MODULE 29205-03

Plasma Arc Cutting (PAC)

Objectives

When you have completed this module, you will be able to do the following:

1. Identify and understand plasma arc cutting processes.
2. Identify plasma arc cutting equipment.
3. Prepare and set up plasma arc cutting equipment.
4. Use plasma arc cutting equipment to make various types of cuts.
5. Properly store equipment and clean the work area after use.

Prerequisites

Before you begin this module, it is recommended that you successfully complete the following: Core Curriculum; Welding Level One; Welding Level Two, Modules 29201-03 through 29204-03.

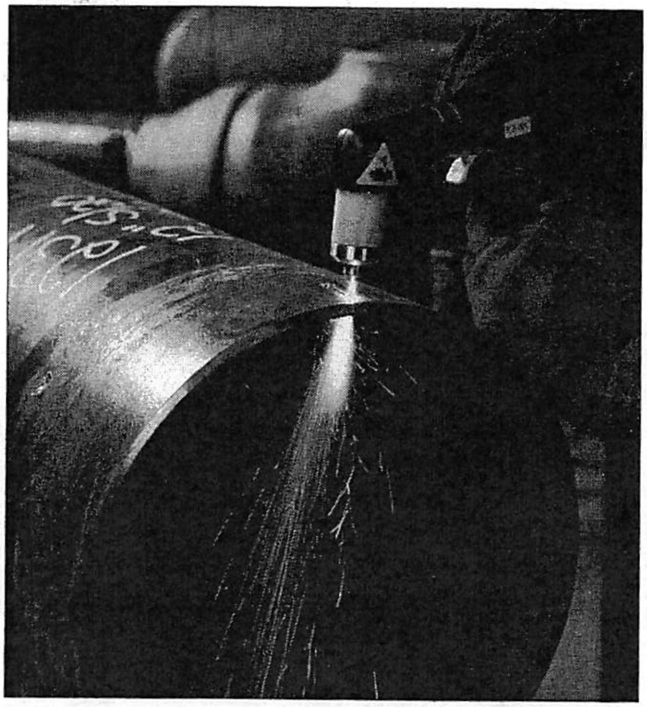
Required Trainee Materials

1. Pencil and paper
2. Appropriate personal protective equipment

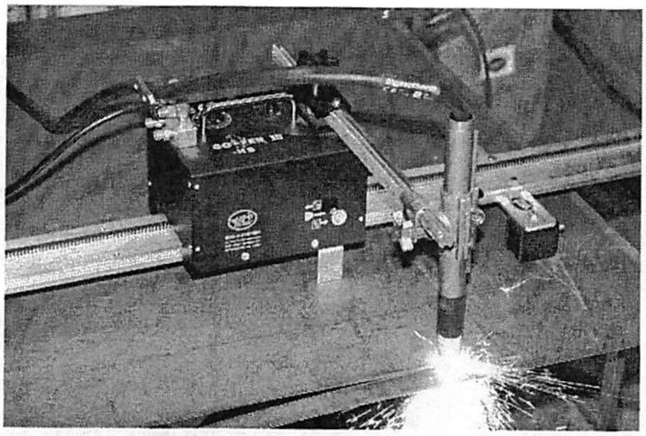
1.0.0 ◆ INTRODUCTION

Plasma arc cutting (PAC) uses a jet of **plasma** to pierce, cut, and gouge metal. The plasma is created by superheating gas in an electric arc. The temperature of the plasma jet is hot enough to melt any metal. The process can be set up for manual or mechanized operation (*Figure 1*) and in most cases is faster and more efficient than any other cutting method. PAC offers the following advantages:

- Cuts both ferrous and nonferrous metals
- Produces minimal dross
- Creates a very minimal heat-affected zone



MANUAL PLASMA ARC CUTTING



MECHANIZED PLASMA ARC CUTTING

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Figure 1 ◆ Plasma arc cutting (PAC).

- Causes very little or no distortion
- Possesses high cutting speeds
- Produces a very narrow kerf

The plasma arc cutting process requires an electrical power supply and a cutting gas, which can include compressed air. Depending on the equipment, a separate shielding or cooling gas may also be required. PAC torches convert the cutting gas into plasma by passing the gas through an electric arc inside the torch. The torch has a relatively small opening (orifice), which constricts the arc and high-pressure gas flow. This results in the plasma stream exiting the torch as a supersonic jet hotter than any flame. Depending on the current flow, the plasma cutting jet may reach temperatures of 30,000°F or higher. When the jet contacts metal, it transfers its tremendous heat, causing the metal to instantly melt. The high-velocity jet blasts the molten metal away, forming a hole, groove, or gouge.

Figure 2 shows plasma arc cutting.

1.1.0 Safety Practices

The following is a summary of safety procedures and practices that must be observed while cutting or welding. Keep in mind that this is just a summary. Complete safety coverage is provided in the Level One module, *Welding Safety*. If you have not completed that module, do so before continuing. Above all, be sure to wear appropriate protective clothing and equipment when welding or cutting.

1.1.1 Protective Clothing and Equipment

- Always use safety goggles with a full face shield or a helmet. The goggles, face shield, or helmet lens must have the proper light-reducing tint for the type of welding or cutting to be performed. Never directly or indirectly view an electric arc without using a properly tinted lens.

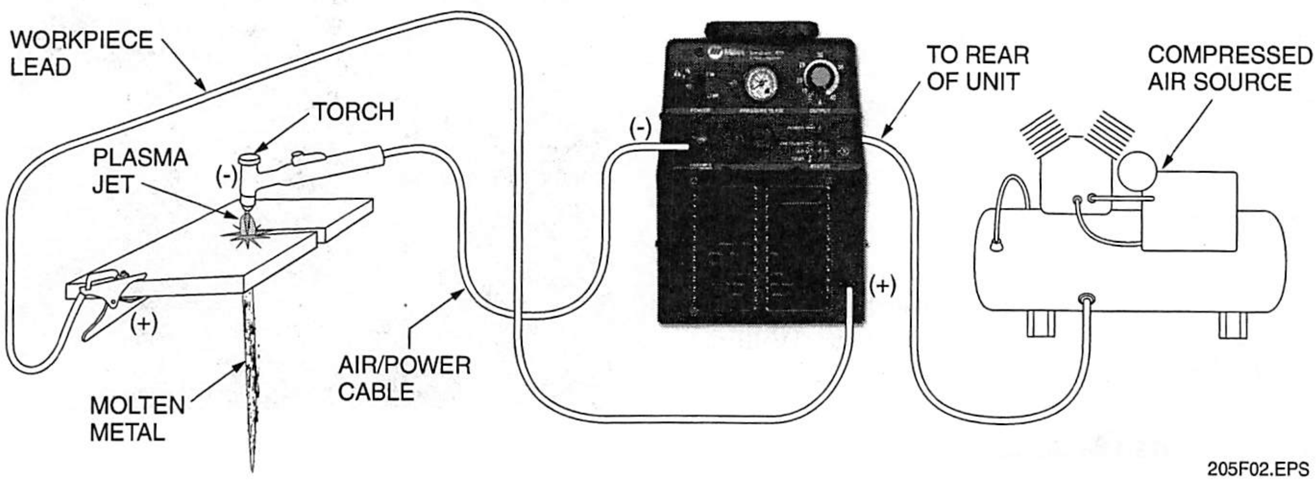

Figure 2 ◆ Typical plasma arc cutting setup diagram.

