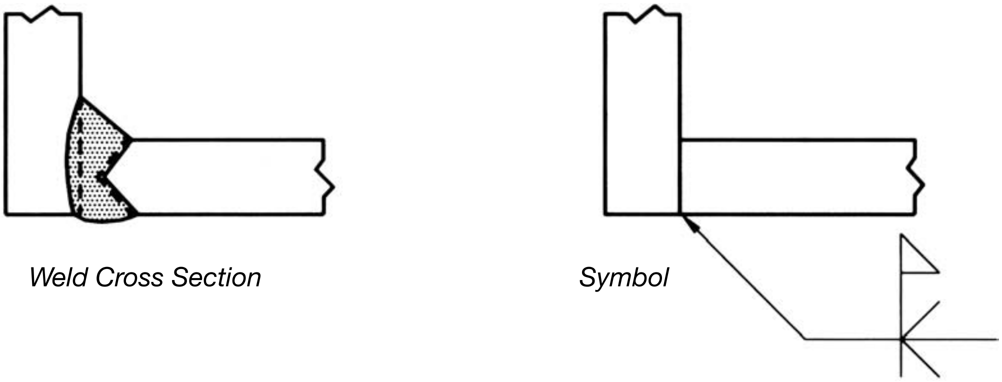
Illustration 8-11 – Weld Joint Designs (continued)

Combinations of Weld Symbols

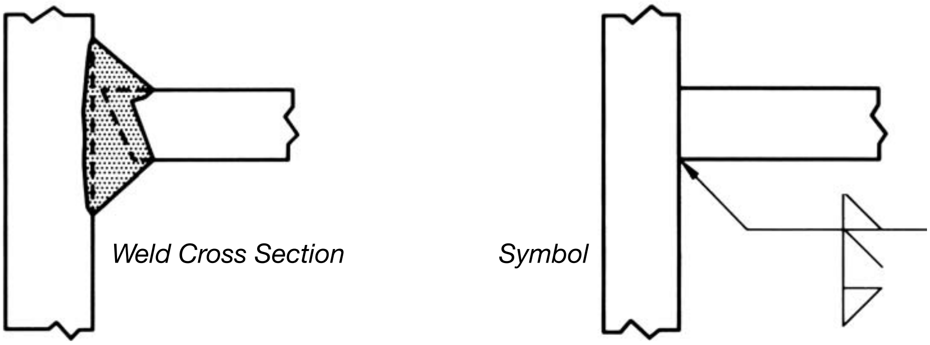
(A) Back or backing, single J-groove and fillet weld symbols



(B) Double-bevel-groove and fillet weld symbols



(C) Single-bevel-groove and double fillet weld symbols



(D) Double-square-groove and double fillet weld symbols

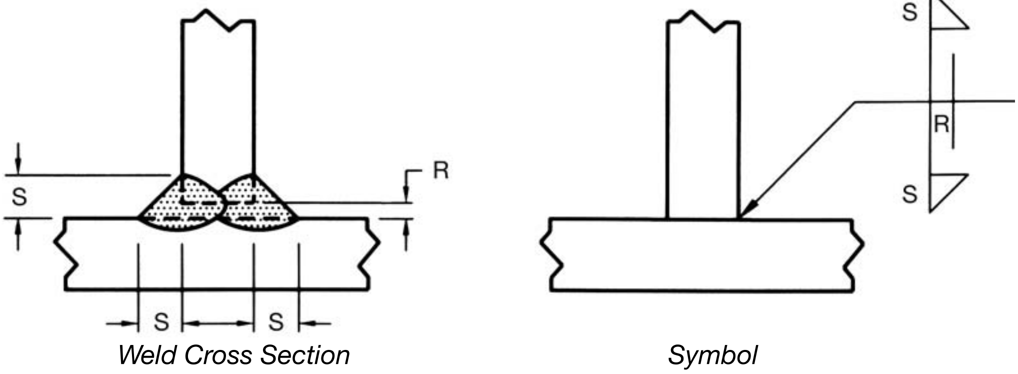
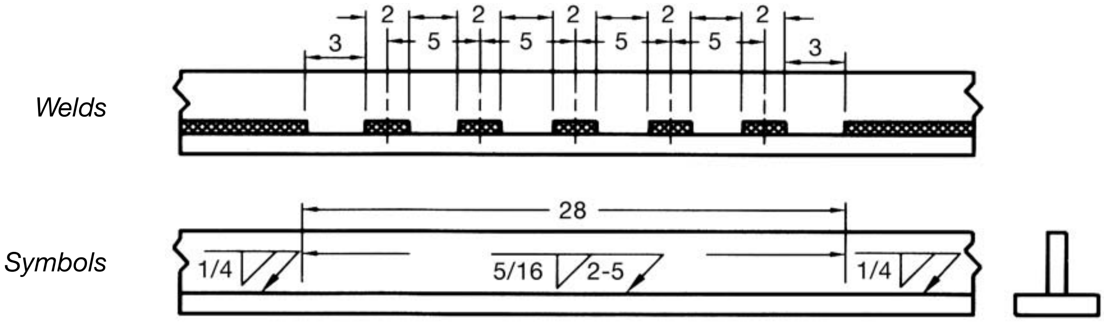


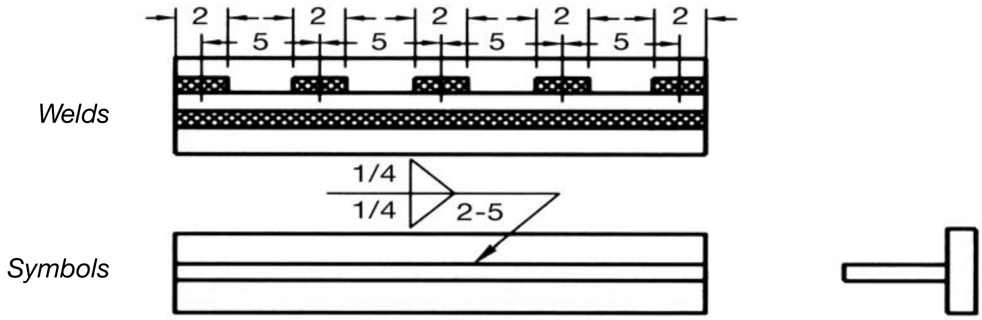
Illustration 8-11 – Weld Joint Designs (continued)

Specification of Location and Extent of Fillet Welds

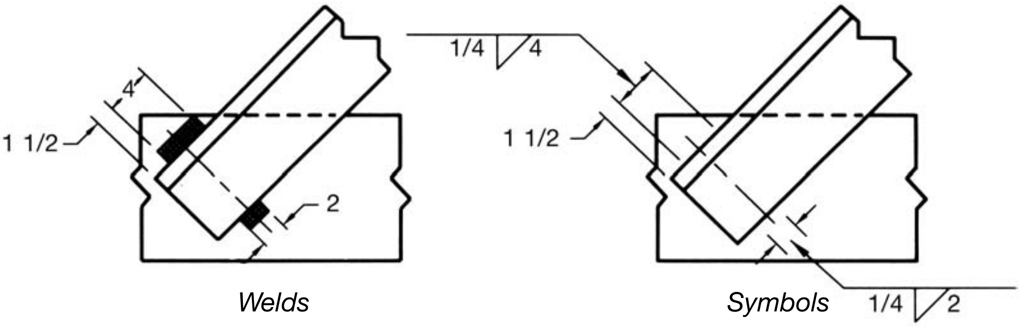
(A) Combined intermittent and continuous welds (one side of joint)



(B) Combined intermittent and continuous welds (both sides of joint)



(C) Welds definitely located



(D) Welds approximately located

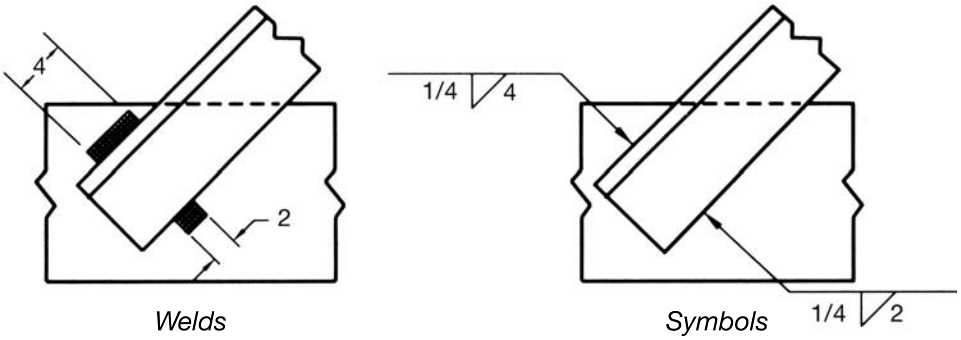
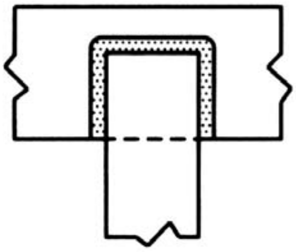


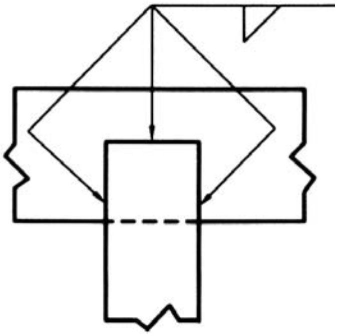
Illustration 8-11 – Weld Joint Designs (continued)

Specification of Extent of Welding

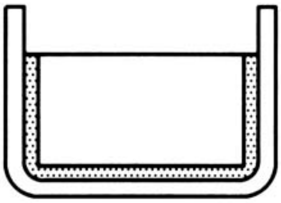
(A) Welds with abrupt changes in direction



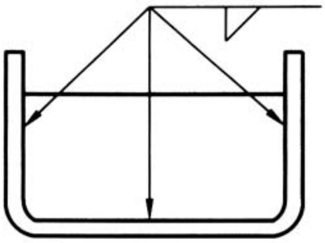
Welds



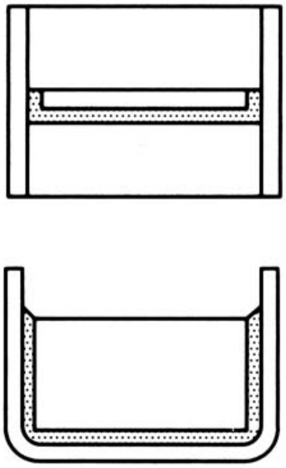
Symbols



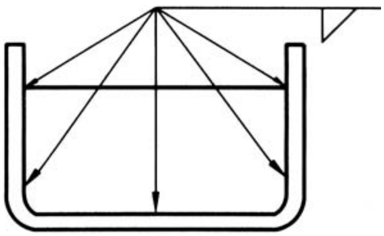
Welds



Symbols



Welds

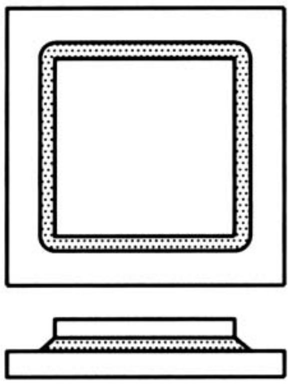


Symbols

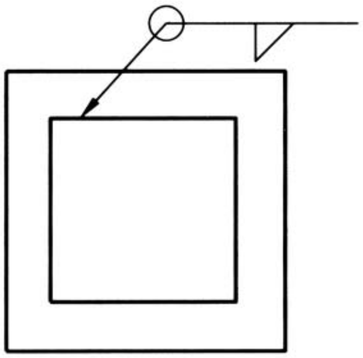
Illustration 8-11 – Weld Joint Designs (continued)

Specification of Extent of Welding

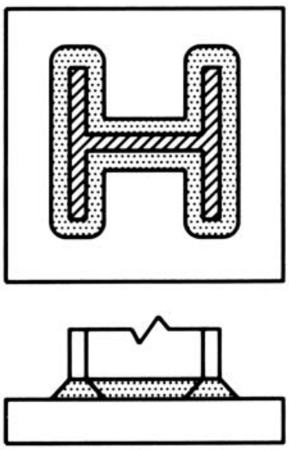
(B) Application of weld-all-around symbol



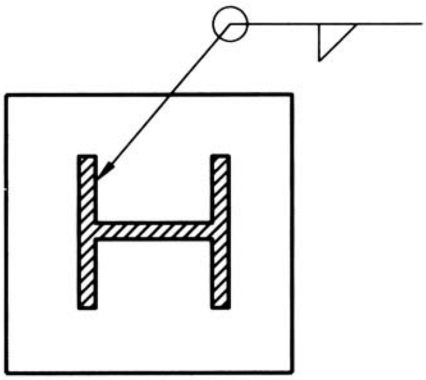
Welds



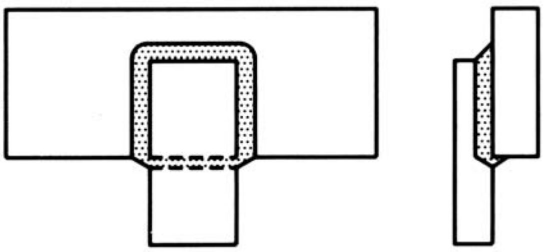
Symbol



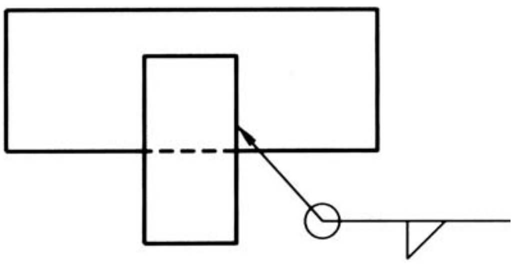
Welds



Symbol



Welds

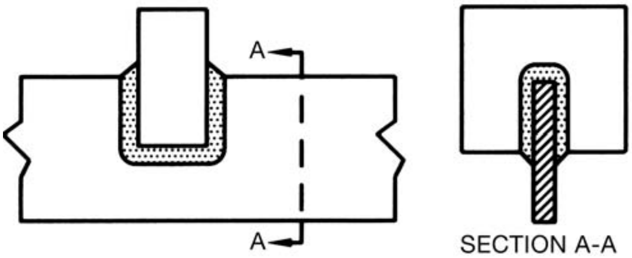


Symbol

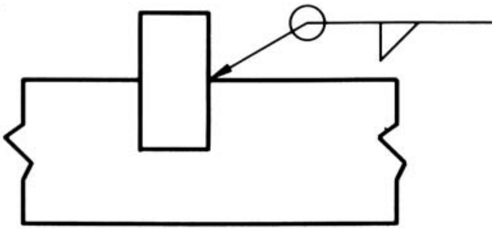
Illustration 8-11 – Weld Joint Designs (continued)

Specification of Extent of Welding

(C) Weld in several planes

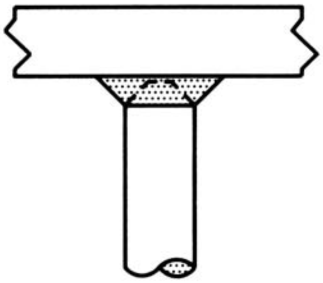


Welds

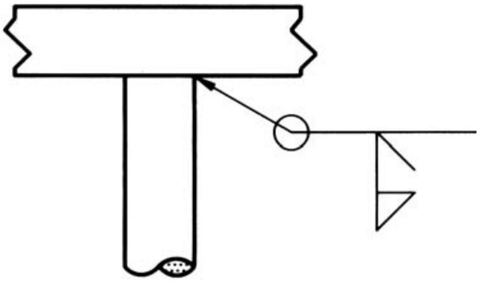


Symbol

(D) Weld around a shaft

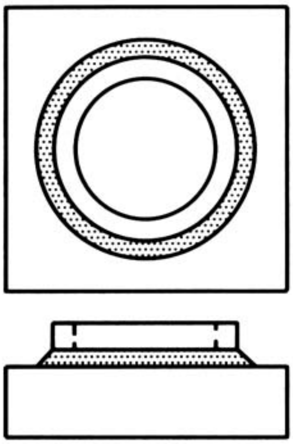


Welds

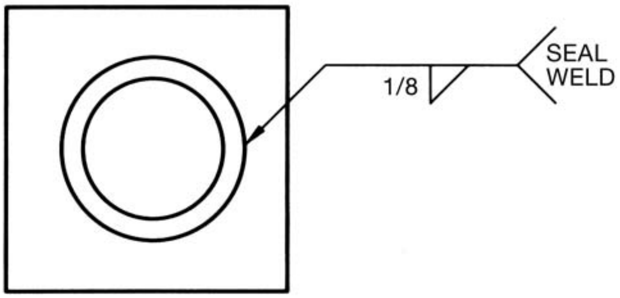


Symbol

(E) Seal weld



Welds

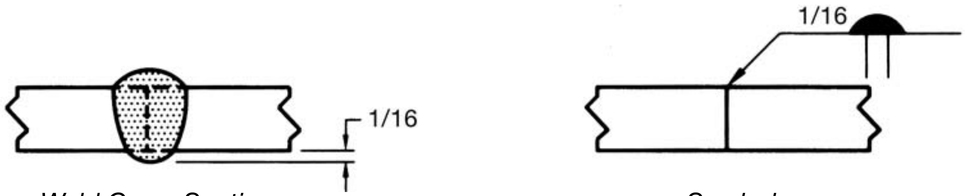


Symbol

Illustration 8-11 – Weld Joint Designs (continued)

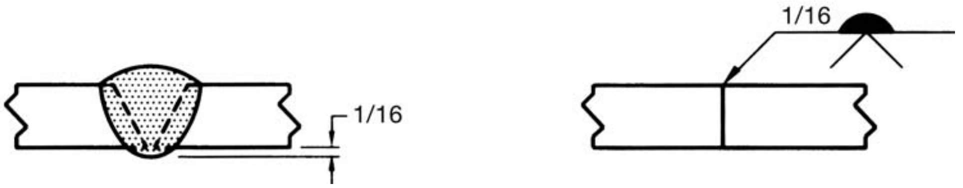
Applications of Typical Weld Symbols

(A) Square-groove weld

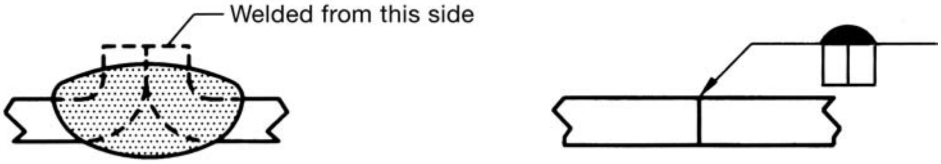


(B) Single-bevel-groove weld

(C) Single-V-groove weld



(D) Edge weld



(B) Corner-flange weld

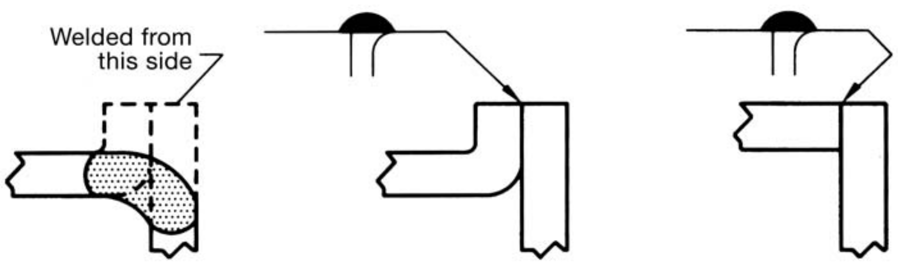


Illustration 8-11 – Weld Joint Designs (continued)

CHAPTER 9
WELDING PROCEDURE VARIABLES

Welding variables are those factors which affect the operation of the arc and the formation of the weld deposit. A smooth running arc and a quality weld deposit will result when all of the variables are in proper balance. It is essential that the effect of each variable on the different properties or characteristics of the weld be fully understood to increase the probability of producing the required weld properties. It should also be recognized that some welding variables are more easily applied as controls of a welding process. Based on their ability to be used as controls, welding variables can be divided into three distinct groups or classes. These are the preselected or fixed variables, primary adjustable variables, and secondary adjustable variables.