Hot Tip

PAC Safety

A plasma arc cutting process that uses air or nitrogen and is set up correctly is generally safer than oxyfuel processes. There is no chance of flashbacks and other dangers caused by flammable gases, like those found in oxyfuel processes. However, the voltages used, the extremely high temperatures of the cutting jet, and the intense ultraviolet radiation of the arc are dangerous.

In addition to the safety practices given in the following section, the practices listed below should be observed:

- Make sure that the PAC power source is turned off before disassembling a plasma torch to replace any consumable components. Open-circuit DC voltages as high as 400 volts may be present between the torch components and the workpiece to which the workpiece lead is connected.
- The extremely high temperatures of the plasma cutting jet can quickly cut through gloves and flesh, resulting in severe injuries. Never place your hands under the workpiece near the cutting jet.

- Wear proper protective leather and/or flame retardant clothing along with welding gloves that will protect you from flying sparks and molten metal, as well as heat.
- Wear 8" or taller high-top safety shoes or boots. Make sure that the tongue and lace area of the footwear will be covered by a pant leg. If the tongue and lace area is exposed or the footwear must be protected from burn marks, wear leather spats under the pants or chaps and over the front top of the footwear.
- Wear a solid material (non-mesh) hat with a bill pointing to the rear or, if much overhead cutting or welding is required, a full leather hood with a welding face plate and the correct tinted lens. If a hard hat is required, use a hard hat that allows the attachment of rear deflector material and a face shield.
- If a full leather hood is not worn, wear a face shield and snug-fitting welding goggles over safety glasses for gas welding or cutting. Either the face shield or the lenses of the welding goggles must be an approved shade five or six filter. For electric arc welding or cutting, wear safety goggles or a welding hood with the correct tinted lens (shade 8 to 14 for PAC).
- If a full leather hood is not worn, wear earplugs to protect your ear canals from sparks.

1.1.2 Fire/Explosion Prevention

- Never carry matches or gas-filled lighters in your pockets. Sparks can cause the matches to ignite or the lighter to explode causing serious injury.
- Never perform any type of heating, cutting, or welding until a hot-work permit is obtained and an approved fire watch is established. Most work-site fires caused by these types of operations are started by cutting torches.
- Never use oxygen to blow off clothing. The oxygen can remain trapped in the fabric for a time. If a spark hits the clothing during this time, the clothing can burn rapidly and violently out of control
- Make sure that any flammable material in the work area is moved or shielded by a fire-resistant covering. Approved fire extinguishers must be available before attempting any heating, welding, or cutting operations.
- Always comply with any site requirements for a hot-work permit and/or a fire watch.
- Never release a large amount of oxygen or use oxygen as compressed air. Its presence around flammable materials or sparks can cause rapid and uncontrolled combustion. Keep oxygen away from oil, grease, and other petroleum products.
- Never release a large amount of fuel gas, especially acetylene. Methane and propane tend to concentrate in and along low areas and can ignite at a considerable distance from the release point. Acetylene is lighter than air but is even more dangerous than methane. When mixed with air or oxygen, it will explode at much lower concentrations than any other fuel.
- To prevent fires, maintain a neat and clean work area and make sure that any metal scrap or slag is cold before disposal.
- Before cutting or welding containers such as tanks or barrels, check to see if they have contained any explosive, hazardous, or flammable materials, including petroleum products, citrus products, or chemicals that decompose into toxic fumes when heated. As a standard practice, always clean and then fill any tanks or barrels with water or purge them with a flow of inert gas to displace any oxygen.

1.1.3 Work Area Ventilation

- Make sure confined space procedures are followed before conducting any welding or cutting in the confined space.
- Always perform cutting or welding operations in a well-ventilated area. Cutting or welding operations involving materials, coatings, or electrodes containing cadmium, mercury, lead, zinc, chromium, and beryllium result in toxic fumes. For long-term cutting or welding of such materials, always wear an approved full face, supplied-air respirator (SAR) that uses breathing air supplied outside of the work area. For occasional, very short-term exposure, a high-efficiency particulate arresting (HEPA)-rated or metal-fume filter may be used on a standard respirator.
- Make sure confined spaces are ventilated properly for cutting or welding purposes.
- Never use oxygen in confined spaces for ventilation purposes.

2.0.0 ◆ PLASMA ARC CUTTING (PAC) PROCESS

There are two types of plasma arc cutting processes: transferred arc and nontransferred arc. The transferred arc process is the most common and is used to cut materials that are electrically conductive, such as metals. The nontransferred arc process is less common and is used to cut materials that are not electrically conductive, such as ceramics and concrete.

2.1.0 Transferred Arc Process

In the transferred arc process, the workpiece is part of the electrical circuit as in other arc processes. The arc is established between the electrode and the work via an arc transfer process. A number of different arc initiation methods are used for the transfer process. These include contact starting, discharge starting to the workpiece, and discharge starting using a pilot arc. Of these methods, discharge starting using a pilot arc is the most common. In this method, a low-voltage and low-current, high-frequency (HF) arc is established between the electrode and the torch nozzle inside the torch. This small arc between the torch electrode and torch nozzle is called a *pilot arc*. The pilot arc is used to ionize the air jet and results in a plasma. When the torch is near the workpiece, a higher-voltage, current-cutting arc is established (transferred) between the torch electrode and the work via the plasma. The higher-voltage and current-cutting arc maintains the plasma jet and the low-current, high-frequency pilot arc is shut off. For the transferred arc process to work, one lead of the power supply (the positive lead) must be connected to the metal to be cut. *Figure 3* shows the transferred arc process.

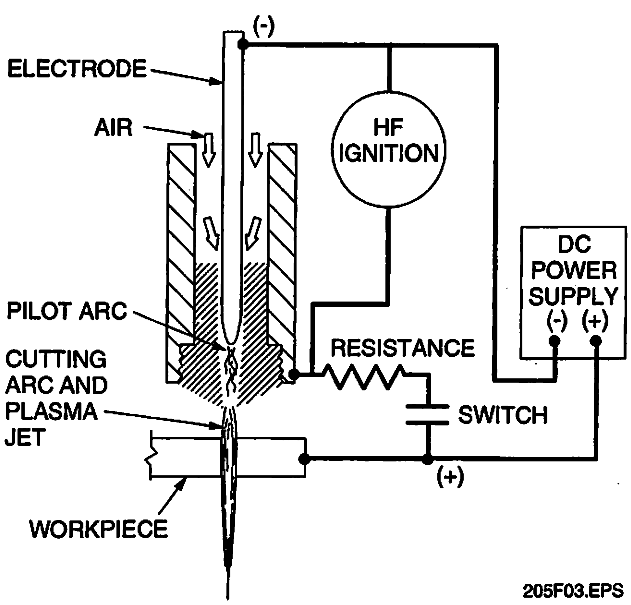

Figure 3 ◆ Schematic of transferred arc process.

2.2.0 Nontransferred Arc Process

In the nontransferred arc process, the entire arc is established within the torch, between the torch electrode and the torch nozzle. The material being cut is not electrically connected to the arc circuit. The nontransferred arc process is not normally found in facilities that cut only metal.

Figure 4 shows the nontransferred arc process.

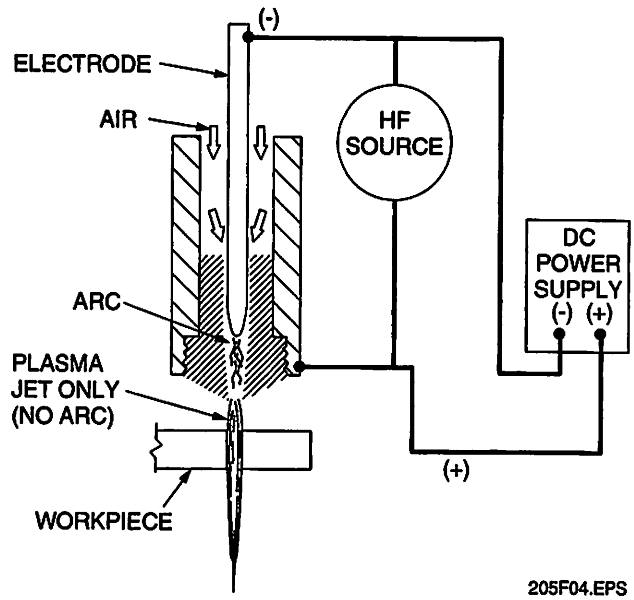

Figure 4 ◆ Schematic of nontransferred arc process.

3.0.0 ◆ PLASMA ARC CUTTING EQUIPMENT

Basic plasma arc cutting equipment includes the following items:

- Power source control unit
- Plasma arc cutting torch with torch cable
- Workpiece lead and lead assembly
- Plasma, shielding and cooling gases, and gas control components

There are many different manufacturers of PAC equipment. The following sections will provide general information common to most types. For specific information on controls, operation, and parts, refer to the manufacturer's manuals for specific equipment at your site.

3.1.0 PAC Power Source-Control Units

Plasma arc cutting is performed with DCEN current. The power sources are special units designed specifically for plasma arc cutting and are available in many sizes and configurations. The smallest and

The Hazards of PAC

Ultraviolet radiation, particle matter, and noise are hazards of PAC, but these are manageable with the proper equipment. Devices such as water tables and water mufflers use water to control such hazards in mechanized plasma applications.

Cutting Ratings

Manufacturers may rate the cutting capability of their equipment in different manners. Some may rate at the listed duty cycle and others may rate at the maximum cutting (severing) capability at a much reduced duty cycle. When selecting a power supply, make sure that you understand the manufacturer's rating system.

simplest PAC units are designed for light-duty manual cutting of sheet metal and light gauge plate. They typically plug into a single-phase 115VAC or 230VAC outlet. Typical maximum cutting amperages for these light-duty units range from 14 to 30 amperes. Their **duty cycle** is usually in the 35% range. The simplest units use filtered compressed air for plasma and cooling gas. They have a high frequency generator for easy arc starting. Some of these small air units even contain their own air compressor to supply gas for cooling and plasma generation. Commercial-grade portable units are available that can operate on various single-phase or three-phase voltages and are rated for cutting material up to 1" thick at duty cycles of 50% to 60%. At maximum current and reduced duty cycles, they are capable of severing material up to 1½" thick. These units normally require an external air or gas supply for the torch. The size of the unit needed is determined by the type and thickness of the metal to be cut.

Console controls are simple. They usually include most of the following controls and indicators:

- Power ON/OFF switch
- Power ON and/or unit-ready indicator
- Air or gas ON/OFF switch or setting (for checking and adjusting torch air or gas flow, or for purging lines)
- Output current control
- Power source trouble indicator(s)

Figure 5 shows a typical commercial-grade plasma arc cutting unit.