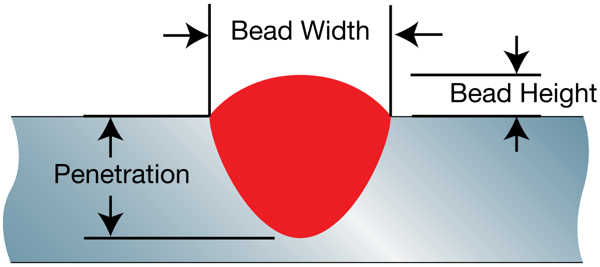


Illustration 9-1 – Bead Height, Width and Penetration

The preselected or fixed variables are those which can only be changed in large steps or intervals and are therefore unfavorable as controls. For the flux cored arc welding process, these variables are set according to the type of material being welded, the thickness of the material, welding position, deposition rate required, and mechanical properties required. These are variables that cannot be changed once the welding starts.

The primary adjustable variables are used to control the welding process after the preselected variables have been established. They control the formation of the weld bead itself by affecting such things as penetration, bead width, bead height, arc stability, deposition rate, and weld soundness. The primary welding variables are welding voltage, welding current, and travel speed. Because they can be easily measured and continually adjusted over a wide range, they can effectively be used as controls. Specific values can be assigned to the primary adjustable variables and these values can be accurately reset time after time.

The secondary adjustable variables can also be changed continuously over a wide range of values. However, they are sometimes difficult to measure accurately. Therefore, it is not easy to employ them as controls since, for the most part, they cannot be assigned exact values. This is especially true in semiautomatic welding operations. Although difficult to measure, these variables should be controlled within the range for proper operation. Secondary adjustable variables are such things as electrode extension or stick-out, work and travel angles.

The different variables affect the characteristics of the weld such as the penetration of the weld, bead height, bead width, and the deposition rate. The definitions of bead height, bead width, and penetration are shown in Illustration 9-1.

The penetration of the weld is defined as the greatest depth, below the surface of the base metal or previous weld bead that the weld metal reaches. The bead height is the height of the weld metal above the surface of the base metal. The bead width is the width of the weld bead. The deposition rate is the weight of metal that is deposited per unit of time.

The welding variables are discussed in this chapter with particular attention to the penetration, bead shape, deposition rate, and how they each affect the other welding variables. Illustration 9-2 is a chart showing the effects of welding variables on the three major characteristics.

FIXED VARIABLES

Electrode Type

The type of electrode wire will have an effect on the welding characteristics of this process. The flux core of the electrodes contains different components that affect bead shape, penetration, deposition rate, and the operating characteristics. Because of this, a wide variety of operating characteristics exist which are similar to those found with the various covered electrodes used in shielded metal arc welding. Some self-shielded flux cored electrodes have been developed to operate on DCEN. These electrodes produce relatively light penetration and are used for many sheet welding and weld surfacing operations. Self-shielded electrodes that operate on DCEP produce deeper penetration. Gas-shielded electrode wires operate on DCEP and provide the deepest penetration of the different types because of the gas shielding in addition to the flux core.

Many electrodes are designed to produce a stable arc and high deposition rates at the higher current levels. Illustrations 9-3 and 9-4 show some deposition rate comparisons between several types of flux cored electrodes.

Desired Characteristic	Arc Voltage	Welding Current	Travel Speed	Nozzle Angle	Tip-to-Work Distance	Wire Size	Gas Type
	WELDING VARIABLE / CHANGE REQUIRED						
Deeper penetration		**1.** Increase		**3.** Trailing Max. 25°	**2.** Decrease	**5.** Smaller[a]	**4.** CO_2
Shallower Penetration		**1.** Decrease		**3.** Leading	**2.** Increase	**5.** Larger[a]	**4.** $Ar+CO_2$[c]
Bead Height and Width – **Larger Bead**		**1.** Increase	**2.** Decrease		**3.** Increase[a]		
Bead Height and Width – **Smaller Bead**		**1.** Decrease	**2.** Increase		**3.** Decrease[a]		
Bead Height and Width – **Higher, Narrower**	**1.** Decrease			**2.** Trailing	**3.** Increase		
Bead Height and Width – **Flatter, Wider**	**1.** Increase			**2.** 90° or Leading	**3.** Decrease		
Faster Deposition Rate		**1.** Increase			**2.** Increase[a]	**3.** Smaller[b]	
Slower Deposition Rate		**1.** Decrease			**2.** Decrease[a]	**3.** Larger[b]	

Key: **1.** first choice, **2.** second choice, **3.** third choice, **4.** fourth choice, and **5.** fifth choice.

a) When these variables are changed, the wire feed speed must be adjusted so that the welding current remains constant.
b) See deposition rate section of welding variables section.
c) This change is especially helpful on materials 20 gauge and smaller thickness.

Illustration 9-2 – Recommended Welding Variable Adjustments for Flux Cored Arc Welding

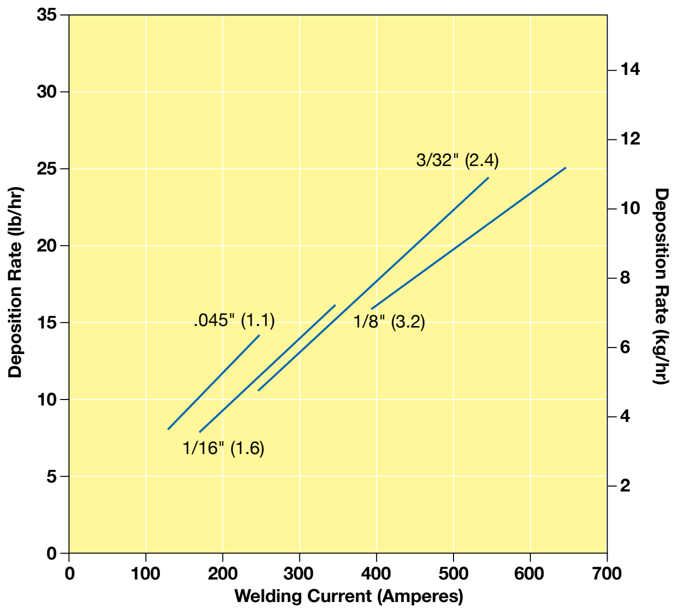


Illustration 9-3 – Deposition Rate Versus Current for Externally Shielded Tubular Electrode Wires

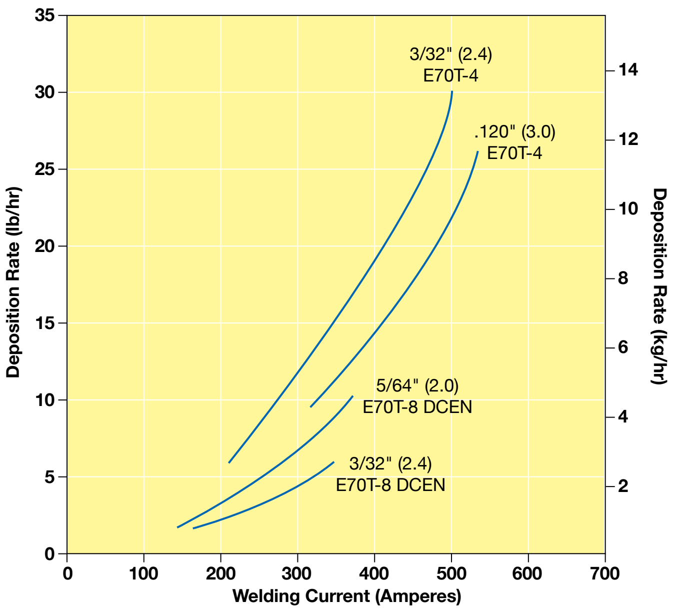


Illustration 9-4 – Deposition Rate Versus Current for Self-Shielded Tubular Electrode Wires

Electrode Size

Each electrode wire diameter of a given type has a usable welding current range. Larger diameter electrode wires use higher welding currents to produce higher deposition rates and deeper penetration. The rate at which the electrode melts is based on the welding current density and the components in the flux. If two electrode wires of the same type, but different diameters, are operated at the same current level, the smaller electrode will give a higher deposition rate because the current density is higher. Illustrations 9-3 and 9-4 also show the deposition rates produced by different electrode diameters. The amount of penetration is also based on the current density. A smaller electrode will produce deeper penetration than a larger electrode at the same current setting. The weld bead will be wider when using the larger electrode wire. The choice of the optimum electrode size to be used is based on the thickness of the metal to be welded, the amount of penetration required, the position of welding, the deposition rate desired, the bead profile desired, and the cost of the electrode wires. A smaller diameter electrode is more costly on a weight basis although, for out-of-position welding, the smaller diameter electrodes are the only ones that can be used. For each application, there is an optimum electrode size that can be used to produce minimum welding costs.

PRIMARY VARIABLES

Welding Current

The amount of welding current has the greatest effect on the deposition rate, weld bead size and shape, and the weld penetration. Welding current is proportional to the wire feed speed for a given electrode type, shielding gas type and pressure and amount of electrode extension. In a constant voltage system, the welding current is controlled by the knob on the wire feeder control, which sets the wire feed speed. The welding current increases with the wire feed speed.

As shown in Illustrations 9-3 and 9-4, the deposition rate of the process increases as the welding current increases. The lower part of the curve is flatter than the upper part because at higher current levels, the melting rate of the electrode increases at a faster rate as the current increases. This can be attributed to resistance heating of the electrode extension beyond the contact tube. When all of the other variables are held constant, increasing the welding current will increase the electrode deposition rate, increase penetration, and increase the size of the weld bead. Illustration 9-5 shows the effect of welding current.

An excessive welding current level will create a large, deep penetrating weld bead which causes excessive convexity and can burn through the bottom of the joint. Insufficient welding current produces large globular transfer and excessive spatter in addition to poor penetration and excessive piling up of the weld metal. With self-shielding electrodes, insufficient current can cause porosity and the pickup of two much nitrogen from the atmosphere. The nitrogen causes a harder weld that has poorer ductility. Illustrations 9-6, 9-7, and 9-8 show the effects of welding current on the penetration, bead height, and bead width.

Welding Voltage (Arc Length)

The welding voltage is determined by the distance between the tip of the electrode and the work. In a constant voltage system, the welding voltage is adjusted by a voltage control knob on the front of the power source. The power source maintains a given voltage which maintains a certain arc length. In a constant current system, the voltage is controlled by the voltage sensing wire feeder. The voltage sensing wire feeder regulates the wire feed speed to maintain the arc length that produces the preselected arc voltage. For a given welding current, there is a certain voltage that will provide the smoothest welding arc. The arc voltage required for an application is dependent on the electrode size, type of shielding gas, position of welding, type of joint, and base metal thickness.

When the other welding variables are held constant and the welding voltage is increased, the weld bead becomes wider and flatter. The effect of varying the arc voltage on a gas-shielded electrode is shown in Illustration 9-9.

The penetration will increase up to an optimum voltage level and then begin to decrease as shown in Illustration 9-6. A higher voltage is often used to bridge a gap be-

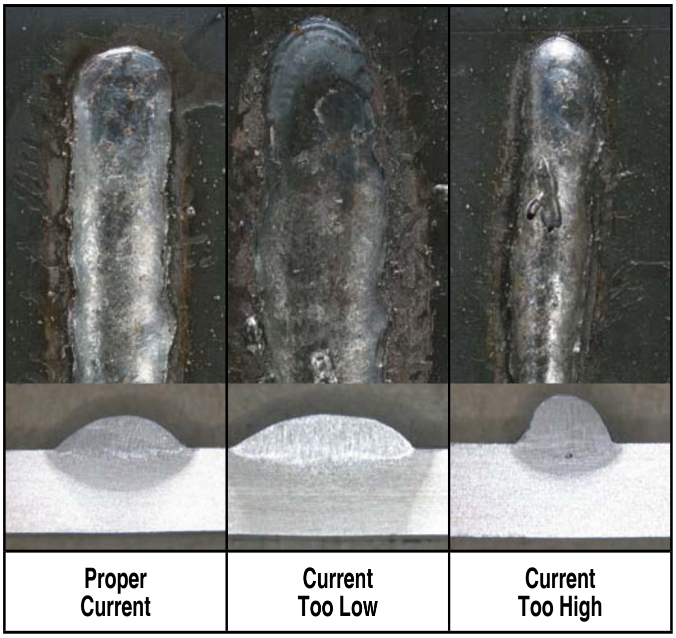


Illustration 9-5 – Effect of Welding Current on Bead Appearance and Bead Formation

cause of the decreased penetration obtained. An excessive voltage or arc length will result in excessive amounts of spatter and irregularly shaped weld beads. When using self-shielded electrodes, an excessive arc length can also cause nitrogen pickup, which causes porosity in low carbon steel weld metal. With the self-shielded stainless steel electrodes nitrogen absorption can cause cracking. With all types of electrodes, undercutting can also be produced. A decrease in the arc length results in a narrower weld bead with a greater convexity and deeper penetration.

An arc voltage that is too low will cause a narrow convex weld bead with excessive spatter and reduced penetration. Illustrations 9-7 and 9-8 show the effects of the welding voltage on bead height and bead width.

Travel Speed

The travel speed influences the weld penetration and the shape of the weld deposit. In semiautomatic welding, this is controlled by the welder and will vary somewhat depending on the welder. In machine and automatic welding, as shown in Illustration 9-6, the penetration is at a maximum with a certain travel speed. Increasing or decreasing the travel speed from this point will reduce the amount of penetration. When the travel speed is decreased, the amount of filler metal deposited per unit of length increases, which creates a large, shallow weld puddle. Weld metal tends to get slightly ahead of the arc which reduces the penetration and produces a wide weld bead. Reducing the travel speed will increase the bead height as is shown in Illustration 9-7. Travel speeds that are too slow can result in overheating the weld metal because of the excessive heat input, which creates a very large heat affected zone. It can also cause excessive piling up of the weld metal, which has a rough appearance and may trap slag. As the travel speed is increased, the heat input into the base metal is reduced, which decreases the melting of the base metal and limits penetration. The bead height and the bead width are also reduced. An excessive travel speed will result in an irregular, ropy weld bead that may have undercutting along the edges. The effect of varying the travel speed on a self-shielded electrode is shown in Illustration 9-10.

The effects of the primary welding variables are summarized in Illustration 9-11 for gas-shielded flux cored electrodes and in Illustration 9-12 for self-shielded flux cored electrodes.