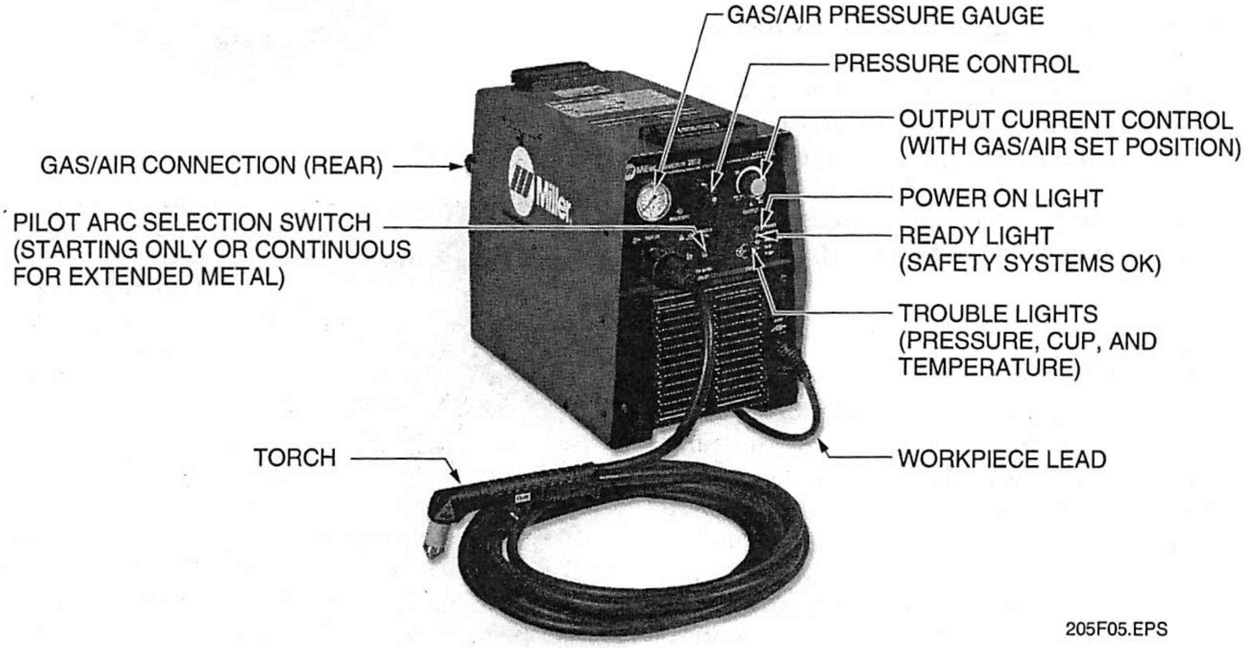

Figure 5 ◆ Typical commercial-grade plasma arc cutting unit.

Hot Tip

Control Interlocks

Interlocks may be incorporated in the controls of PAC systems. An interlock common among PAC systems monitors the air supply pressure. If the plasma torch is run without an adequate supply of air, internal arcing may damage the torch. For this reason, a gas pressure switch interlock is included in the circuit. Adequate gas pressure must be present before the torch will operate. The interlock also shuts down the torch if there is a gas supply failure during cutting. Another interlock is an overtemperature switch that shuts down the unit if the duty cycle is exceeded and the unit overheats. Some units are also equipped with a retaining cup switch that shuts down the unit if the retaining cup holding the tip, nozzle, and swirl ring in the torch is loose.

Larger industrial units are used for heavy-duty manual cutting and general-duty mechanized cutting. They usually operate on a three-phase 230/460 VAC input power and can produce DC output currents up to 750 amperes. Their duty cycle is usually 100%. They can cut stainless steel and aluminum up to 2½" thick and carbon steel up to 3" thick. Some units are water cooled, often containing their own closed-loop torch cooling system.

The larger units are often dual-flow mechanized units that operate with several types of gases. One gas is used for cutting and the other is used as a shield around the cutting area to improve the quality of the cut. Some units may use only one of the gases for the pilot arc.

Although gouging is not the primary use for plasma arc torches, some commercial and industrial units may be used for gouging when fitted with a gouging torch or a torch with gouging components. Plasma arc gouging is sometimes referred to with the nonstandard term PAG.

Controls on the larger units typically include a power ON/OFF switch, output current control and ammeter, several gas flow controls and gauges, gas selector controls, local/remote switch, and open circuit voltmeter. *Figure 6* shows a typical industrial manual plasma arc cutting unit. Note the leather cable cover accessory used to protect the torch cable from damage due to hot or molten metal.

3.2.0 PAC Torches

The most common plasma arc cutting torch uses a pilot arc and transferred arc system. In many torches, a high-frequency pilot arc is started between the electrode and the nozzle. A small amount of gas is injected into the arc chamber where it is heated to a plasma and escapes through the nozzle as a fine jet. However, the torch current circuit is designed so that the full voltage (**potential**) and current is not available in the torch between the electrode and nozzle. The base metal to be cut is connected to the control unit power source by the workpiece clamp. This gives the workpiece a higher potential difference than the nozzle. When the torch is near the workpiece, the

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Figure 6 ◆ Typical industrial manual plasma arc cutting unit.

Hot Tip

Auto Voltage Power Sources

Some newer PAC units sense the input voltage and frequency when they are connected to a power source. The units continuously and automatically reconfigure themselves to operate properly with the connected power. This eliminates improper initial power connections and provides continuous adjustment to changing input voltage so that the PAC arc current remains stable during cutting operations.

higher-current arc extends (transfers) to the workpiece because of its higher potential. The control unit automatically increases the amperage and gas flow(s) to produce the longer cutting arc and shuts off the pilot arc. *Figure 7* shows the plasma transferred arc cutting process that takes place between the torch and the workpiece.

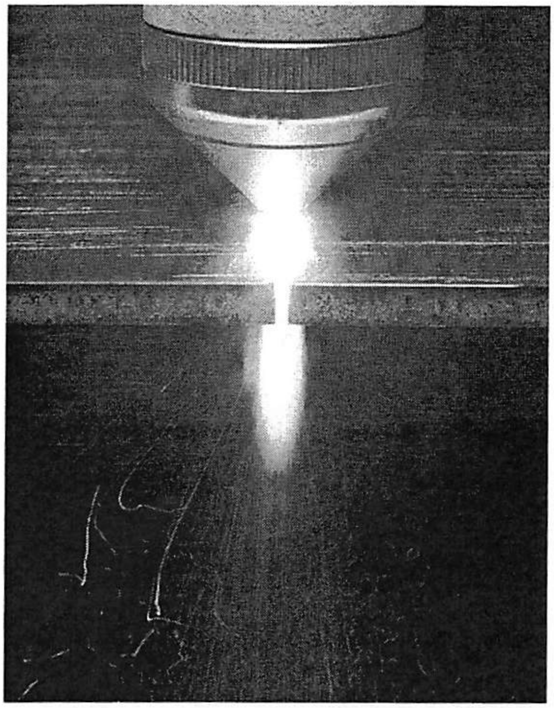

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Figure 7 ◆ A transferred plasma cutting arc.

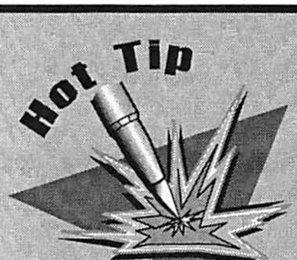
Plasma arc torches may be handheld for manual cutting or machine mounted for mechanized cutting. The heaviest duty torches are usually mechanized and water cooled. Handheld torches are usually light-duty to medium-duty and may be water cooled in the heavier duty versions. Some torches are equipped with separate passages and orifices for cooling and shielding gases. Torches have a button or lever on the torch handle to start the pilot arc. A foot pedal can also be used to start the arc. When a foot pedal is used, the switch on the control panel is set for remote operation.