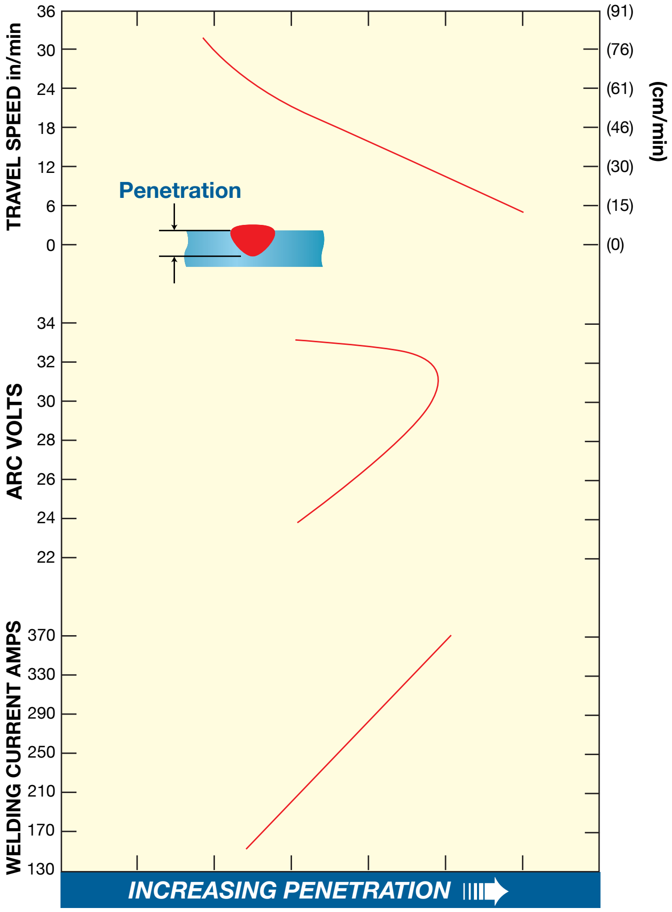


Illustration 9-6 – Effect of Travel Speed, Arc Volts, and Welding Current on Penetration

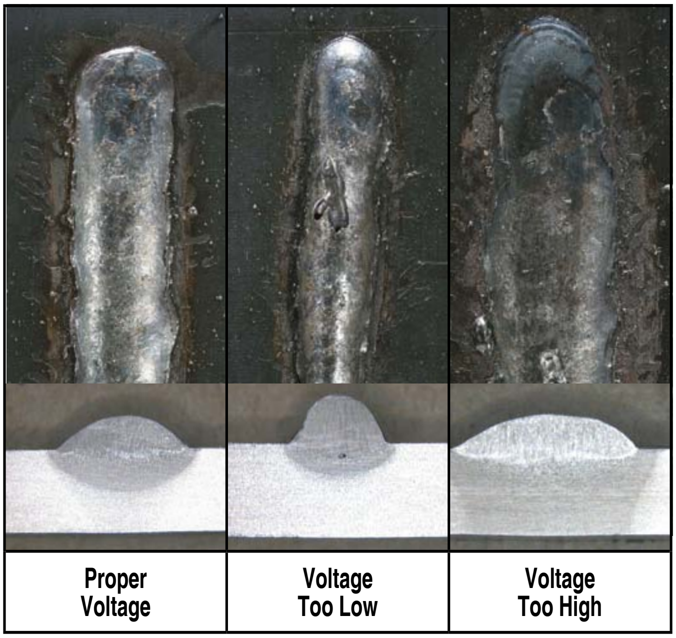


Illustration 9-9 – Effect of Welding Voltage on Bead Appearance and Bead Formation

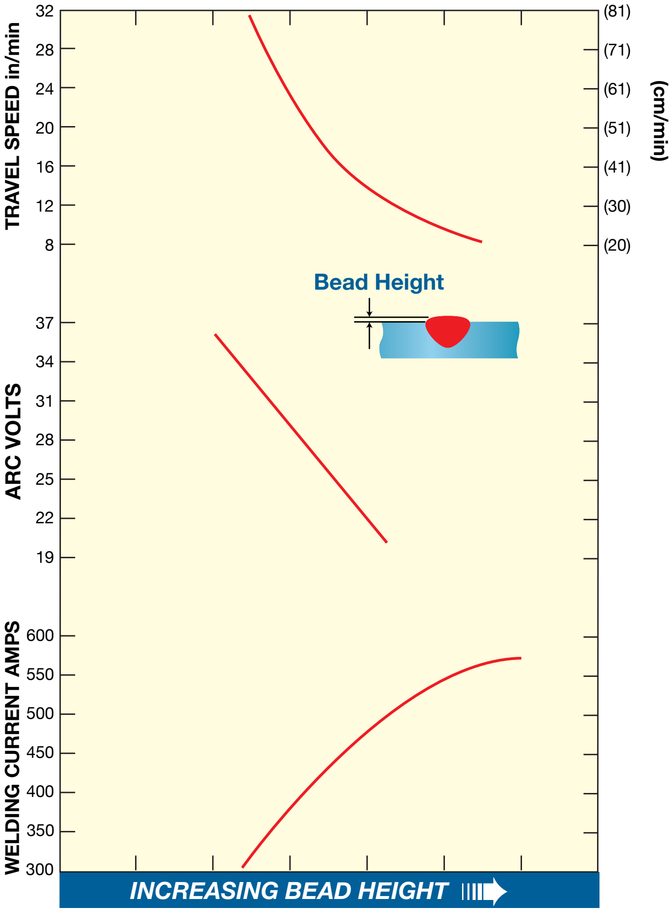


Illustration 9-7 – Effect of Travel Speed, Arc Volts, and Welding Current on Bead Height

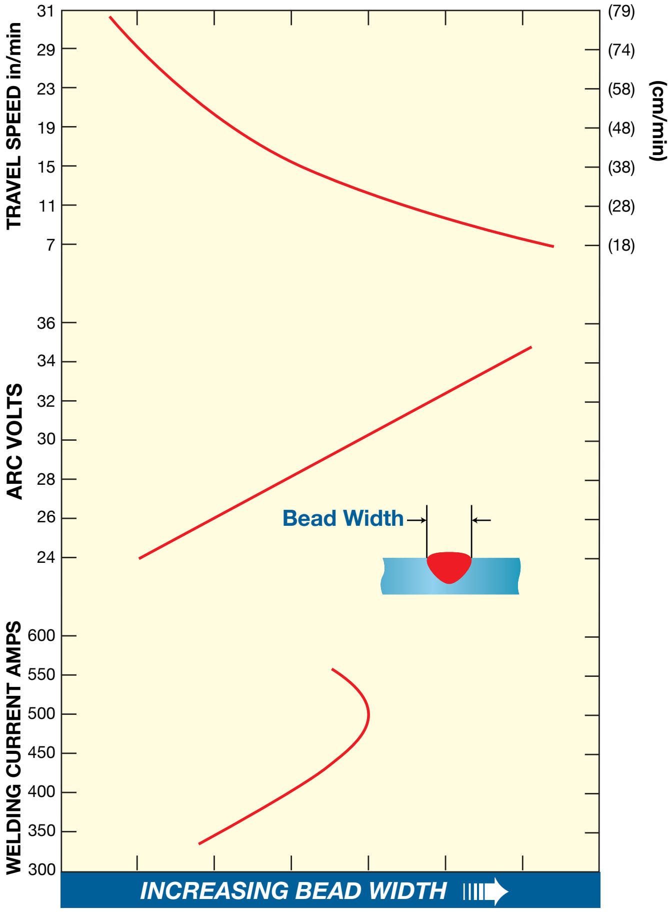


Illustration 9-8 – Effect of Travel Speed, Arc Volts, and Welding Current on Bead Width

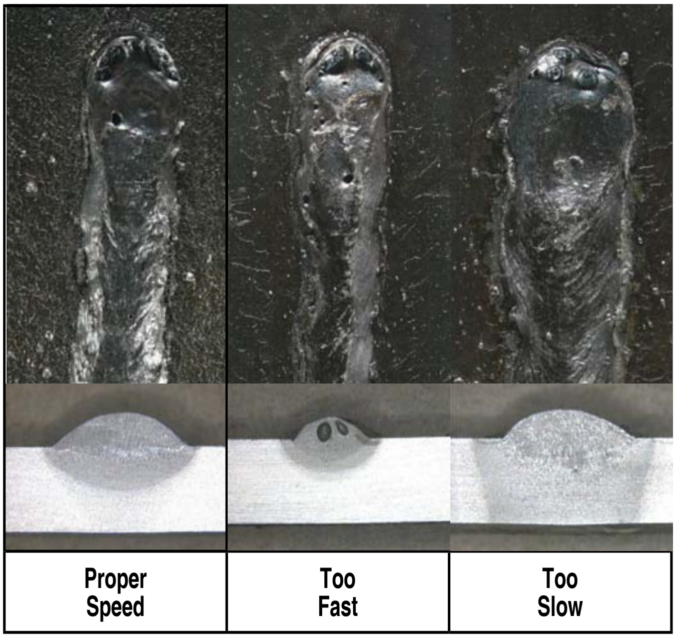


Illustration 9-10 – Effect of Travel Speed on Bead Appearance and Bead Formation

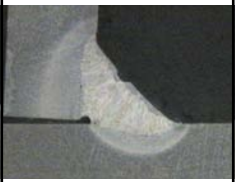
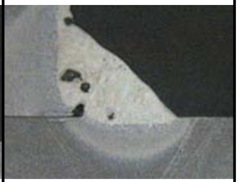
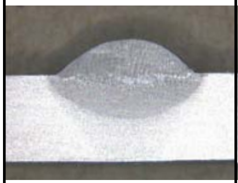
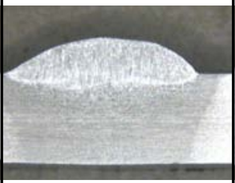
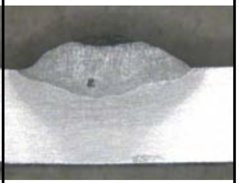
GOOD Proper Current Voltage & Speed	BAD Welding Current Too Low (High Voltage)	BAD Welding Current Too High (Low Voltage)	BAD Welding Speed Too Fast	BAD Welding Speed Too Slow	BAD Insufficient Shielding Gas Coverage
					
Cross-section Fillet	Cross-section Fillet	Cross-section Fillet	Cross-section Fillet	Cross-section Fillet	Cross-section Fillet
					
Cross-section Weld Bead	Cross-section Weld Bead	Cross-section Weld Bead	Cross-section Weld Bead	Cross-section Weld Bead	Cross-section Weld Bead
					
Face Weld Bead	Face Weld Bead	Face Weld Bead	Face Weld Bead	Face Weld Bead	Face Weld Bead
A smooth, regular, well formed bead. No undercutting, overlapping or pileup. Uniform in cross section. Excellent weld at minimal material and labor cost.	Excessive spatter and porosity. Weld bead excessively wide and flat. Undercutting along edges weakens joint. Irregular bead contour.	Weld bead excessively convex and narrow. Difficult slag removal. Wasted filler metal and productive time.	Bead too small, with contour irregular. Not enough weld metal in cross section. Poor mechanical properties. Undercut at toe lines of fillet	Excessive bead width. Overlapping without penetration at edges. Fillet with unequal legs. Wasted filler metal and productive time.	Excessive spatter and porosity Bead very irregular with poor penetration. Weld metal not properly shielded. Wasted electrode and productive time.

Illustration 9-11 – Examples of Good and Bad Welds – Flux Cored with External Shielding Gas

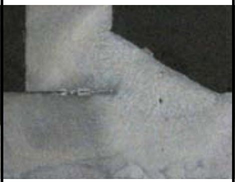
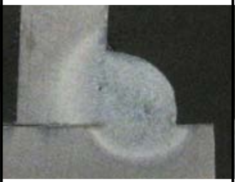
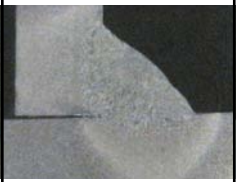
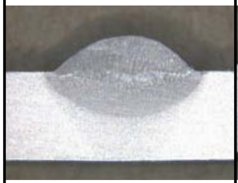
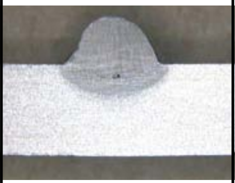
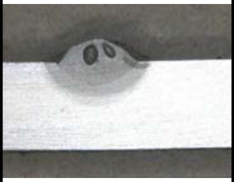
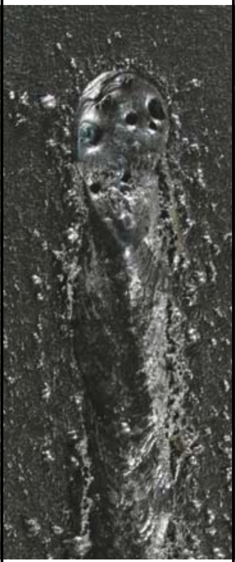
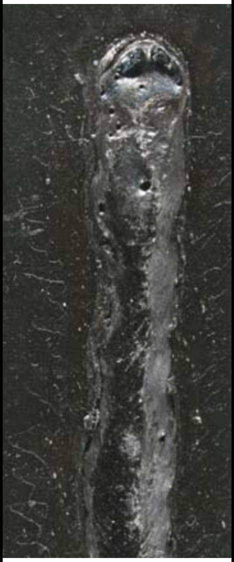
GOOD Proper Current Voltage & Speed	BAD Welding Current Too Low (High Voltage)	BAD Welding Current Too High (Low Voltage)	BAD Welding Speed Too Fast	BAD Welding Speed Too Slow	BAD Insufficient Shielding Gas Coverage
					
Cross-section Fillet	Cross-section Fillet	Cross-section Fillet	Cross-section Fillet	Cross-section Fillet	Cross-section Fillet
					
Cross-section Weld Bead	Cross-section Weld Bead	Cross-section Weld Bead	Cross-section Weld Bead	Cross-section Weld Bead	Cross-section Weld Bead
					
Face Weld Bead	Face Weld Bead	Face Weld Bead	Face Weld Bead	Face Weld Bead	Face Weld Bead
A smooth, regular, well formed bead. No undercutting, overlapping or piling up. Uniform in cross section. Excellent weld at minimal material and labor cost.	Excessive spatter and porosity. Weld bead excessively wide and flat. Undercutting along edges weakens joint. Irregular bead contour.	Weld bead excessively convex and narrow. Difficult slag removal. Wasted filler metal and productive time.	Bead too small, with contour irregular. Not enough weld metal in cross section. Poor mechanical properties. Undercut at toe lines of fillet	Excessive bead width. Overlapping without penetration at edges. Fillet with unequal legs. Wasted filler metal and productive time.	Excessive spatter and porosity Bead very irregular with poor penetration. Weld metal not properly shielded. Wasted electrode and productive time.

Illustration 9-12 – Examples of Good and Bad Welds – Flux Cored without External Shielding Gas

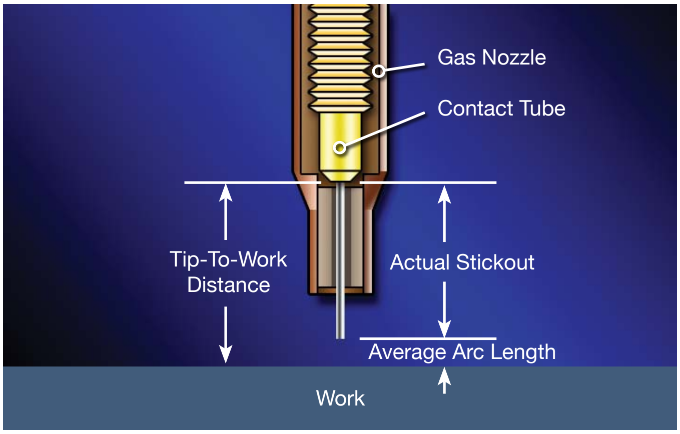


Illustration 9-13 – Electrode Extension

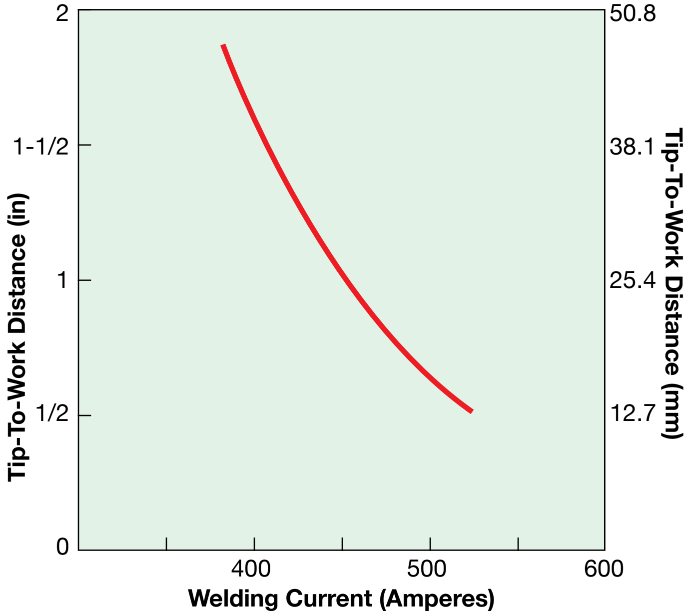


Illustration 9-14 – Effect of Electrode Extension on the Welding Current

SECONDARY VARIABLES

Electrode Extension

The electrode extension is the distance between the tip of the contact tube and the tip of the electrode as shown in Illustration 9-13.

The length of electrode that extends beyond the contact tube is resistance heated in proportion to its length. The amount of resistance heating that occurs affects the electrode deposition rate and the amount of penetration, as well as weld quality and arc stability, by varying the welding current. Increasing the electrode extension reduces the welding current as shown in Illustration 9-14.

In semiautomatic welding, the electrode extension can be varied by the welder to compensate for joint variation without interrupting the welding operation. Electrode extension provides a good control during welding to change the amount of penetration obtained.

In flux cored arc welding, the electrode extension is a variable that must be held in balance with the shielding conditions and the related welding variables. As the electrode extension is increased, the amount of preheating of the wire is increased. For gas-shielded flux cored electrodes, an electrode extension ranging from 3/4 to 1-1/2 in. (19-38 mm) is normally recommended.

Because the shielding comes from the core of self-shielded electrodes alone, a longer electrode extension is generally recommended to take advantage of the extra preheating effect which is needed to activate the shielding components in the electrode core. Welding guns for self-shielded electrodes often have nozzles where the contact tube is set inside far enough to ensure a minimum electrode extension. Electrode extensions ranging from 3/4 to 3-1/2 in. (19-89 mm) are commonly used. This will vary depending on the type of electrode wire so the manufacturer's data should be consulted for each electrode. An electrode extension that is too long will produce an unstable arc and cause excessive spatter. An extension that is too short will cause an excessive arc length at a particular voltage setting. With gas-shielded electrodes, excessive spatter may result which can build up in the nozzle and restrict the shielding gas flow. Poor shielding gas coverage can result in porosity and surface oxidation of the weld bead.

The amount of electrode extension also has an effect on the deposition rate. Increasing the electrode extension will increase the preheating effect on the electrode and, therefore, increase the deposition rate. Illustration 9-15 shows this for a gas-shielded flux cored electrode.

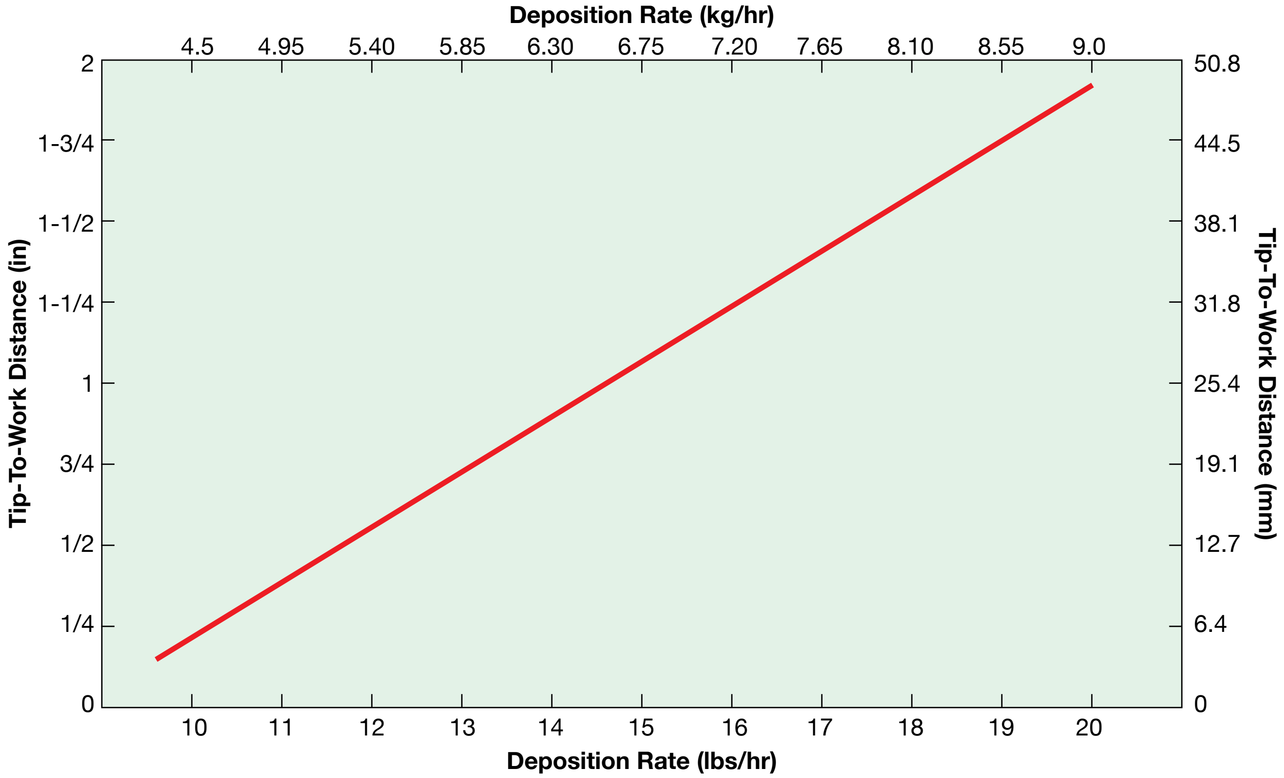


Illustration 9-15 – Effect of Electrode Extension on Deposition Rate

Electrode Angle

The angle at which the welding electrode is held with respect to the weld joint is called the electrode angle. These angles have an effect on the shape of the weld bead and the amount of penetration. The electrode angles are called the travel and work angles and are shown in Illustration 9-16.

The travel angle is the angle between the joint and electrode in the longitudinal plane. A push angle exists when the electrode points in the direction of travel. A drag angle exists when the electrode points in the direction opposite of travel. The work angle is the angle between the electrode and the plane perpendicular to travel.

The angle at which the electrode is held during welding determines the direction in which the arc force acts on the weld pool. The electrode angles are used to shape the weld bead and to prevent the slag from running ahead of the weld pool and becoming trapped in the weld. When making flat position fillet and groove welds, gravity tends to make the molten slag run ahead of the weld pool. To compensate for this, a drag angle is used which forces the slag back. The proper travel angle depends on the method of flux cored arc welding being used, the thickness of the base metal, and the position of welding. Using gas-shielded electrodes, maximum weld penetration is obtained with a 10° drag angle. Drag angles ranging from about 2° to 15° are normally recommended, but a drag angle greater than 25° should not be used. Drag angles greater than this do not provide good control of penetration. As the drag angle is decreased, the bead height decreases and the width increases. This effect continues into the push angle up to a point where the bead will start to narrow down again. Push angles are generally not recommended because of the greater chances of slag entrapment occurring. For self-shielded electrodes, the drag angles used are similar to those used in shielded metal arc welding. Flat and horizontal position welding is done using drag angles ranging from 20° to 45°. Larger angles may be used for thin sections. As the thickness of the metal increases, smaller angles are used to increase the penetration. For vertical position, uphill welding, a push angle of 5° to 10° is recommended.

When making fillet welds in the horizontal position, the weld metal tends to flow in both the horizontal and vertical directions. To compensate for the vertical flow, a work angle of 40° to 50° from the upper plate is used.

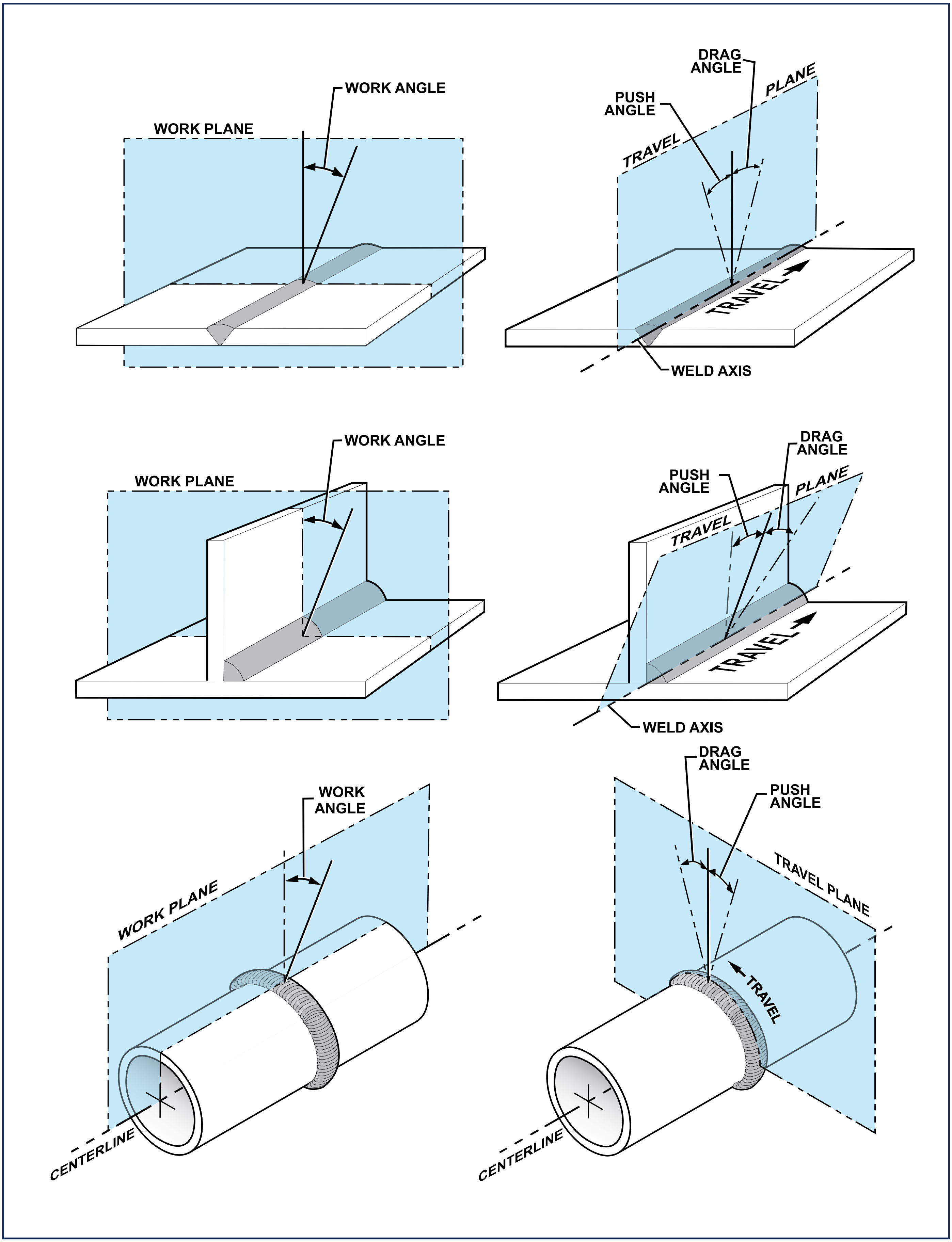


Illustration 9-16 – Travel Angle and Work Angle

CHAPTER 10
WELDING PROCEDURE SCHEDULES

The welding procedure schedules in this chapter give typical welding conditions which can be used to obtain high quality welds under normal welding conditions. Flux cored arc welding uses a wide variety of operating conditions for welding mainly steels, some stainless steels and some nickels. The procedure schedules presented in this chapter are in no way a complete guide to the procedures that can be used for flux cored arc welding and are not the only conditions which may be used to obtain a specific weld. Other conditions could be used because of factors such as weld appearance, welder skill, method of application, and the specific application which may require variations from the schedules. For example, automatic flux cored arc welding normally requires higher amperage settings and faster travel speeds than semiautomatic welding. The type of electrode wire has a significant effect on the conditions. This is because the type of electrode wire indicates whether a shielding is required, the recommended electrical polarity, the recommended amount of electrode extension, and other factors. As the particular requirements of the application become known, the settings may be adjusted to obtain the optimum welding conditions. Qualifying tests or finals should be made under the actual conditions before applying the information in the tables to actual production welding.

When changing or adjusting the variables for welding, the effect of the variables on each other must be considered. One variable cannot usually be drastically changed without adjusting or changing the other variables, in order to obtain a stable arc and good overall welding conditions.

The following schedules are based on welding plain carbon steels using various types of electrodes wires in appropriate positions. Generally, electrode wires over 1/16" (1.6 mm) diameter are limited to the flat and horizontal positions. The welding schedules include the semiautomatic and automatic methods of application, using self-shielded and CO_2 shielded electrode wires. The tables use the base metal thickness or fillet size, number of weld passes, electrode diameter, welding current, welding voltage, wire feed speed, gas flow rate (if used) and travel speed as variables. Each table contains the type of shielding gas (if used), type of joint and the position of welding being used. All of the schedules are based on using direct current electrode positive. Both the welding current and wire feed speed values are given because, even through the welding current is set by the wire feed speed, it is sometimes more convenient to directly establish the welding current without exactly knowing the wire feed speed. Illustrations 10-1 and 10-2 show wire feed speeds and their corresponding welding currents for several sizes of tubular electrode wire. Many of the charts include welding conditions for both groove and fillet welds given on the same chart. Generally, fillet welds will use the higher current levels for the ranges given and groove welds will use the lower end of the current range.

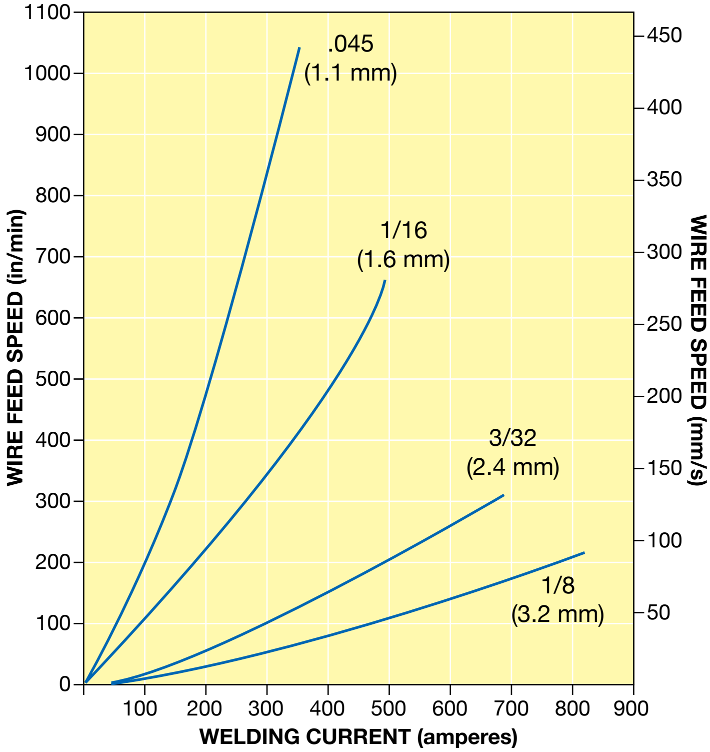


Illustration 10-1 – Wire Feed Speed Versus Welding Current for Externally Shielded Tubular Wires

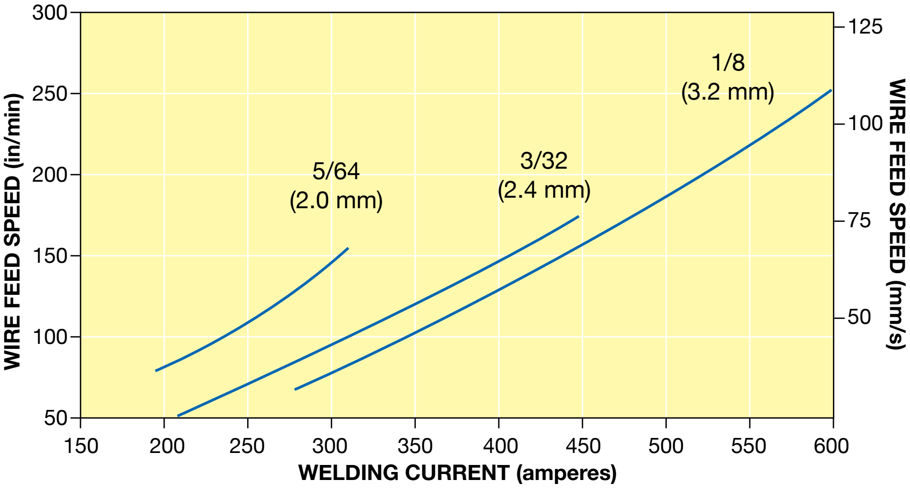
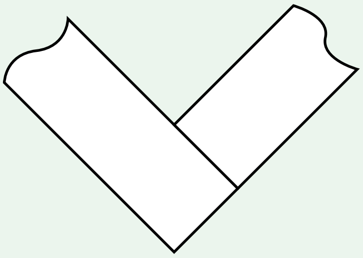


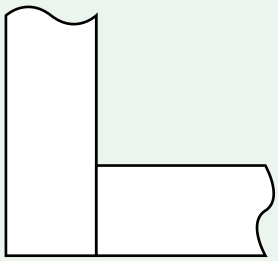
Illustration 10-2 – Wire Feed Speed Versus Welding Current for Self-Shielded Tubular Wires



1) For fillet welds only.
2) Shielding gas is carbon dioxide.
3) Flat position only.
4) Semiautomatic welding.

Thickness of Base Metal in. (mm)	Number of Passes	Electrode Diameter in. (mm)	Welding Voltage	Welding Current	Wire Feed Speed in./min. (mm/s)	Gas Flow Rate Ft^3/hr. (l/min)	Travel Speed in./min. (mm/s)
1/8 (3.2)	1	3/32 (2.4)	24-26	300	100 (42)	35-45 (17-21)	44 (19)
3/16 (4.8)	1	3/32 (2.4)	24-26	350	120 (51)	35-45 (17-21)	42 (18)
	1	1/8 (3.2)	24-26	450	90 (38)	35-45 (17-21)	47 (20)
1/4 (6.4)	1	3/32 (2.4)	24-26	400	155 (66)	35-45 (17-21)	24 (10)
	1	1/8 (3.2)	25-27	500	105 (44)	35-45 (17-21)	30 (13)
5/16 (7.9)	1	3/32 (2.4)	28-30	500	205 (87)	35-45 (17-21)	22 (9)
	1	1/8 (3.2)	28-30	500	105 (44)	35-45 (17-21)	22 (9)
3/8 (9.5)	1	3/32 (2.4)	28-30	500	205 (87)	35-45 (17-21)	15 (6)
	1	1/8 (3.2)	29-31	575	130 (55)	35-45 (17-21)	20 (8)
1/2 (12.7)	1	3/32 (2.4)	29-31	525	220 (93)	35-45 (17-21)	11 (5)
	1	1/8 (3.2)	30-32	625	150 (63)	35-45 (17-21)	14 (6)
5/8 (15.9)	3	3/32 (2.4)	29-31	475	190 (80)	35-45 (17-21)	12 (5)
	3	1/8 (3.2)	28-30	500	105 (44)	35-45 (17-21)	14 (6)
3/4 (19.1)	3	3/32 (2.4)	29-31	500	205 (87)	35-45 (17-21)	13 (5)
	3	1/8 (3.2)	29-31	500	105 (44)	35-45 (17-21)	13 (5)

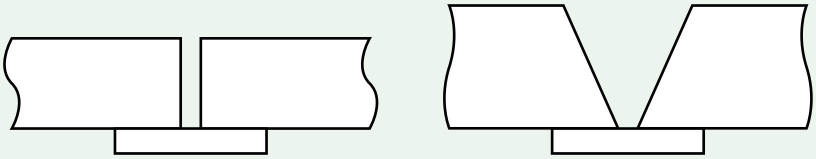
Illustration 10-3 – Flux Cored Arc Welding of Plain Carbon and Low Alloy Steels Using External Shielding Gas



1) For fillet welds only.
2) Shielding gas is carbon dioxide.
3) Horizontal position only.
4) Semiautomatic welding.

Thickness of Base Metal in. (mm)	Number of Passes	Electrode Diameter in. (mm)	Welding Voltage	Welding Current	Wire Feed Speed in./min. (mm/s)	Gas Flow Rate Ft³/hr. (l/min)	Travel Speed in./min. (mm/s)
1/8 (3.2)	1	3/32 (2.4)	24-26	300	120 (51)	35-45 (17-21)	60 (25)
3/16 (4.8)	1	3/32 (2.4)	24-26	400	155 (66)	35-45 (17-21)	36 (15)
	1	1/8 (3.2)	24-26	425	75 (32)	35-45 (17-21)	38 (16)
1/4 (6.4)	1	3/32 (2.4)	24-26	400	155 (66)	35-45 (17-21)	24 (10)
	1	1/8 (3.2)	25-27	450	90 (38)	35-45 (17-21)	26 (11)
5/16 (7.9)	1	3/32 (2.4)	25-27	440	175 (74)	35-45 (17-21)	20 (8)
	1	1/8 (3.2)	26-28	460	93 (39)	35-45 (17-21)	20 (8)
3/8 (9.5)	1	3/32 (2.4)	26-28	475	190 (80)	35-45 (17-21)	15 (6)
	1	1/8 (3.2)	28-30	500	105 (44)	35-45 (17-21)	16 (7)
1/2 (12.7)	3	3/32 (2.4)	24-26	400	155 (66)	35-45 (17-21)	18 (8)
	3	1/8 (3.2)	25-27	450	90 (38)	35-45 (17-21)	20 (8)
5/8 (15.9)	3	3/32 (2.4)	26-28	450	180 (90)	35-45 (17-21)	14 (6)
	3	1/8 (3.2)	27-29	450	90 (38)	35-45 (17-21)	14 (6)
3/4 (19.1)	6	3/32 (2.4)	28-30	400	155 (66)	35-45 (17-21)	20 (8)
	6	1/8 (3.2)	28-30	470	96 (41)	35-45 (17-21)	22 (9)

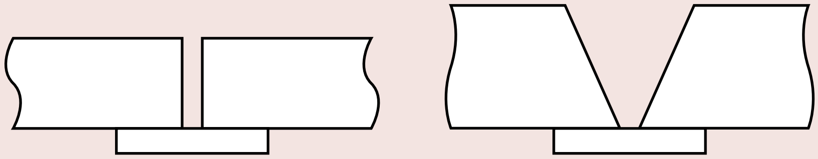
Illustration 10-4 – Flux Cored Arc Welding of Plain Carbon and Low Alloy Steels Using External Shielding Gas



1) For square groove welds up to 3/8 inch (9.5 mm) (9.5 mm) base metal thickness.
2) Shielding gas is carbon dioxide.
3) Flat position.
4) Semiautomatic welding.