The typical plasma arc cutting torch usually contains a replaceable retaining cup, copper electrode with a hafnium or thoriated tungsten insert, a gas swirl ring, and a nozzle (tip). Nozzles have various-sized holes for cutting metals of different thicknesses. The torch contains coolant passages for gas or water cooling. *Figure 8* shows a typical handheld PAC torch and its consumable components.

Mechanized PAC torches are designed to be mounted in automated carriers. Usually, they can be used in the same carriers designed for oxyfuel cutting heads. However, the oxyfuel carriers must be capable of moving at the much greater speeds of plasma arc cutting.

Some types of PAC torches (water injection torches) inject pressurized water to create a whirlpool of water around the jet, below the point where the arc narrows in the torch's arc cavity. The water swirls around the plasma jet at high velocity and compresses the jet even tighter. The narrower jet cuts with a more uniform melt rate and leaves the kerfs of stainless steel and titanium free of slag. This type of torch is normally mechanized.

As shown in *Figure 8*, several styles of shrouds, heat shields, nozzles (tips), and electrodes are usually available for a given model of PAC torch. These components vary in style and size to adapt to different metal types and thicknesses. Sometimes nozzles and parts for gouging are offered to fit some of the heavier duty torches. Electrode types and styles vary with torch manufacturers. The most common parts that are changed in a torch are the electrode and the nozzle. The electrode is changed when it becomes contaminated, and the nozzle is changed when it becomes worn (orifice washed out) or when metal of a different type or thickness is to be cut.



Contact-Start or Discharge-Start Torches

High-frequency pilot arc starting of a PAC torch can interfere with nearby electronic circuits, including computers and microprocessor controllers. To eliminate the use of a high-frequency start, some newer PAC torches use an internal contact or capacitor-discharge pilot arc starting system. One such contact-start system has a spring-loaded electrode that is in contact with the nozzle when the torch is off. When a trigger is pressed, the PAC unit senses the shorted electrode via high-current flow and opens the gas solenoid. Gas pressure then forces the electrode away from the nozzle. This action draws an arc that establishes the plasma flow. The arc instantly transfers to the workpiece because of the higher voltage difference between the electrode and the workpiece.

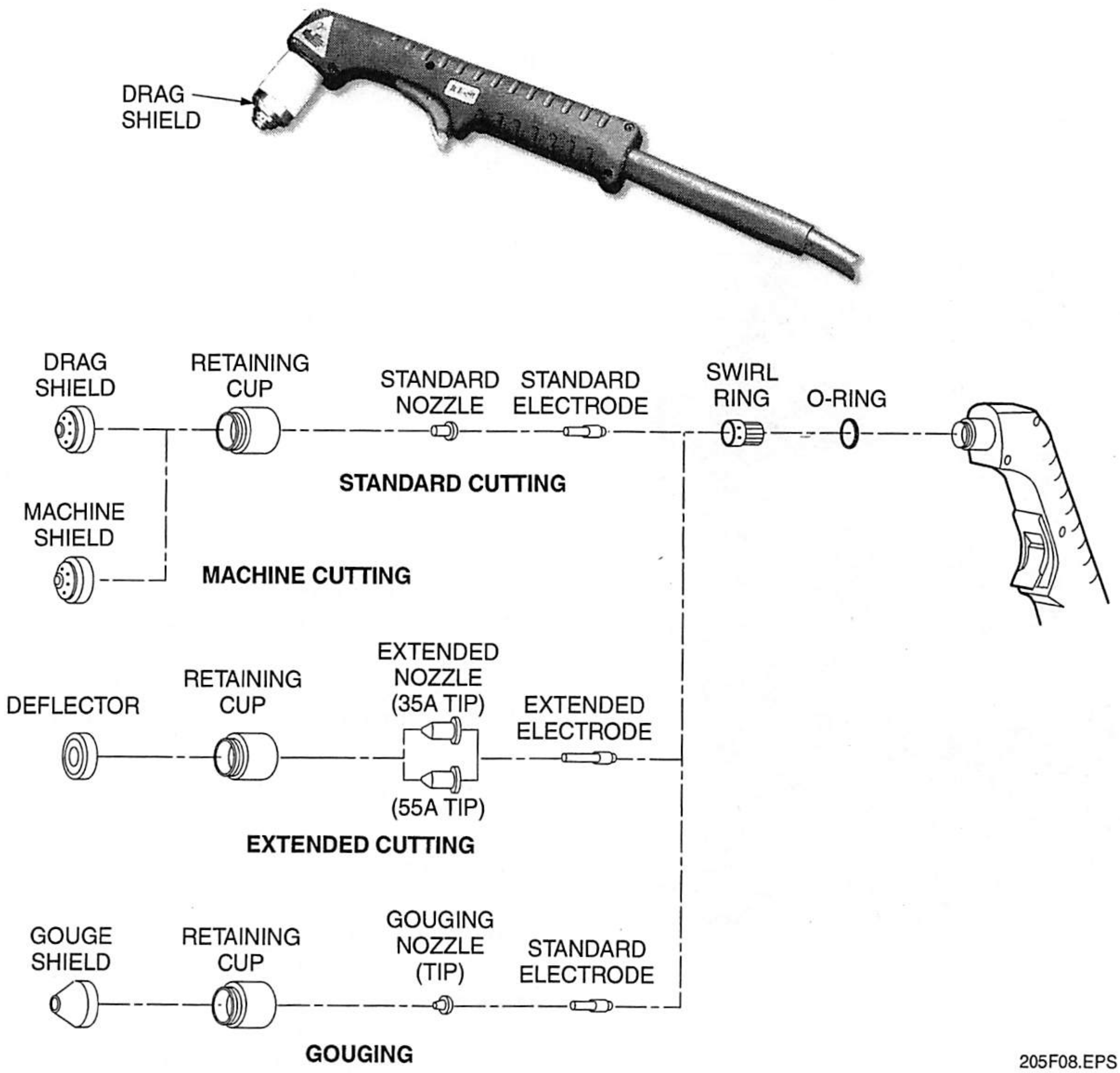
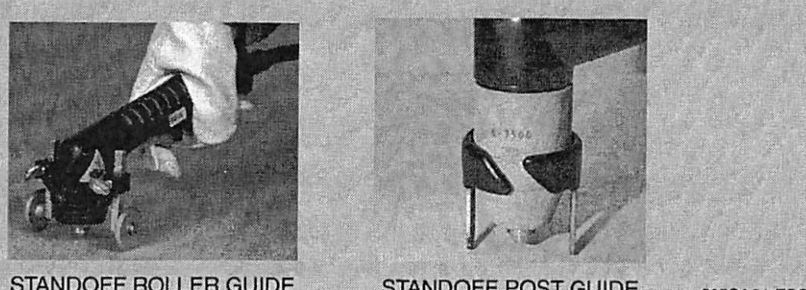


Figure 8 ◆ Typical handheld torch and consumables.