Thickness of Base Metal in. (mm)	Number of Passes	Electrode Diameter in. (mm)	Welding Voltage	Welding Current	Wire Feed Speed in./min. (mm/s)	Gas Flow Rate Ft^3/hr. (l/min)	Travel Speed in./min. (mm/s)
1/8 (3.2)	1	3/32 (2.4)	24-26	325-350	120 (51)	35-45 (17-21)	56 (24)
3/16 (4.8)	1	3/32 (2.4)	24-26	350-375	130 (55)	35-45 (17-21)	48 (20)
1/4 (6.4)	1	3/32 (2.4)	25-27	375-400	137 (58)	35-45 (17-21)	41 (17)
3/8 (9.5)	2	1/8 (3.2)	26-28	450-500	107 (45)	35-45 (17-21)	24 (10)
1/2 (12.7)	2	1/8 (3.2)	28-30	475-525	120 (51)	35-45 (17-21)	14 (6)
5/8 (15.9)	2	1/8 (3.2)	30-32	575-600	155 (66)	35-45 (17-21)	14-16 (6)
3/4 (19.1)	3	1/8 (3.2)	30-32	575-600	155 (66)	35-45 (17-21)	15-20 (6-8)
7/8 (22.2)	3	1/8 (3.2)	30-32	575-600	155 (66)	35-45 (17-21)	13-18 (5-8)
1 (25.4)	4	1/8 (3.2)	31-32	575-600	155 (66)	35-45 (17-21)	12-20 (5-8)

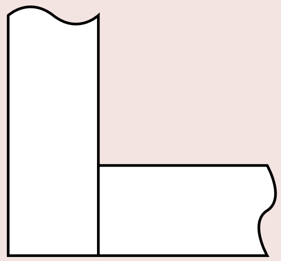
Illustration 10-5 – Flux Cored Arc Welding of Plain Carbon and Low Alloy Steels Using External Shielding Gas



1) For square groove welds up to 3/8 inch (9.5 mm) base metal thickness.
2) Shielding gas is carbon dioxide.
3) Flat position only.
4) Automatic welding.

Thickness of Base Metal in. (mm)	Number of Passes	Electrode Diameter in. (mm)	Welding Voltage	Welding Current	Wire Feed Speed in./min. (mm/s)	Gas Flow Rate Ft^3/hr. (l/min)	Travel Speed in./min. (mm/s)
1/8 (3.2)	1	3/32 (2.4)	16-18	225-250	65 (27)	35-45 (17-21)	55 (23)
3/16 (4.8)	1	3/32 (2.4)	17-19	275-300	90 (38)	35-45 (17-21)	36 (15)
1/4 (6.4)	1	3/32 (2.4)	26-28	350-375	240 (102)	35-45 (17-21)	22 (9)
		1/8 (3.2)	27-29	375-400	125 (53)	35-45 (17-21)	14 (6)
3/8 (9.5)	1	3/32 (2.4)	27-29	400-425	270 (114)	35-45 (17-21)	17 (7)
		1/8 (3.2)	29-31	500-525	185 (78)	35-45 (17-21)	14 (6)
1/2 (12.7)	1	3/32 (2.4)	27-29	425-450	290 (123)	35-45 (17-21)	14 (6)
		1/8 (3.2)	29-31	525-550	190 (80)	35-45 (17-21)	13 (5)
5/8 (15.9)	3	3/32 (2.4)	27-29	400-425	270 (114)	35-45 (17-21)	14-20 (6-8)
		1/8 (3.2)	29-31	475-500	170 (72)	35-45 (17-21)	13-18 (5-8)
3/4 (19.1)	3	3/32 (2.4)	27-29	400-425	270 (114)	35-45 (17-21)	14-20 (6-8)
		1/8 (3.2)	29-31	475-500	170 (72)	35-45 (17-21)	13-18 (5-8)

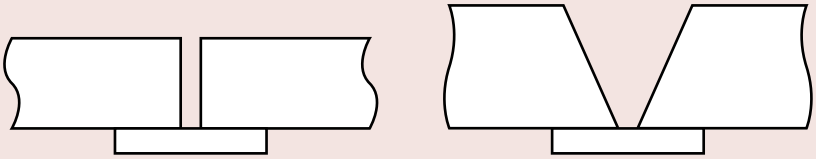
Illustration 10-6 – Flux Cored Arc Welding of Plain Carbon and Low Alloy Steels Using External Shielding Gas



1) For fillet welds only.
2) Horizontal position.
3) Semiautomatic welding.

Thickness of Base Metal in. (mm)	Number of Passes	Electrode Diameter in. (mm)	Welding Voltage	Welding Current	Wire Feed Speed in./min. (mm/s)	Travel Speed in./min. (mm/s)
1/8 (3.2)	1	3/32 (2.4)	25	200-225	80 (34)	16 (7)
3/16 (4.8)	1	3/32 (2.4)	26	250-275	95 (40)	12 (5)
1/4 (6.4)	1	3/32 (2.4)	286	375-400	130 (55)	10 (4)
3/8 (9.5)	2	1/8 (3.2)	28	400-425	95 (40)	12-14 (5-6)
1/2 (12.7)	2	1/8 (3.2)	29	425-450	107 (45)	14 (6)
5/8 (15.9)	3	1/8 (3.2)	28-30	400-425	95 (40)	12-16 (5-7)
3/4 (19.1)	3	1/8 (3.2)	28-30	425-450	107 (45)	12-16 (5-7)
7/8 (22.2)	3	1/8 (3.2)	29-31	475-500	120 (51)	12-16 (5-7)
1 (25.4)	4	1/8 (3.2)	28-31	425-450	107 (45)	12-16 (5-7)

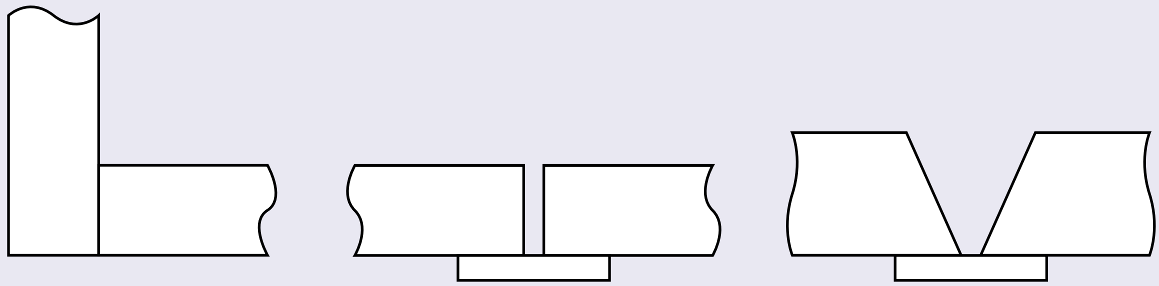
Illustration 10-7 – Flux Cored Arc Welding of Plain Carbon and Low Alloy Steels Using Self-Shielded Electrode Wires



1) For square groove welds up to 3/8 inch (9.5 mm) base metal thickness.
2) Flat position only.
3) Semiautomatic welding.

Thickness of Base Metal in. (mm)	Number of Passes	Electrode Diameter in. (mm)	Welding Voltage	Welding Current	Wire Feed Speed in./min. (mm/s)	Travel Speed in./min. (mm/s)
1/8 (3.2)	1	3/32 (2.4)	19	200-225	60 (25)	12 (5)
3/16 (4.8)	1	3/32 (2.4)	20	250-275	80 (34)	9 (4)
1/4 (6.4)	1	1/8 (3.2)	28	375-400	110 (47)	14 (6)
3/8 (9.5)	2	1/8 (3.2)	28-30	400-425	135 (57)	13-16 (5-7)
1/2 (12.7)	2	1/8 (3.2)	27-29	425-450	150 (63)	14-16 (6-7)
5/8 (15.9)	3	1/8 (3.2)	29-31	400-425	130 (55)	13-18 (5-8)
3/4 (19.1)	3	1/8 (3.2)	28-30	425-450	150 (63)	13-16 (5-7)
7/8 (22.2)	3	1/8 (3.2)	29-31	475-500	170 (72)	13-18 (5-8)
1 (25.4)	4	1/8 (3.2)	28-31	425-450	150 (63)	13-16 (5-7)

Illustration 10-8 – Flux Cored Arc Welding of Plain Carbon and Low Alloy Steels Using Self-Shielded Electrode Wires



1) For fillet and groove welds.
2) Shielding gas is carbon dioxide.
3) All positions
4) Semiautomatic welding.
5) Reduce amperage 25-35% for vertical positions
6) For square-groove welds up to 1/4 inch (6.4 mm) base metal thickness.

Thickness of Base Metal in. (mm)	Number of Passes	Electrode Diameter in. (mm)	Welding Voltage	Welding Current	Wire Feed Speed in./min. (mm/s)	Gas Flow Rate Ft^3/hr. (l/min)	Travel Speed in./min. (mm/s)
1/8 (3.2)	1	.045 (1.1)	22-24	150	60 (25)	35-45 (17-21)	30 (13)
3/16 (4.8)	1	.045 (1.1)	22-24	200	80 (34)	35-45 (17-21)	24-30 (10-13)
1/4 (6.4)	1	.045 (1.1)	23-25	220	110 (47)	35-45 (17-21)	15-18 (6-8)
3/8 (9.5)	2	.045 (1.1)	24-25	220	135 (57)	35-45 (17-21)	8-10 (3-4)
1/2 (12.7)	2	.045 (1.1)	24-26	220	150 (63)	35-45 (17-21)	8-10 (3-4)
3/4 (19.1)	3	.045 (1.1)	24-26	220	150 (63)	35-45 (17-21)	8-10 (3-4)

Illustration 10-9 – Flux Cored Arc Welding of Plain Carbon and Low Alloy Steels Using Small Diameter Externally Shielded Electrode Wires

CHAPTER 11
PREWELD PREPARATIONS

Preweld preparations are necessary to obtain a good quality weld. Operations that may need to be done before the welding is started are items such as preparing the weld joint, maintenance of welding gun and cable assembly, fixturing the weldment, setting the variables, and, in some cases, preheating. The amount of preweld preparation depends upon the size of the weld and weldment, the type of base metal, the ease of fit-up, the quality requirements, the governing code or specifications, and the welder.

PREPARING THE WELD JOINT

There are different ways of preparing the edges of the joint for welding. The methods that are the most often used for edge preparation are oxygen fuel gas cutting, plasma arc cutting, air carbon arc gouging, shearing, machining, grinding, and chipping. When they can be used, the thermal cutting methods, oxy-fuel gas, plasma arc cutting, and air carbon arc cutting, are generally faster than the mechanical cutting methods, with the exception of shearing. Oxygen fuel gas cutting is used on carbon and low alloy steels. Plasma arc cutting is used on carbon, low alloy and stainless steels and is best for applications where high production rates are required. Air carbon arc cutting is used for preparing joints in most steels including stainless steels. This process should not be used on stainless steels for critical corrosion applications because of the carbon deposited, unless the cut surfaces are cleaned by grinding and brushing. The surfaces cut by these thermal methods sometimes have to be ground lightly to remove scale or contamination. Common types of prepared weld joints are the square, V-, U-, J-, bevel-, and combination-grooves. The more complex types of bevels require longer joint preparation times, which makes the joint preparation more expensive.

Since flux cored arc welding is used on all metal thicknesses, all of the different joint preparations are widely employed. Joints for fillet, or square-groove welds are prepared simply by squaring the edges of the members to be welded if the as-received edge is not suitable.

Next to the square edge preparation, the V-groove and single-bevel grooves are the types most easily prepared by oxygen fuel cutting, plasma arc cutting, chipping or machining. These methods leave a smooth surface if properly done. The edges of U- and J-grooves can be done by using special tips and techniques with oxy-fuel cutting or by machining. Machining produces the most uniform groove. Carbon arc cutting is used extensively for preparing U-grooves in steels and for removing part of root passes, so that the joint can be welded from both sides. Chipping is sometimes done on the back side of the weld, when full penetration is required and a thermal cutting method is not being used.

Weld backings are commonly used in flux cored arc welding to provide support for the weld metal and to control the heat input. Copper, steel, stainless steel, and backing tape are the most common types of weld backing. Copper is a widely used method of weld backing because it does not fuse to thin metals. It also provides a fast cooling rate because of the high heat conductivity of copper, which makes this the best method of controlling the heat input. Steel backing is used when welding steels. These are fusible and remain part of the weldment unless they are cut off. These are often removed by oxy-fuel, air carbon arc cutting, or grinding. Stainless steels are good backing materials for welding of stainless steels. Backing tape is popular because it can be molded to any joint configuration, such as the inside of a pipe.

CLEANING THE WORK METAL

The welds made by flux cored arc welding are susceptible to contamination during the welding process. The surface of the base metal should be free of grease, oil, paint, plating, dirt, oxides or any other foreign material. This is especially critical when welding stainless steel. Flux cored arc welding is less sensitive to contaminants than gas metal arc welding because of the scavengers and deoxidizers present in the flux core. Some flux cored electrodes that are made specially for welding over rust and scale are available. This is done to make preweld cleaning less expensive. Very dirty workpieces are usually cleaned by using solvent cleaners followed by vapor degreasing. Simple degreasing is often used for cleaning carbon and low alloy steel that have oxide free surfaces. Acid pickling is generally used for cleaning scale and rust and can be removed mechanically by grinding and abrasive blasting.

The type of cleaning operation will vary, depending on the type of metal. Carbon and low alloy steels may be cleaned chemically in a hydrochloric acid solution. Nickel alloys and stainless steels may be cleaned by pickling which removes iron, sand blast residue and other contaminants. Welding should never be done near chlorinated solvents because the arc can create phosgene gas which is toxic. Chemical cleaning can be done by pickling.

Just before welding, there are several other tasks that should be performed. One is to grind or file the edges of the joint smooth so that there are no burrs present. Burrs can cause physical pain as well as create a place to trap contaminants in a weld joint. Grinding is often used on plain carbon and low alloy steels to remove burrs and rust or mill scale from the area in and around the joint. The surfaces of the joint and surrounding area should be wire brushed. Mild steel brushes are used for cleaning plain carbon and low alloy steel. Stainless steel wire brushes are used for cleaning stainless steel. The joint surfaces and surface of the previous weld bead should also be cleaned off between passes of a multiple pass weld. Stainless steel brushes should be used on these metals to avoid contamination due to rust or carbon from the mild steel wire brushes. Welding should be done soon after cleaning, especially on metals that form surface oxides such as stainless steel. Wire brushing does not completely remove the oxide but it reduces the thickness and makes them easier to weld. Gloves should be worn while cleaning stainless steels to prevent oil or dirt, from the fingers, from getting on the joint surfaces, which can also cause contamination.

FIXTURING AND POSITIONING

Fixturing can affect the shape, size and uniformity of a weld bead. Fixtures are devices that are used to hold the parts to be welded in proper relation to each other. When fixturing is not used, it usually indicates that the resulting weld distortion can be tolerated or be corrected by straightening operations. The three major functions of fixtures are:

1) Locate and maintain parts in their position relative to the assembly.

2) Increase the welding efficiency of the weld.

3) Control distortion in the weldment.

When a welding fixture is employed, the components of a weldment can be assembled and securely held in place while the weldment is positioned and welded. The use of those devices is dependent on the specific application. These devices are more often used when large numbers of the same part are produced. When a fixture is used, the production time for the weldments can be greatly reduced. They are also good for applications where close tolerances' must be held.

Positioners are used to move the workpiece into a position so that welding can be done more conveniently, which improves the appearance and the quality of the weld bead. Positioning is sometimes needed simply to make the weld joint more accessible. The main objective of positioning is to put the joint in the flat or other more favorable position. Positioners are particularly important in flux cored arc welding because they allow the use of larger diameter flux cored electrode wires when the weld joint can be rotated into the flat or horizontal fillet. The larger diameter electrodes produce higher deposition rates, are less expensive, and generally reduce the overall welding costs. Flat position welding usually increases the quality of the weld because it makes the welding easier.

Illustration 11-1 – Induction Heating
Photo courtesy of Miller Electric Manufacturing Co.

PREHEATING

Preheating is sometimes required, but this depends on the type of metal being welded, the base metal thickness, and the amount of joint restraint. These factors were discussed in Chapter 7. The specific amount of preheat needed for a given application is often obtained from the welding procedure.

The preheat temperature of the metal should be carefully controlled. There are several methods of performing this: furnace heating, electric induction coils, and electric resistance heating blankets. On thin materials, hot air blasts or radiant lamps may be used. With these methods, temperature indicators are attached to the parts being preheated. Oxy-fuel torches are another method of preheating. This method gives more localized heating than the methods that were previously mentioned. When using oxy-fuel torches, it is important to avoid localized overheating and deposits of incomplete combustion products from collecting on the surface of the parts to be welded. There are several methods of measuring the temperature of preheat such as temperature sensitive crayons, pellets and hand-held temperature indicators. The crayons and pellets melt at a specific predetermined temperature. The hand-held temperature indicators can give meter readings, digital readings, or recorder readings of the temperature, depending on the type used.

CHAPTER 12
WELDING DISCONTINUITIES AND DEFECTS

Flux cored arc welding, like the other arc welding processes can have welding procedure problems that result in weld discontinuities or defects. Discontinuities that can occur when using flux cored arc welding are slag inclusions, porosity, wormhole porosity, undercutting, incomplete fusion, excessive melt through, wagon tracks, excessive weld spatter, arc strikes and craters. These problems with the welding technique or procedure weaken the weld and can cause cracking. A poor welding technique and improper choice of welding parameters are major causes of weld defects. Some defects are caused by the use of improper base metal, filler metal, or shielding gas. The base metal and filler metal should also be cleaned to avoid creation of a discontinuity. Other problems that can occur and reduce the quality of the weld are arc blow, loss of shielding, defective electrical contact between the contact tube and the electrode, and wire feed stoppages.

DISCONTINUITIES CAUSED BY WELDING TECHNIQUE

Slag Inclusions

Flux cored arc welding produces a slag covering over the weld. Slag inclusions occur when slag particles become trapped inside the weld. These slag inclusions produce a weaker weld and can serve as crack initiation points. These can be caused by:

Illustration 12-1
Slag Inclusion

1) Slag left on the previous weld pass
2) An erratic travel speed
3) Improper electrode angles that let the slag get ahead of the arc
4) A weaving motion that is too wide
5) A travel speed that is too slow which lets the weld puddle get ahead of the arc
6) Too low an amperage setting

This discontinuity can be prevented by:

1) Cleaning the slag off of the previous weld bead, especially along the toes of the weld
2) Using a uniform travel speed
3) Increase the drag angle to prevent the slag from getting ahead of the arc
4) Using a tighter weaving motion
5) Increasing the travel speed so that the arc is at the front of the weld puddle
6) Increase the amperage setting

Wagon Tracks

Wagon tracks are linear slag inclusions that run along the longitudinal axis of the weld. These result from allowing the slag to run ahead of the weld puddle and by slag left on the previous pass. This is especially common when slag forms in undercuts on the previous pass. This discontinuity occurs along the toe line of the previous weld bead and can be corrected by correcting the electrode travel angles, increasing the travel speed, or by doing a better slag cleaning.