Hot Tip

Standoff Guides and Shields

When performing low-amperage cutting, it is possible to drag the torch on the workpiece using a drag shield without causing damage or sacrificing the cut. Cutting at current levels above 60 amps or extended cutting operations usually require a standoff guide, which attaches to the cup and holds the tip the required distance from the workpiece. The standoff distance (torch tip to work distance) should be kept between $\frac{1}{16}$" and $\frac{1}{4}$", depending on the thickness of the workpiece.



> **Hot Tip**
>
> *Replacing Consumables*
>
> The torch nozzle and electrode are considered consumables (components requiring frequent replacement due to deterioration), and both should be replaced at the same time. It's a good idea to keep a replacement torch nozzle and electrode handy. This will reduce downtime when cutting with the plasma unit.

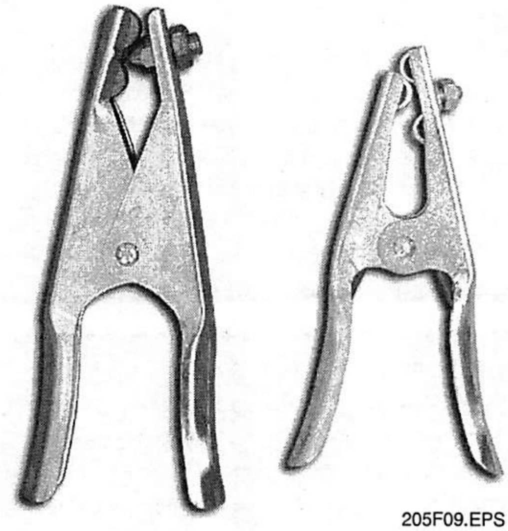


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Figure 9 ◆ Typical workpiece clamps.

3.3.0 Workpiece Clamp

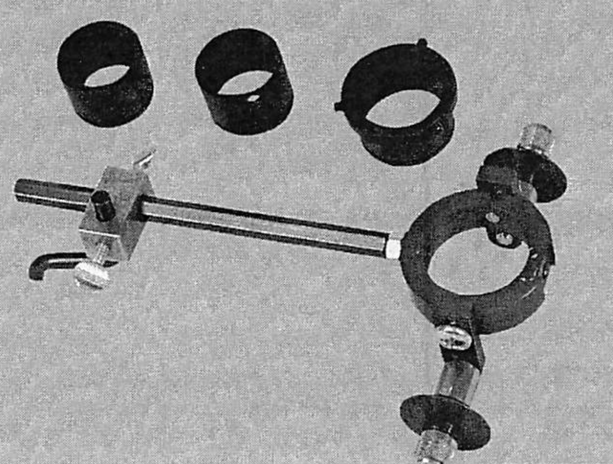
The workpiece clamp provides the connection between the end of the workpiece lead and the workpiece. Workpiece clamps are mechanically connected to the welding lead and come in a variety of shapes and sizes. The size of a workpiece clamp is the rated amperage that it can carry without overheating. If a workpiece clamp needs to be replaced, be sure to select one that is rated at least the same as the rated capacity of the power source it will be used on. *Figure 9* shows typical workpiece clamps.

3.3.1 Locating the Workpiece Lead

When PAC is to be used to cut on equipment containing electrical or electronic components, batteries, bearings, or seals, the workpiece clamp must be properly located to prevent damage to associated components. If the cutting current passes through any type of bearing, seal, valve, contacting surface, or electrical or electronic component, it could cause severe damage to the item from arcing and overheating. This will result in costly replacement. If cutting is near a battery, the battery must be removed to prevent hydrogen gas explosions caused by a cutting spark.

Carefully check the area to be cut and position the workpiece clamp so that the cutting current will not pass through any connecting surface. If in doubt, ask your supervisor for assistance before proceeding.

> **Hot Tip**
>
> *Plasma Torch Cutting Guides*
>
> Many manufacturers furnish cutting guide accessories that are usable on several models of their torches. A circle cutting guide kit that can also be used as a freehand standoff roller guide is shown here.



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> **WARNING!**
> To prevent damaging arcing across gapped or contacting surfaces, make sure the path from the workpiece clamp to the torch arc does not pass through these surfaces. Cutting current can severely damage bearings, seals, valves, or contacting surfaces. Position the workpiece clamp to prevent cutting current from passing through them.

> **WARNING!**
> Disconnect the grounded battery lead on any mobile equipment that is being repaired using the plasma arc cutting process. This prevents the cutting current from causing a battery explosion or battery damage.
>
> Do not cut near batteries. A spark could cause a battery to explode, showering the area with battery acid. Always remove the batteries. Workpiece leads must never be connected to pipes carrying flammable or corrosive materials. The cutting current could cause overheating or sparks, resulting in an explosion or fire.

> **CAUTION**
> The cutting current can destroy electronic or electrical equipment. Have an electrician check the equipment and, if necessary, isolate the system before cutting.

3.4.0 PAC Gases and Controls

All plasma arc cutting units require one or more types of gases. The specific type of gas required and the controls necessary to set and adjust these gases vary with the type, size, and manufacturer of the PAC equipment.

3.4.1 PAC Gases

Several different gases and gas mixtures are used with plasma arc cutting units. Gases used include air, nitrogen, oxygen, argon and argon mixtures, hydrogen, and carbon dioxide. The simplest units use clean, compressed air to cut carbon steel, stainless steel, and aluminum up to about 3⁄16" thick. Most heavy-duty air plasma units are rated to cut carbon steel and stainless steel up to about 1¼" thick and sever up to 1¾" thick. Some dual-flow PAC units require two different gases. One gas may be used for the pilot arc and for cutting, and another for shielding or cooling. *Table 1* provides general recommendations for plasma and shield gases.

Specific gas requirements for a particular PAC unit or system are specified in the manufacturer's operating instructions manual and/or information tag(s) on the unit. Refer to these specifications, and use only the gases specified for the type of equipment being used.