Illustration 12-2
Wagon Tracks

Porosity

Porosity is a gas pocket in the weld metal that may be scattered in small clusters or along the entire length of the weld. These voids left in the weld cause it to be weakened. Porosity may be internal, on the surface of the weld bead, or both. This discontinuity is caused by one or more of the following:

1) Inadequate shielding gas flow rate for gas-shielded electrodes
2) Wind drafts that deflect the shielding gas
3) Contaminated or wet shielding gas
4) Excessive welding current
5) Excessive welding voltage
6) Excessive electrode extension
7) An excessive travel speed which causes freezing of the weld puddle before gases can escape
8) Rust, grease, oil, moisture or dirt on the surface of the base metal or electrode
9) Impurities in the base metal, such as sulfur and phosphorous in steel

Illustration 12-3 – left to right: Linear Porosity, Clustered Porosity, Uniformly Scattered Porosity

This problem can be prevented or corrected by:

1) Increasing the shielding gas flow rate
2) Setting up wind shields
3) Replacing the cylinder of shielding gas
4) Lowering the welding current (reducing the wire feed speed)
5) Decreasing the voltage
6) Decreasing the electrode extension
7) Reducing the travel speed
8) Cleaning the surface of the base metal or electrode
9) Changing to a different base metal with a different composition

Wormhole Porosity

Illustration 12-4 Wormhole Porosity

Wormhole porosity is the name given to elongated gas pockets and is usually caused by sulfur in the steel or moisture on the surface of the base metal which becomes trapped in the weld joint. Wormhole porosity can seriously reduce the strength of the weld. The best methods of preventing this are to clean the surfaces of the joint and preheat to remove moisture. If sulfur in the steel is the problem, a more weldable grade of steel should be selected.

Undercutting

Illustration 12-5 Undercutting

Undercutting is a groove melted in the base metal next to the toe or root of a weld that is not filled by the weld metal. This is particularly a problem with fillet welds. Undercutting causes a weaker joint at the toe of the weld, which may result in cracking. It is caused by one or more of the following:

1) Excessive welding current
2) Arc voltage too high
3) Excessive travel speed which does not allow enough filler metal to be added
4) Erratic feeding of the electrode wire
5) Excessive weaving speed
6) Incorrect electrode angles, especially on vertical and horizontal welds

This can be prevented by:

1) Reducing the weld current
2) Reducing the welding voltage
3) Using a travel speed slow enough so that the weld metal can completely fill all of the melted out areas of the base metal
4) Cleaning the nozzle, inside of the contact tube, or removing the jammed electrode wire
5) Pausing at each side of the weld bead when a weaving technique is used
6) Correcting the electrode angles being used

Incomplete Fusion

Illustration 12-6 – Incomplete Fusion

Incomplete fusion occurs when the weld metal is not completely fused to the base metal. This can occur between the weld metal and the base metal or between passes in a multiple pass weld. This is less of a problem with flux cored arc welding than with shielded metal arc welding and short-circuiting transfer gas metal arc welding because of the deeper penetration obtained. More care should be taken when using a weaving technique because there is more chance of creating this discontinuity. Incomplete fusion between passes in a multiple pass weld often results from welding over a previous weld bead that has excessive convexity. If an excessively convex weld bead is created, the surface should be ground off enough so that complete fusion can be made in the next pass. Causes of incomplete fusion can be:

1) Excessive travel speed which causes an excessively convex weld bead
2) Welding current too low
3) Poor joint preparation that has too large of a root face or too small a root opening
4) Letting the weld metal get ahead of the arc or letting the weld layer get too thick, which keeps the arc away from the base metal.

Incomplete fusion can be prevented by:

1) Reducing the travel speed
2) Increasing the welding current
3) Increasing the root opening and decreasing the root face
4) Using proper electrode angles or increasing the travel speed

Overlapping

Illustration 12-7 Overlapping

Overlapping is the protrusion of the weld metal over the edge or toe of the weld bead. This defect can cause an area of incomplete fusion which creates a notch and can lead to crack initiation. If overlapping is allowed to occur, grinding off the excess weld metal after welding can be done. Overlapping is produced by one or more of the following:

1) Too slow a travel speed which permits the weld puddle to get ahead of the electrode
2) Arc welding current that is too low
3) An incorrect electrode angle that allows the force of the arc to push the molten weld metal over unfused sections of the base metal.

Overlapping can be prevented or corrected by:

1) Using a higher travel speed
2) Using a higher welding current
3) Using the correct electrode angles

Melt-Through

Melt-through occurs when the arc melts through the bottom of the weld and creates holes. It is usually caused by the heat input being too high. This can also be caused by one or more of the following:

1) Excessive welding current
2) A travel speed that is too slow
3) A root opening that is too wide or a root face that is too small

This can be prevented by:

1) Reducing the welding current
2) Increasing the travel speed
3) Reducing the width of the root opening, using a slight weaving motion, or increasing the electrode extension.

Excessive Welding Spatter

Flux cored arc welding may produce a small amount of spatter but excessive weld spatter creates a poor weld appearance, wastes electrodes, causes difficult slag removal and can lead to incomplete fusion in multipass welds. Excessive spatter can also block the flow of shielding gas from the nozzle which causes porosity. The amount of spatter produced by flux cored arc welding will vary depending on the type of metal transfer, type of electrode and the type of shielding gas used. (Electrode wires that produce a large droplet size globular metal transfer will produce more spatter than those that produce a fine globular transfer. Self-shielded electrodes tend to produce higher spatter levels than gas-shielding types.) The shielding gas provides slightly better arc stability. A gas-shielded electrode that is used with carbon dioxide shielding will produce higher spatter levels than the same electrode used with argon-carbon dioxide or argon-oxygen mixtures. This is due to the coarser droplet size promoted by the carbon dioxide shielding. Excessive weld spatter may also result from operating the electrode wire outside the operating ranges of amperage, voltage and electrode extension for which the electrode was designed by the manufacturer. Methods of reducing the amount of spatter would then be to reduce the welding current, welding voltage, or electrode extension. When gas-shielded wires are being used, changing the shielding gas from carbon dioxide to an argon-carbon dioxide mixture will further reduce spatter levels. If spatter is caused, it can be removed by grinding or chipping.

Illustration 12-8
Excessive Spatter

Arc Strikes

Many codes prohibit striking the arc on the surface of the workpiece. Striking the arc on the base metal outside the weld joint can produce a hard spot on the surface of the base metal. These arc strikes might create a small notch on the surface of the metal which can act as an initiating point for cracks.

Illustration 12-9
Arc Strikes

Craters

Weld craters are depressions on the weld surface at the point where the arc was broken. These are caused by the solidification of the metal after the arc has been broken. The weld crater often cracks and can serve as an origin for linear cracking back into the weld metal or into the base metal. These craters can usually be removed by chipping or grinding and the depression can be filled in with a small deposit of filler metal. There are two common methods of preventing craters. The first is to reverse the travel of the electrode a little way back into the weld bead from the end before breaking the arc. The other method is to stop the travel long enough to fill the crater before breaking the arc.

Distortion and Warpage

Distortion and warpage are caused by the nonuniform expansion and contraction of weld and base metal during the heating and cooling process of welding. If warpage changes the required dimensions of the total weldment, the weldment may not be acceptable. Methods to reduce distortion and warpage are:

1) Deposit only the required amount of weld metal.
2) Alternate sides or sequence welds.

Illustration 12-10
Distortion

3) Preset parts to compensate for distortion.

Inadequate Joint Penetration

Inadequate joint penetration is commonly located at the root of the weld and is caused by an insufficient heat input while welding. Insufficient heat input can be caused by too low amperage, too much electrode stickout, or too fast a travel speed.

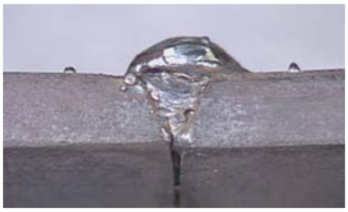


Illustration 12-11
Inadequate Joint Penetration

Inadequate joint penetration can also be caused by improper joint design or incorrect preparation of the joint edges. A tight root opening or a small groove angle restricts the weld metal causing lack of penetration at the root. To prevent this problem, insure that enough heat is being used on a properly designed joint and that the welder or operator has the skill necessary to produce the desired weld.

CRACKING

Weldment cracking can be caused by an improper welding procedure, welder technique, or materials. All types of cracking can be classified as either hot or cold cracking. These cracks are transverse or longitudinal to the weld. Transverse cracks are perpendicular to the axis of the weld where longitudinal shrinkage stresses are acting on excessively hard and brittle weld metal. Longitudinal cracks are often caused by high joint restraint and high cooling rates. Preheating will often help to reduce these problems.

Hot cracking occurs at elevated temperatures and generally happens just after the weld metal starts to solidify. This type of cracking is often caused by excessive sulfur, phosphorous and lead contents in the steel base metal. It can also be caused by an improper method of breaking the arc or in a root pass when the cross sectional area of the weld bead is small compared to the mass of the base metal.

Hot cracking often occurs in deep penetrating welds and it can continue through successive layers if it is not repaired. Hot cracking can be prevented or minimized by:

1) Preheating to reduce shrinkage stresses in the weld
2) Using clean or uncontaminated shielding gas, base metals and filler metals
3) Increasing the cross sectional area of the weld bead
4) Changing the contour of the weld bead
5) Using base metal with very low contents of those elements that tend to cause hot cracking.
6) In steel, using filler metals that are high in manganese

Crater cracks are shallow hot cracks that are caused by improperly breaking the arc. Several types are shown in Illustration 12-12.

Crater cracks may be prevented the same way that craters are, by reversing the travel of the electrode back into the weld bead a little way, gradually reducing the welding current at the end of the weld, or by stopping the travel before breaking the arc.

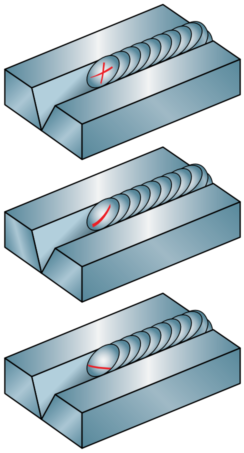


Illustration 12-12
Crater Cracks

Cold cracking occurs after the weld metal solidification is complete. Cold cracking may occur several days after welding and is generally caused by hydrogen embrittlement, excessive joint restraint, and rapid cooling. Preheating, the use of a dry, high purity shielding gas, and a proper cleaning procedure can help reduce this problem. Cold cracking is often less of a problem with flux cored arc welding than gas metal arc welding because of the higher heat input of flux cored arc welding, which provides more of a preheating effect. This helps to slightly reduce the problems with cold cracking due to excessive cooling rates.

Illustration 12-13
Longitudinal Crack

Centerline cracks are cold cracks that often occur in single pass concave fillet welds. A longitudinal crack is a centerline crack that runs down the center of the weld as shown in Illustration 12-13.

Cold cracking may be caused by one or more of the following:

1) A weld bead that is too small for the thickness of the base metal
2) Poor fit-up
3) High joint restraint
4) Extension of a crater crack

The best methods of preventing centerline cracks are:

1) Increasing the bead size
2) Decreasing the gap width
3) Preheating
4) Filling weld craters

Base metal and underbead cracks are cold cracks that form in the heat affected zone of the base metal.

Underbead cracks occur underneath the weld bead as shown in Illustration 12-14.

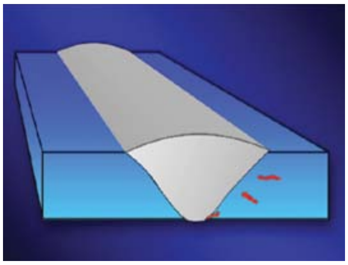


Illustration 12-14
Underbead Cracks

Base metal cracks are those cracks that originate in the heat affected zone of the weld. This type of cracking is caused by excessive joint restraint, entrapped hydrogen, and a brittle microstructure. A brittle microstructure is caused by rapid cooling or excessive heat input. Underbead and base metal cracking can be reduced or eliminated by using preheat.

OTHER PROBLEMS

Arc Blow

The electric current that flows through the electrode, workpiece, and work cable sets up magnetic fields in a circular path perpendicular to the direction of the current. When the magnetic fields around the arc are unbalanced, it tends to bend away from the greatest concentration of the magnetic field. This deflection of the arc is called arc blow. Deflection is usually in the direction of travel or opposite to it, but it sometimes occurs to the side. Arc blow can result in an irregular weld bead and incomplete fusion.

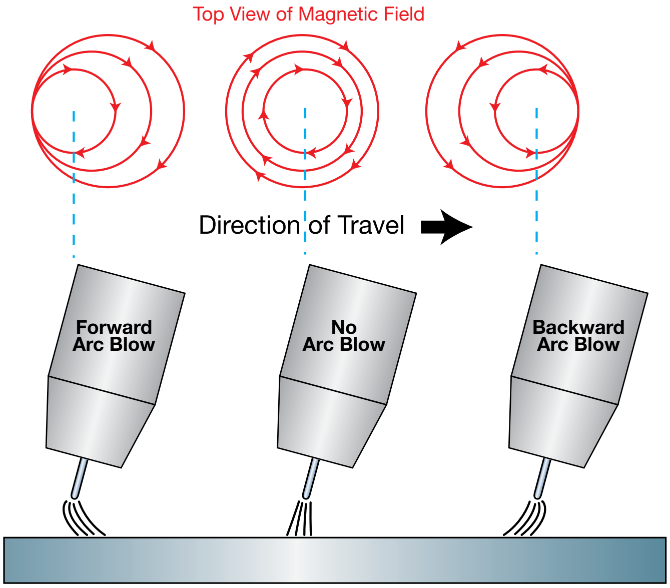


Illustration 12-15 – Arc Blow

Direct current is susceptible to arc blow, especially when welding is being done in corners and near the end of joints. Arc blow occurs with direct current because the induced magnetic field is in one direction. Arc blow is shown in Illustration 12-15.

It is often encountered when welding magnetized metal or near a magnetized fixture. This problem also occurs when welding complex structures and on massive structures with high currents and poor fit-up. Forward arc blow is encountered when welding away from the ground connection or at the beginning of a weld joint. Backward arc blow occurs toward the grounding connection, into a corner or toward the end of a weld joint. There are several methods that can be used to correct the arc blow problem:

1) Welding toward an existing weld or tack weld
2) Reducing the welding current and reducing the arc voltage
3) Placing the work connection as far as possible from the weld, at the end of the weld, or at the start of the weld, and weld toward the heavy tack weld
4) Change position of fixture or demagnetize base metal or fixture

Inadequate Shielding

Many discontinuities that occur in flux cored arc welding are caused by inadequate shielding of the arc. Inadequate shielding can cause oxidation of the weld puddle and porosity in the weld bead. This will usually appear as surface porosity. This problem can easily be detected because the arc will change color, the weld bead will be discolored and the arc will become unstable and difficult to control. The most common causes of this problem when using gas-shielded flux cored arc welding are:

Illustration 12-16
Inadequate Shielding

1) Blockage of gas flow in the torch or hoses or freezing of the regulator with carbon dioxide
2) A leak in the gas system
3) Weld spatter blocking the nozzle of the welding
4) A very high travel speed
5) Improper flow rate
6) Wind or drafts
7) Too much distance between nozzle and work

The most common causes of this problem for self-shielded electrodes are:

1) Electrode extension that is too short and doesn't allow proper activation of shielding gas core components.
2) A very high travel speed
3) Winds or drafts. Self-shielding electrodes can withstand higher winds and drafts than gas-shielded electrodes and are popular for use in field conditions where wind is a problem

In general, inadequate shielding is more of a problem with gas-shielding electrodes.

There are several ways that this problem can be corrected or prevented. The torch and hoses should be checked before welding to make sure that the shielding gas can flow freely and is not leaking. The nozzle and contact tube should be cleaned of spatter regularly. A very high travel speed may leave the weld puddle or part of it exposed to the atmosphere. This may be corrected, in some cases by inclining the gun in the direction of travel, using a nozzle that directs shielding gas back over the heated area, or by increasing the gas flow rate. The best method is to slow the travel speed. Increasing the gas flow rate will increase the expense of the welding. An improper flow rate may occasionally be a problem. For example, when using carbon dioxide shielding in the overhead position, highest gas flow rates may have to be used to provide adequate shielding. Carbon dioxide is heavier than air and will tend to fall away from the weld area. An excessive gas flow rate can cause excessive turbulence in the weld puddle. When winds or air drafts are present, there are several corrective steps that may be taken. One is to switch from a gas-shielded electrode to a self-shielded electrode. Setting up screens around the operation is another method of solving this problem. Increasing the gas flow rate is helpful when using gas-shielded electrodes, or increasing the electrode extension when using self-shielded electrodes. An excessive distance between the end of the nozzle and the molten weld puddle will also create a problem in providing adequate shielding, which can be corrected by shortening this distance.

Clogged or Dirty Contact Tube

The power delivered to the arc in flux cored arc welding depends on a transfer of current from the tip of the contact tube to the electrode by means of a sliding contact tube. A clogged, dirty or worn contact tube can cause changes in the amount of power transferred to the electrode, which can have an effect on the arc characteristics. It can also cause an irregular weld bead and possible incomplete fusion because of the power fluctuations. A clogged contact tube can stop the feed of the electrode wire, which stops the welding arc. A contact tube can become dirty or clogged by spatter from the arc, by rust, scale, drawing compounds left from the manufacture of the wire on the surface of the electrode, or by metal chips created by tight wire feed rolls. These problems can best be prevented by making sure that the electrode wire is clean and the wire feed rolls are tight enough to feed the wire without creating chips. A wire wipe, made of cloth is often attached to the wire feeder to clean the electrode wire as it is fed.