3.4.2 PAC Gas Controls

Plasma arc cutting gases are used to generate plasma, cool the torch, and shield the cut against corrosion. All gases must have their pressures

Table 1. Recommended Plasma/Shield Gas Combinations

Material	Air/Air	O_2/Air	N_2/CO_2	N_2/Air	H35/N_2
Carbon Steel	Most Economical Good Cut Quality Good Speed Good Gouging Good Weldability	Best Cut Quality Maximum Cut Speed Best Weldability	Some Dross Long Electrode Life	Not Recommended	Best Gouging Long Electrode Life Some Dross
Stainless Steel	Most Economical Good Speed Some Dross	Not Recommended	Good Cut Quality Good Gouging Minimal Dross Long Electrode Life	Long Electrode Life Lowest Shield Gas Cost	Best Cut Quality Best Gouging Minimal Dross Long Electrode Life Cuts Thicker Material
Aluminum	Most Economical Good Speed Some Dross	Not Recommended	Good Cut Quality Good Gouging Minimal Dross Long Electrode Life	Not Recommended	Best Cut Quality Best Gouging Minimal Dross Long Electrode Life Cuts Thicker Material

O_2 = Oxygen N_2 = Nitrogen CO_2 = Carbon Dioxide H35 = Mixture of 35% Hydrogen and 65% Oxygen

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reduced before they can be used. The type of regulator used to control the gas pressure depends on the type of PAC equipment being used and the base metal being cut.

When a shop compressed air supply is being used, a heavy-duty air filter/dryer is required to eliminate oil and moisture from the pressurized air. The high-pressure shop air must be reduced externally, or by the PAC internally, for the required working pressure. Also, depending on the equipment being used, the shop air must be provided at a flow rate, generally measured in cubic feet per hour (cfh), that is sufficient for the cutting or gouging operation.

Gases other than compressed air are normally supplied in high-pressure cylinders at 1,500 psi to 2,000 psi. The high cylinder pressures are reduced by pressure regulators to a lower working pressure. A gas hose connected to the working pressure outlet of the regulator delivers the gas to the PAC console. Most heavy-duty systems will require two high-pressure cylinders (and two pressure regulators), one containing the cutting gas and the other a shielding or cooling gas. Some systems use a combination of compressed shop air and high-pressure cylinders. *Figure 10* shows an industrial dual-flow PAC with two internal gas pressure regulators.

Stop-start flow control to the torch is usually controlled by a solenoid valve that electrically opens and closes a gas valve. Solenoid valves are usually mounted inside the unit and are controlled by a pushbutton on the torch. There is one solenoid for each gas source.

Many smaller plasma arc cutting units come equipped with a built-in air compressor. These light-duty machines are portable and run on 110V power, which makes them ideal for use at remote job sites. *Figure 11* shows a portable plasma arc cutter.

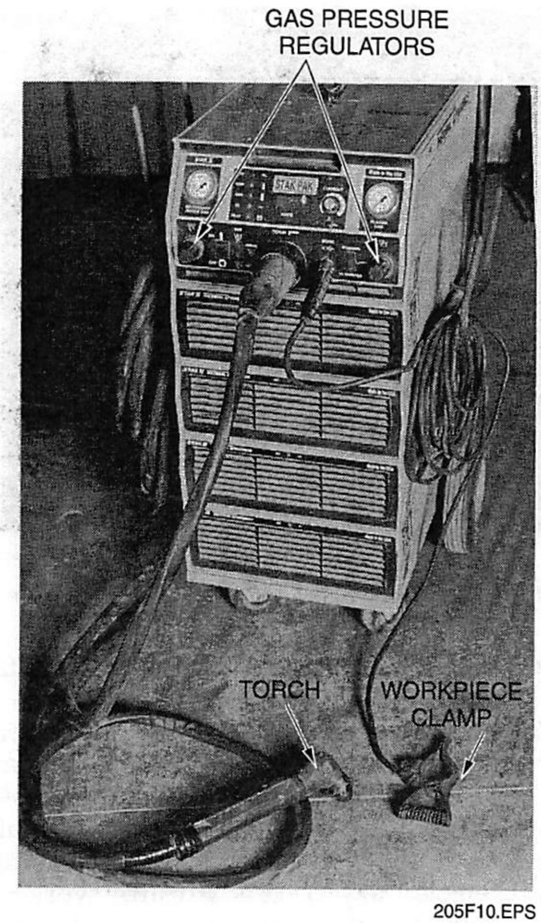
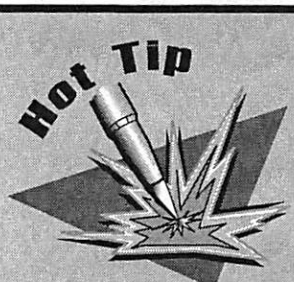


Figure 10 ◆ Industrial dual-flow PAC unit.

4.0.0 ◆ PREPARING THE WORK AREA FOR PAC

The plasma arc cutting control unit and work must be located close enough to each other for the torch cable to comfortably reach the workpiece. If possible, the workpiece should be located at a comfortable height and position for the torch



Minimum Shop Airflow Rate

Always check to be sure that the shop air supply will provide the minimum flow rate required for the PAC equipment being used. If the airflow rate is too low, it will cause poor cuts and overheating of the torch. Refer to the manufacturer's specifications for the required flow rate for the equipment being used.

Dry Air

To conserve consumables, make sure to have air driers in your compressed air system. Moisture in the compressed air can also damage the equipment.

Inert Gas

Originally, the PAC process was developed to cut nonferrous metals using inert gases. Advances in technology led to using air and/or oxygen as the plasma gas so steel could be cut using PAC.

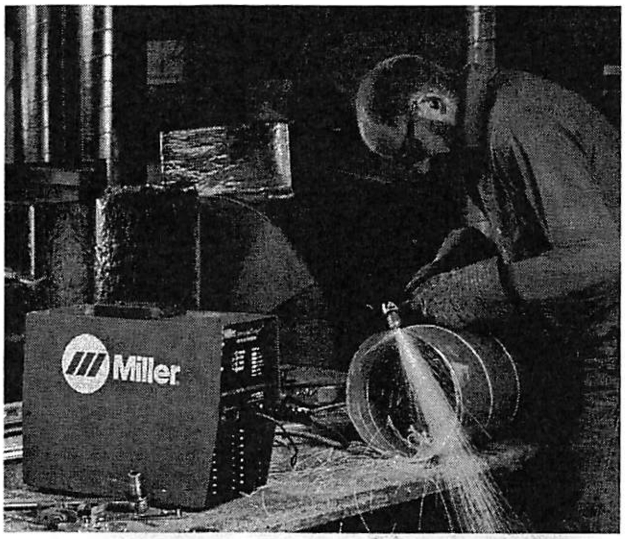


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Figure 11 ◆ Light-duty PAC with internal air compressor.

operator. The cutting area should be well ventilated and cleared of all combustible material.