Illustration 12-16 A Worn Contact Tube

Wire Feed Stoppages

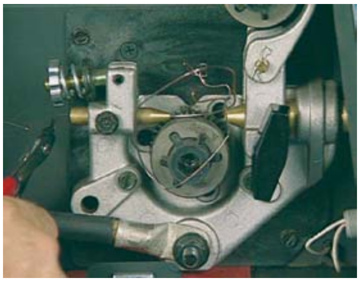


Illustration 12-17 – Wire Wrapped Around Feed Rolls

Wire feed stoppages are generally less of a problem with flux cored arc welding than with gas metal arc welding because of the larger diameter electrode wires used in flux cored arc welding. However, this can still be a problem. Wire feed stoppages cause the arc to be extinguished and can create an irregular weld bead because of the stops and starts. Wire stoppages can also cause a loss of welding time because many of the problems take a long time to correct when wire becomes wrapped around the wire feed rolls, wadded up in bird nests in the wire feeder, or broken. Wire feed stoppages can be caused by:

1) A clogged contact tube
2) A clogged circuit in the welding gun assembly
3) Sharp bends or kinks in the wire feed conduit
4) Excessive pressure on the wire feed roll which can cause breakage of the wire
5) Inadequate pressure on the wire feed rolls
6) Attempting to feed the wire over excessively long distances
7) A spool of wire clamped too tightly to the wire reel support

Wire feed stoppages, in many cases, must be corrected by taking the gun assembly apart and cutting and removing the wire, or by cutting and removing the wire from the wire feeder. These both result in time lost to locate the problem and feed the new length of wire through the assembly to the gun. Wire stoppages can be prevented by:

1) Cleaning the contact tube
2) Cleaning the conduit, which is usually done with compressed air
3) Straightening or replacing the wire feed conduit
4) Reducing the pressure on the wire feed rolls to prevent breakage
5) Increasing the pressure on the wire feed rolls to provide adequate driving force
6) Using a shorter distance from the wire feeder to the gun or from the wire feeder to the electrode wire source
7) Reducing clamping pressure on the wire spool

CHAPTER 13
POSTWELD PROCEDURES

There are several operations that may be required after welding, such as cleaning, inspection of the welds, and postheating. These are items which may or may not be part of the procedure. The operations performed will depend on the governing code or specification, type of metal, and the quality of the weld deposit.

CLEANING

Flux cored arc welding produces a moderate slag covering that must be removed after welding. Slag removal is also required between passes of a multipass weld to prevent slag inclusions and incomplete fusion.

Slag removal is generally done using a chipping hammer. A certain amount of spatter is created in flux cored arc welding, which can make slag removal slightly more difficult. If an excessive amount of spatter is created, slag removal may become very difficult. After the slag has been removed, wire brushing or buffing can be done to remove the loose slag particles and to remove discoloration around the bead. Mild steel brushes can be used on most steels but stainless steel brushes should be used on stainless steel to prevent contamination. Spatter can be removed by grinding or wire brushing. Flux cored arc welding usually produces a smooth weld surface. If a different weld profile is needed, grinding can be used, although grinding of weld profiles should be avoided, due to the expense.

INSPECTION AND TESTING

Inspection and testing of the weld is usually done after cleaning to determine the quality of the weld joint. There are many different methods of inspection and testing, which will not be covered in detail in this book. The use of these methods will often depend on the code or specification that covered the welding or by the product specifications. Testing of a weldment may be done nondestructively or destructively.

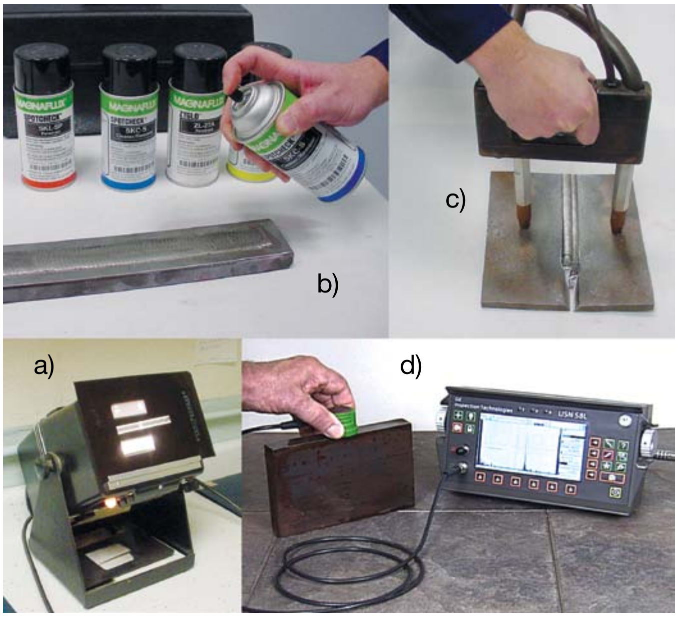


Illustration 13-2 – Nondestructive Testing Methods – a) Radiographic, b) Penetrant, c) Magnetic Particle, and d) Ultrasonic Testing

Nondestructive testing is used to locate defects in the weld and base metal. There are many different nonde-

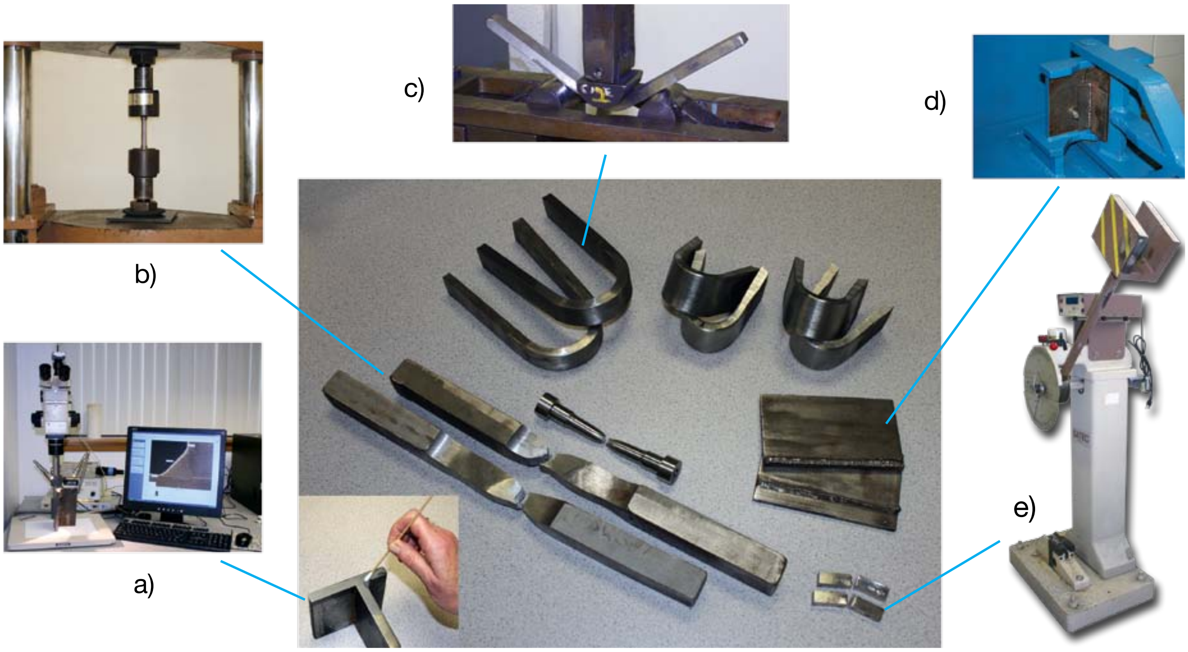


Illustration 13-1 – Destructive Testing Methods –
a) Etched Cross-Section, b) Tensile Strength, c) Guided Bend, d) Fillet Weld Break, and e) Impact Testing

structive testing methods. The most widely used nondestructive testing methods are visual, magnetic particle, liquid penetrant, ultrasonic, and radiographic. Visual, magnetic particle, and liquid penetrant inspection are used to locate surface defects, while ultrasonic, magnetic particle, and radiographic inspection are used to locate internal defects.

Destructive testing is used to determine the mechanical properties of the weld, such as the strength, ductility, and toughness. Destructive testing is also accomplished by several methods, depending on the mechanical properties being tested. Some of the most common types of destructive testing are tensile bar tests, impact tests, and bend tests.

Illustration 13-3 – Annealing

REPAIRING OF WELDS

Repairing the weld is usually needed when defects are found during inspection. When a defect is found, it can be gouged, ground, chipped, or machined out, depending on the type of material being welded. For steels, grinding and air carbon arc gouging are commonly used. When maximum corrosion resistance is required, air carbon arc gouging is used on stainless steels only when grinding or wire brushing of the groove face to remove carbon deposits is done. For stainless steels, chipping is a common method for removing defects. Air carbon arc gouging is preferred for many applications because it is usually the quickest method. Grinding is popular for removing surface defects and shallow lying defects. Once the defects have been removed, the low areas created by the grinding and gouging can be rewelded using flux cored arc welding or some other welding process. The welds are then reinspected to make sure that the defects have been properly repaired.

POSTHEATING

Postheating is the heat treatment applied to the weld or weldment after welding. Postheating is often required after the weld has been completed, but this depends upon the type of metal being welded, the specific application, and the governing code or specifications. Many of the low carbon and low alloy steels are rarely postheated. There are various types of postheating that are used to obtain specific properties. Some of the most commonly used postheats are annealing, stress relieving, normalizing, and quenching and tempering. Stress relieving is the most widely used heat treatment after welding. Postheating is accomplished by most of the same methods that are used for preheating, such as furnaces, induction coils, and electric resistance heating blankets. One method that is used for stress relieving and does not involve the reheating of the weldments is called vibratory stress relief. This method vibrates the weldment during or after welding to relieve the residual stresses during or after solidification. Annealing is a process involving heating and cooling that is usually applied to induce softening. This process is widely used on steels that become very hard and brittle because of welding. There are several different kinds and when used on ferrous metals it is called full annealing. Full annealing is the heating up of a material to cause recrystallization of the grain structure, which causes softening. This softening process is done by heating a ferrous metal to a temperature above the transformation range and slowly cooling to a temperature below this range. This process is usually done in a furnace to provide a controlled cooling rate.

Normalizing is a heat treatment that is applied only to ferrous metals. Normalizing occurs when the metal is heated to a temperature above the transformation range and is cooled in still air to a temperature below this range. The main difference between normalizing and annealing is that a normalized weldment is cooled in still air which produces a quicker cooling rate and an annealed weldment is slowly cooled in a furnace. A normalizing heat treatment will refine the metal grain size and give a tougher weld, while an annealing heat treatment will result in a softer weld.

Stress relieving is the uniform heating of a weldment to a high enough temperature, below the critical range, to relieve most of the residual stresses due to welding. This is followed by uniform cooling. This operation is performed on many steels after welding to relieve the residual stresses due to welding. This also reduces warpage during machining that may occur with a high residual stress buildup. On parts and metals that are likely to crack due to the internal stress created by welding, the parts should be put into stress relief immediately after welding, without being allowed to cool to room temperature. The terms normalizing and annealing are misnomers for this heat treatment.

Illustration 13-4 – Stress Relieving

Quenching and tempering is another postweld heat treatment that is commonly used. The metal is heated up and then quenched to form a hard and brittle metallurgical structure. The weldment is then tempered by reheating to a particular temperature, dependent on the degree of ductility, strength, toughness, and hardness desired. Tempering reduces the hardness of the part as it increases the strength, toughness and ductility of the weld.

CHAPTER 14
WELDER TRAINING AND QUALIFICATION

WELDER TRAINING

Flux cored arc welding requires a certain degree of skill to produce good quality welds. In semiautomatic welding, the welder has to manipulate the welding gun and control the speed of travel. Less skill is required to operate this process when compared to the manual welding processes because the machine controls the arc length and feeds the electrode wire. Welders skilled in manual welding processes and gas metal arc welding generally have less difficulty learning flux cored arc welding. This process uses similar equipment and welding techniques to those used in gas metal arc welding. At higher current levels, when using larger diameter wires, flux cored arc welding has a smoother arc and is easier to handle than larger diameter solid wires with a carbon dioxide shielding. Because of the deep penetrating characteristics of the process, lack of fusion and incomplete penetration are easier to avoid and compensate for, than gas metal arc welding using short-circuiting transfer.

The exact content of a training program will vary depending on the specific application of the process. A training program should have enough flexibility so that it can be adapted to changing needs and applications. Because of this, the emphasis may be placed on certain areas of training based on the complexity of the parts to be welded, type of metal, and governing code or specification. A welding course that covers all position welding would require more training time than one that simply covers flat position welding only. A welding course for pipe would require more training time than one for welding plate. The major purpose of the training program is to give the welder the skill and knowledge to be able to do the best job possible. A training program may be broken up into several areas depending on the training requirements of the student.

Basic Flux Cored Arc Welding

The basic flux cored arc welding training program is used to teach the students the basic skills necessary to weld plate. This course provides training on how to make quality fillet and groove welds. The course also gives the students the knowledge of how to set up the equipment, clean the base metal, basic operating principles and the difficulties that are commonly encountered. The training also covers the different welding techniques used for gas-shielded and self-shielded electrodes. Also covered are the techniques for welding out-of-position using small diameter electrodes. The training obtained by the student should give the skill to perform a job welding plate. This course should also provide the background skill and knowledge required to take an advanced course for a specific application such as for welding pipe. The following is an outline for a course approximately 35 hours long:

1) Flux Cored Arc Welding, Course Overview

2) Introduction to Flux Cored Arc Welding

3) Safety & Health of Welders

4) Equipment Set Up, Adjustment & Maintenance

5) Fillet Welds, T-Joints, Horizontal, Vertical & Overhead Positions (Gas & Self-Shielded)

6) Electrode Classification & Selection

7) Single-V-Groove Weld, Butt Joint, Horizontal (2G) Position (Gas & Self-Shielded)

8) Single-V-Groove Weld, 2G Destructive Test

9) Single-V-Groove Weld, Butt Joint, Vertical (3G) Position, Up (Gas & Self-Shielded)

10) Single-V-Groove Weld, Butt Joint, Overhead (4G) Position (Gas & Self-Shielded)

11) Single-V-Groove Weld, Butt Joint, Horizontal (2G) Position (Gas & Self-Shielded)

12) Single-V-Groove Weld, Butt Joint, Vertical (3G) Position, Up with Stringers (Gas & Self-Shielded)

13) Single-V-Groove Weld 3G Destructive Test

14) Single-V-Groove Weld, Butt Joint, Flat (1G) Position (Self-Shielded)

15) Fillet Weld, Lap Joint, Flat (1F) Position (Metal-Cored)

16) Single-V-Groove Weld, Butt Joint, Flat (1G) Position, (Metal-Cored) & Destructive Test

17) Single-V-Groove Weld, Butt Joint, Horizontal (2G) Position, Pipe

18) Single-V-Groove Weld, Butt Joint, Horizontal Fixed Position (5G) Pipe

WELDER QUALIFICATION

Before the welder can begin work on any job covered by a welding code or specification, the welder must become qualified under the code that applies.

Many different codes are in use today, and it is very important that the specific codes are referred to when taking qualification tests. In general, the following types of work are covered by codes: pressure vessels and piping, highway and railway bridges, public buildings, tanks and containers, cross country pipelines, ordnance material, ships and boats, and nuclear power plants. Several of the specifications include consideration of the flux cored arc welding process. These are:

1) ASME Boiler and Pressure Vessel Code, Section IX, Qualification Standard for Welding and Brazing

2) ANSI/AWWA D-100 Welded Steel Tanks for Water Storage

3) AWS D1.1, Structural Welding Code

4) ANSI/AWS B2.1, Standard for Welding Procedure and Performance Qualification

5) AWS D14.1, Specification for Welding Industrial and Mill Cranes

6) AWS D14.3, Specification for Welding Earthmoving and Construction Equipment

7) API 1104 Standard for Welding Pipelines and Related Facilities,

8) G 115, Marine Engineering Regulations

These specifications do not provide qualifications of the flux cored arc welding process for all applications and service requirements. For applications where AWS or other specifications are not available or do not apply and general criteria for qualification is desired, AWS B2.1, Standard for Welding Procedure and Performance Qualification, is often used. Qualification is obtained differently under the various codes. Qualification under one code will not necessarily qualify a welder to weld under a different code. In most cases, under the ASME BPVC Section IX, Qualification Standard for Welding and Brazing, qualififcation for one employer will not allow the welder to work for another employer. If the welder uses a different process or the welding procedure is altered drastically, requalification is required. In most cases, if the welder is continually employed, welding requalification is not required, providing the work performed meets the quality requirements.

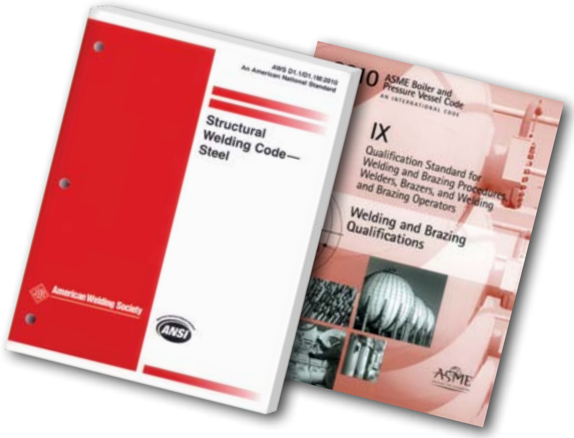


Illustration 14-3 – Typical Qualification Standards

Qualifications tests may be given by responsible manufacturers or contractors. On pressure vessel work, the welding procedure must also be qualified and this must be done before the welders are qualified. Under other codes, this is not necessary. To become qualified, the welder must make specified welds using the required process, base metal, base metal thickness, electrode type, position and joint design. For example, in the AWS Structural Welding Code (D1.1), certain joint designs are considered prequalified for flux cored arc welding. Test specimens must be made according to standardized sizes and under the observation of a qualified person. For most government specifications, a government inspector must witness the making of weld specimens. Specimens must be properly identified and prepared for testing. The most common test is a guided bend test. In some cases, radiographic examinations, fracture tests, or other tests are employed. Satisfactory completion of test specimens, providing that they meet acceptability standards, will qualify the welder for specific types of welding. The welding that will be allowed again depends on the particular code. In general, the code indicates the range of thicknesses which may be welded, the positions which may be employed, and the alloys which may be welded.

Qualification of welders is a highly technical subject and cannot be covered fully here. It is recommended that the actual code be obtained and studied prior to taking any tests.

CHAPTER 15
WELDING SAFETY

Safety is an important consideration when welding.

Material Safety Data Sheets (MSDSs)

OSHA requires that employers must have a comprehensive hazard communication program to inform employees about hazardous substances that might be used in the workplace. The purpose of the MSDSs is to explain the hazards involved in handling/using products such as welding consumables and the precautionary measures which must be put in place for safe welding. The employer must maintain continuous training concerning such materials, and safety in general. Provisions to safeguard employees are included in Material Safety Data Sheets (MSDSs) as prescribed by the Hazard Communications Standard of the U.S. Department of Labor. Information must be provided for all substances taken into the workplace except food, drugs, cosmetics or tobacco products used for personal consumption. The use of these data sheets in all manufacturing workplaces has been mandated since 1985. Employees must be trained on the information in Material Safety Data Sheets and labels.

AWS/ANSI Z49.1

A set of safety rules which should be followed is presented in the American National Standard Institute Z49.1, “Safety in Welding and Cutting”, published by the American Welding Society. There are a number of hazards associated with shielded metal arc welding. These do not necessarily result in serious injuries. They can also be of a minor nature which can cause discomforts that irritate and reduce the efficiency of the welders. These hazards are:

1) Electrical shock

2) Arc radiation

3) Air contamination

4) Compressed gases

5) Fire and explosion

6) Weld cleaning and other hazards

ELECTRICAL SHOCK

There are several precautions that should be taken to prevent an electrical shock. First, make sure that the arc welding equipment is properly installed, grounded, and in good working condition. The electrical equipment should be maintained and installed in accordance with the National Electrical Code and any state and local codes that apply. Equipment should be operated within NEMA Standards usual operating conditions for proper safety and equipment life. The case or frame of the power supply should be connected to an adequate electrical ground, such as an approved building ground, cold water pipe, or ground rod. Welding cables with frayed or cracked insulation and faulty or badly worn connections can cause electrical short circuits and shocks. An improperly insulated welding cable is both an electrical shock hazard and a fire hazard.

The welding area should be dry and free of any standing water. When it is necessary to weld in a damp or wet area, the welder should wear rubber boots and stand on a dry, insulated platform.

ARC RADIATION

Flux cored arc welding produces an intense welding arc which emits ultraviolet and infrared rays. Skin that is exposed to the arc for a short time can suffer serious ultraviolet and infrared burns which are essentially the same as sunburn, but the burn caused by welding can take place in a much shorter time and can be very painful. The welder should always wear protective clothing suitable for welding to be done. These clothes should be fairly heavy and fire resistant. Leather is often used to make jackets, capes, and bibs, or other similar arrangements to shield the shoulders, arms, and chest from radiation and spatter. Leather gloves should be worn, but the gloves are often lighter than those used for shielded metal arc welding.

The eyes must be protected from the radiation emitted by the welding arc. The welding arc should never be viewed by the naked eye at a distance closer than 30 ft. (9 m). Arc burn can result if the eyes are not protected. Arc burn of the eye is similar to sunburn of the skin and is extremely painful for about 24 to 48 hours. Usually arc burn does not permanently injure the eyes, but it can cause intense pain. There are several commercial solutions that are available to soothe the skin and eyes during the period of suffering. Infrared arc rays can cause fatigue of the retina of the eye. The effects of infrared rays are not nearly as noticeable or immediate as the effects of ultraviolet rays. Infrared rays

Illustration 15-1 – Welding Helmets
Photos courtesy of Miller Electric Manufacturing Co.

Welding Current (Amperes)	Minimum Protective Shade	Suggested[a] Shade No. (Comfort)
Under 60	7	9
60-160	10	11
160-250	10	12
250-550	10	14

a) As a rule of thumb, start with a shade that is not too dark to see the weld zone. Then go to a lighter shade which gives sufficient view of the weld zone without going below the minimum. In oxyfuel gas welding, cutting, or brazing where the torch and/or the flux produces a high yellow light, it is desirable to use a filter lens that absorbs the yellow or sodium line of the visible light spectrum.

Illustration 15-2 – Suggested Filter Glass Shades for Flux-Cored Arc Welding

Illustration 15-3 – A Well-Dressed FCAW Welder

are probably more dangerous in that their effects can be longer lasting and result in impaired vision.

The flux cored welding arc is a relatively high energy arc which is much brighter than lower current welding arcs. Even though more smoke is given off from the arc area, it does not shield arc rays effectively. Protection for the eyes and face is provided by a head shield that has a window set in it, with a filter lens in the window. Helmets with large windows are popular for welding with this process. Small and large window helmets are shown in Illustration 15-1. Head shields are generally made of fiberglass or a pressed fiber material so that they will be lightweight. The filter lens is made of a dark glass or plastic that is capable of absorbing infrared rays, ultraviolet rays and most visible light coming from the arc. The lens shade used varies for different welders, different metals, and different current levels, but it should be dark enough so that the arc can be viewed without discomfort and not so dark that the welder cannot see the arc clearly. Illustration 15-2 shows the AWS suggested lens shades. The higher the lens number, the darker the lens. A clear glass should be put on the outside of the welding lens to protect it from spatter, scratching, and breakage. Welding should never be done with a broken filter lens or with cracks in the head shield.

AIR CONTAMINATION

One of the main problems with flux cored arc welding is that it gives off more smoke and fumes than processes such as gas tungsten arc welding, gas metal arc welding, and submerged arc welding. It even tends to produce higher smoke and fume levels than shielded metal arc welding. A hazard warning for fume is placed on the electrode wire box.

The welding area should be adequately ventilated because fumes and gases such as ozone, carbon monoxide and carbon dioxide are hazardous for the welder to breathe. When welding is done in confined areas, an external air supply is required. This is furnished by the use of a respirator on a special helmet. A second person should stand just outside the confined area to lend assistance to the welder if necessary. Another method is to use an exhaust system to remove welding fumes. Special fume extractor nozzles that are attached to the welding gun are popular for use with flux cored arc welding to reduce the smoke levels produced. These nozzles are connected to a filter and an exhaust pump, which greatly reduce the smoke level.

The shielding gas may displace the air that the welder needs for breathing. Because of this, welding should not be done in an enclosed area or hole, which can cause suffocation without the use of a respirator. Welding should never be done near degreasing and cleaning operations. The fumes from chlorinated solvents used for cleaning form a very toxic gas, called phosgene, when exposed to an arc. A mechanical exhaust system should be used when welding metals with lead, cadmium, and zinc coatings. AWS/ANSI Z49.1 should be consulted for ventilation requirements.

COMPRESSED GASES

The shielding gas used for flux cored arc welding is compressed and stored in cylinders. One advantage of self-shielded flux cored wire is that compressed gas cylinders are not required, so this is primarily a safety consideration when gas-shielded electrodes are used. Improper handling of compressed gas cylinders can create a safety hazard. When in use, gas cylinders should be secured to a wall or other structural support. The valve of the cylinder should be opened slowly and the welder should stand away from the face of the regulator when doing this. The welding arc should never be struck on a compressed gas cylinder. When not in use, gas cylinders should be stored with their caps on. Caps should also be on when they are moved. If the valve would get knocked off, the cylinder acts like a missile, because of the escaping gas, and can cause injury and damage. When compressed gas cylinders are empty, the valve should be closed and they should be marked empty. This is done by marking the letters, "MT" or "EMPTY" on the cylinder.

FIRES AND EXPLOSIONS

Fires and explosions are hazards that can exist in a welding area if the proper precautions are not taken. The flux cored arc welding process can produce sparks and spatter which can start a fire or explosion in the welding area, if not kept free of flammable, volatile, or explosive materials, Heavy, fire resistant clothing, usually leather, is worn by the welder to protect him from burns. Fires can also be started by an electrical short, or by overheated, worn welding cables.

In case of a fire that is started by a flammable liquid or an electrical short, a CO_2 or dry chemical type of fire extinguisher should be used. Fire extinguishers should be kept at critical areas around the shop and the welders should make a mental note of where they are located.

Other precautions relating to explosions are also important. A welder should not weld on containers that have held combustibles unless it is absolutely certain that there are no fumes or residue left. Welding should not be done on sealed containers without providing vents and taking special precautions. When the welding gun is set down or not in use, it should never be allowed to touch a compressed gas cylinder.

WELD CLEANING AND OTHER HAZARDS

Hazards are also encountered during the weld cleaning process. Precautions must be taken to prevent the skin and eyes from hot slag particles. Flux cored are welding produces a moderate slag covering which must be removed. The welding helmet or safety glasses, gloves, and heavy clothing protect the skin from slag chipping and grinding of the weld metal. Safety glasses shall also be worn underneath the welding helmet to protect the eyes from particles that could get inside the welding helmet. Screens shall be set up if there are other people in the area, to protect them from arc burn.

SUMMARY OF SAFETY PRECAUTIONS

1) Make sure your arc welding equipment is installed properly and grounded and is in good working condition. This will help prevent fatal electric shocks.

2) Always wear protective clothing suitable for the welding to be done. This will help prevent injuries and burns.

3) Always wear proper eye protection, when welding, cutting, or grinding. Do not look at the arc without proper eye protection. This will prevent eye injuries and "arc flash."

4) Avoid breathing the air in the fume plume directly above the arc. This will prevent illness due to overexposure to hazardous materials in the fume plume.

5) Keep your work area clean and free of hazards. Make sure that no flammable, volatile, or explosive materials are in or near the work area. Good housekeeping will help prevent accidents.

6) Handle all compressed gas cylinders with extreme care. Keep caps on when not in use. Damaged cylinders can rupture with explosive violence.

7) Make sure that compressed gas cylinders are secured to the wall or to other structural supports. The impact of a fall can cause cylinder rupture or valve failure.

8) When compressed gas cylinders are empty close the valve and mark the cylinder "empty". This will prevent contamination from entering the cylinder.

9) Do not weld in a confined space without special precautions. Poor ventilation can lead to asphyxiation. Accumulation of flammable gases can explode. Always practice "confined space" safety. (See ANSI/AWS Z49.1, Section 7)

10) Do not weld on containers that have held combustibles without taking special precautions. The heat of welding can ignite residual gases and cause an explosion. The heat can cause the release of hazardous fumes. Always assure a container is clean and safe for welding.

11) Do not weld on sealed containers or compartments without providing vents and taking special precautions. The heat of welding can cause gases to expand. The increased pressure can lead to an explosion.

12) Use mechanical exhaust at the point of welding when welding lead, cadmium, chromium, manganese, brass, bronze, zinc, or galvanized steel, and when welding in a confined space. These "low allowable-limit materials" can cause serious injury. Ventilation will prevent overexposure.

13) When it is necessary to weld in a damp or wet area, wear rubber boots and stand on a dry insulated platform. This will minimize the chance of electric shocks.

14) Do not use cables with frayed, cracked, or bare spots in the insulation. This will prevent stray arcs between the bare cable and the ground. It will prevent electric shocks.

15) When the welding gun is not in use, do not hang it on a compressed gas cylinder.

REFERENCES FOR WELDING SAFETY

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2) "Occupational Safety and Health Standards" Code of Federal Regulations Title 29 - Part 1910, U.S. Dept. of Labor. Available from the Superintendent of Documents, U.S. Printing Office, Washington, DC.

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4) "Effects of Welding on Health," EWH series, American Welding Society, Miami, FL.

5) "Hazard Communication Standard," 29 CFR 1910.1200, U.S. Department of Labor, Washington, DC.

6) "Threshold Limit Values for Chemical Substances and Physical Agents and Biological Exposure Indices," American Conference of Governmental Industrial Hygienists, Cincinnati, OH.

7) "Welding Workplace Safety," by Hallock Campbell. Data Sheet No. 79A, Sept., 1986, Welding Journal.

8) "Safety Signs and Colors," standards series ANSI Z535 America National Standards Institute, New York, NY.

9) "Electric Arc Welding Power Sources", EW-1, National Electrical Manufacturers Association, Rosslyn, VA.

10) "Arc Welding Equipment," E-60974 Series, Canadian Standards Association.

11) "Safety Standards for Arc Welding Equipment," series 60974, Underwriters Laboratories, Northbrook, IL.

12) "National Electric Code", NFPA 70, National Fire Protection Association, Quincy, MA.

13) "Thoriated Tungsten Electrodes," Safety and Health Fact Sheet No. 27, American Welding Society, Miami, FL.

14) "Lens Shade Selector," F2.2. American Welding Society, Miami, FL.

15) "Transparent Welding Curtains" by Sliney, Moss, Miller & Stephens, May 1982, Welding Journal, Miami, FL.

16) "The Welding Environment," American Welding Society Miami, FL.

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18) "Characterization of Arc Welding Fume", CAWF, American Welding Society, Miami, FL.

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20) "Industrial Ventilation - A Manual of Recommended Practice", American Conference of Governmental Industrial Hygienists, Cincinnati, OH.

21) "A Sampling Strategy Guide for Evaluating Contaminants in the Welding Environment," F1.3, American Welding Society, Miami, FL.

22) "Laboratory Method for Measuring Fume Generation Rates and Total Fume Emission of Welding and Allied Processes," F1.2, American Welding Society, Miami, FL.

23) "Handling Acetylene Cylinders in Fire Situations", Safety Bulletin No. SB-4, Compressed Gas Association, York, NY.

24) Hot Work Permits (Flame or Sparks) Data Sheet 522, National Safety Council, Chicago, Illinois.

25) "Standard for Fire Prevention During Welding, Cutting and Other Hotwork," NFPA 51B, National Fire Protection Association, Quincy, MA.

26) "Safe Practices for the Preparation of Containers and Piping for Welding and Cutting." F4.1, American Welding Society, Miami, FL.

27) "Safe Hot Tapping Practices in the Petroleum and Petrochemical Industries," RP 2201, American Petroleum Institute, Washington, DC.

28) "Cylinders: Safe Storage, Handling, and Use," Safety and Health Fact Sheet No. 30. American Welding Society, Miami, FL.

29) "Arc Welding and Cutting Noise," AWN, American Welding Society, Miami, FL.

30) "Safety and Health Fact Sheets," SHF, American Welding Society, Miami, FL.

31) "Using Transparent Welding Curtains" by Dean R. Wilson, Welding Journal, September 2005, American Welding Society, Miami, FL.

32) "Methods for Sampling and Analyzing Gases from Welding and Allied Processes," F1.5, American Welding Society, Miami, FL.

33) "Guide for Estimating Welding Emissions for EPA and Ventilation Permit Reporting," F1.6, American Welding Society, Miami, FL.

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42) "Specification for Robotic Arc Welding Safety," D16.1, American Welding Society, Miami, FL.

43) "Risk Assessment Guide for Robotic Arc Welding." D16.3, American Welding Society, Miami, FL.

44) "Braze Safely" BRS, American Welding Society, Miami, FL.

45) "Brazing Handbook," BRH, American Welding Society, Miami, FL.

46) "Soldering Handbook," SHB, American Welding Society, Miami, FL.

47) "Resistance Welding Manual," RWM, American Welding Society, Miami, FL.

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51) "Recommended Practices for Electron Beam Welding," C7.1, American Welding Society, Miami, FL.

52) "Thermal Spray Manual," TSM, American Welding Society, Miami, FL.

53) "Thermal Spraying Practice, Theory and Application," TSS, American Welding Society, Miami, FL.

54) "Recommended Practices for Laser Beam Welding, Cutting, and Drilling," C7.2, American Welding Society, Miami, FL.

Web Sites

1) American Welding Society, http://www.aws.org

2) Occupational Safety and Health Administration, http://www.osha.gov

3) National Institute for Occupational Safety and Health, http://www.cdc.gov/niosh

4) National Fire Protection Association, http://www.nfpa.org

5) U.S. Government Printing Office, http://www.gpo.gov

6) American Conference of Governmental Industrial Hygienists, http://www.acgih.org

7) Canadian Standards Association, http://www.csa.ca

8) American National Standards Association, http://www.ansi.org

9) Compressed Gas Association, http://www.cganet.com

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12) National Electrical Manufacturers Association, http://www. www.nema.org

13) Global Engineering Documents, http://www.global.ihs.com

14) World Engineering Xchange, Ltd., http://pubs.aws.org

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APPENDIX
Sources for Standards
Organizations that originate or contribute to code preparation and updating

Association of American Railroads (AAH)
425 Third Street, SW
Washington, DC 20024
(202) 639-2100
http://www.aar.org

American Association of State Highway and Transportation Officials (AASHTO)
444 N Capitol Street NW, Suite 249
Washington, DC 20001
(202) 624-5800
http://www.transportation.org

American Bureau of Shipping and Affiliated Companies (ABS)
16855 Northchase Drive
Houston TX 77060 USA
(281) 877-5800
http://www.eagle.org

American Institute of Steel Construction (AISC)
One East Wacker Drive, Suite 700
Chicago, IL 60601-1802
(312) 670-2400
http://www.aisc.org

American National Standards Institute (ANSI)
1899 L Street, NW
11th Floor
Washington, DC 20036
(202) 293-8020
http://www.ansi.org

American Petroleum Institute (API)
1220 L Street, NW
Washington, DC 20005-4070
(202) 682-8000
http://www.api.org

American Society of Mechanical Engineers (ASME)
P.O. Box 2300, 22 Law Drive
Fairfield, NJ 07007-2300
(800) 843-2763 (U.S/Canada)
http://www.asme.org

American Society for Nondestructive Testing (ASNT)
P.O. Box 28518 , 1711 Arlingate Lane
Columbus, OH 43228-0518
(800) 222-2768 or (614) 274-6003
http://www.asnt.org

American Society for Testing Materials (ASTM)
P.O. Box C700, 100 Barr Harbor Drive
West Conshohocken, PA 19428-2959
(610) 832-9500
http://www.astm.org

American Welding Society (AWS)
550 NW LeJeune Road
Miami, FL 33126
(800) 443-9353
http://www.aws.org

Compressed Gas Association (CGA)
14501 George Carter Way, Suite 103
Chantilly, VA 20151
(703) 788-2700
http://www.cganet.com

Global Engineering Documents
15 Inverness Way East
Englewood, CO 80112
(800) 854-7179
http://global.ihs.com

Hobart Institute of Welding Technology (HIWT)
400 Trade Square East
Troy, OH 45373
(800) 332-9448 or (937) 332-5433
http://www.welding.org

MIL-STDS & NAVSHIP Specifications & Standards Document Automation and Production Service
700 Robbins Avenue
Bldg 4/D
Philadelphia, PA 19111
(215) 697-6257
https://assist.daps.dla.mil

National Board of Boiler & Pressure Vessel Inspectors (NBBPVI)
1055 Crupper Avenue
Columbus, OH 43229-1183
(614) 888-8320
http://www.nationalboard.org

National Certified Pipe Welding Bureau (NCPWB)
1385 Piccard Drive
Rockville, MD 20850
(301) 869-5800
http://www.mcaa.org

National Electrical Manufacturers Association (NEMA)
1300 North 17th Street, Suite 1752
Rosslyn, VA 22209
(703) 841-3200
http://www.nema.org

National Fire Protection Association (NFPA)
1 Batterymarch Park
Quincy, MA, 02169-7471
(617) 770-3000
http://www.nfpa.org