Plasma arc cutting or gouging can spray molten metal for considerable distances, sometimes 25' or more. It is important that everything combustible be removed from the range of the sprayed metal. If necessary, flame-resistant shields or curtains should be erected to protect any nearby workers or equipment from ultraviolet arc rays and metal splash. It is also important to station a fire watch in the area.

Eye and ear protection are essential when performing PAC due to noise and to prevent metal spray from entering the operator's eyes and ears. If the site ventilation is not adequate to keep the smoke and fumes away from the operator, a respirator must be used.

WARNING!

PAC produces fumes and gases that can be harmful to your health. The composition and rate of generation of fumes and gases depend on factors such as arc current, cutting speed, material being cut, and gases used. The fume and gas byproducts usually consist of ozone, oxides of the metal being cut, and oxides of nitrogen. These fumes must be removed from the work area through an exhaust system. Check all applicable local codes; some may require that exhaust be filtered before it is vented to the atmosphere.

5.0.0 ◆ SETTING UP PAC EQUIPMENT

PAC equipment is easy to set up because it is supplied as a complete system. However, there are some important considerations and preparations to complete before cutting is attempted:

- The unit must have the rated power and duty cycle to cut the intended metal type and thickness.
- The required primary power (phase, voltage, and amperage) must be available for the control unit.
- The required nozzle (tip) must be installed in the torch.
- The required gas or gases must be on-line and at the required pressures and flow rates.
- Spare consumable components must be on hand.

5.1.0 Setting Correct Cutting Amperage

The cutting amperage depends on the type of equipment being used, the type and thickness of the material being cut, and the type of gas being used (*Figure 12*). Light-gauge sheet steel may require as little as 7 amps, while 2" aluminum plate may require 250 amps. Always refer to the manufacturer's recommendations to identify the correct amperage for the equipment and job to be performed. Using the incorrect amperage will result in a poor-quality cut, and if the amperage is too high, severe damage to the torch could occur.

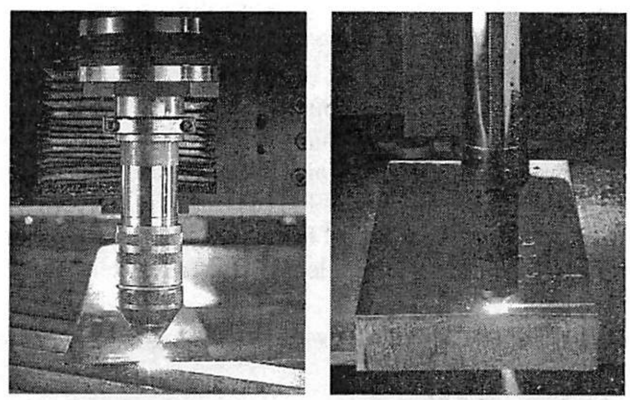

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Figure 12 ◆ Gas and amperage settings vary according to material type and thickness.

5.2.0 Installing Gas Cylinders and Setting Gas Parameters

Several different gases may be used on the same system for cutting the same or different type and thickness of metals. In many cases, the same gas or mixture is not used for both thick and thin metals of the same type. Refer to the manufacturer's instructions or the tag on the unit for specific gas recommendations.

5.2.1 Installing a Gas Cylinder

When installing a gas cylinder on the PAC unit, follow these steps:

Step 1 After locating the correct gas type, move it to the unit and secure it in an upright position.

Step 2 Remove the protective valve cap.

> **WARNING!**
> If oxygen is being used, be sure any cloth used on or near the fittings or regulators does not have any oil or grease on it. Oil or grease compressed with oxygen will explode and can cause personal injury or death.

Hot Tip

Safety Caps

Safety caps should be kept with cylinders at all times. Immediately after removing a cylinder's regulator assembly, reinstall the safety cap over the cylinder valve. This protects the cylinder valve if the cylinder falls over. If the cylinder valve is broken, the cylinder may propel itself like a rocket. This could result in serious injury or death.

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Step 3 If dirt is visible in the connection seat, wipe it out with a clean, dry cloth.

> **WARNING!**
> Always stand to one side of the regulators when opening valves to avoid personal injury. The regulator adjustment screws can fly off. Wear protective eyewear.

Step 4 While standing to one side of the valve with safety goggles in place, momentarily crack open the valve slightly to blow any dirt or debris from the valve.

Step 5 Connect the regulator to the cylinder valve, and tighten with the proper wrench. Connect the hose from the PAC unit to the regulator.

Step 6 Open the cylinder valve very slowly at first, then all the way.

> **CAUTION**
> Do not use pliers or pipe wrenches to tighten the regulator's connections. Also be careful not to overtighten the connections because they are made of soft bronze and can be easily damaged.

6.0.0 ◆ OPERATING PAC EQUIPMENT

Plasma arc cutting equipment is simple to operate. The cutting unit's operating instructions usually provide information for properly setting air or gas pressure and/or flow rates, output current, torch standoff distance (torch tip to work distance), and torch travel speed for various metal types and thicknesses.

Hot Tip

Gas Pressure and Flow Rates

PAC unit gas pressures and/or flow rates vary with equipment design, gas type, and cut depth (metal thickness). Typical gas flow rates vary from 15 cfh for nitrogen when cutting 0.1" aluminum, carbon steel, or stainless steel to 62 cfh of argon and 31 cfh of nitrogen when cutting 3" carbon steel or 2½" aluminum or stainless steel. Refer to the manufacturer's instructions for the correct gas pressure and flow rates.

NOTE

The following steps are provided for general reference only. Refer to the manufacturer's operation manual for specific instructions on the PAC equipment being used.

To operate the equipment, follow these steps:

Step 1 Make sure the capacity of the PAC power source matches or exceeds the work to be done.

Step 2 Identify the location of the primary disconnect for the electrical outlet to be used.

Step 3 If not already wired into a disconnect box, plug the PAC power source into the outlet.

Step 4 Check that the recommended gas(es) is available. If pressurized cylinder(s) are used, check that the cylinder(s) have adequate pressure for the work to be done. Connect the compressor's air line if compressed air is to be used.

Step 5 Turn on the PAC power source.

Step 6 In accordance with the PAC manufacturer's instructions, adjust the gas regulator pressure(s) and/or flow meter(s) rates to the values recommended for the type and thickness of metal being cut.

Step 7 Set the output current (amperage) control to the value recommended in the manufacturer's instructions for the type and thickness of metal being cut.

Step 8 Attach the work lead clamp to the workpiece to be cut.

CAUTION

If cutting on machinery or other equipment, be sure to position the work lead clamp so that the cutting current will not pass through seals, bearings, or other contacting surfaces that could be damaged from heat or arcing. Also, isolate any electrical components.

Step 9 Prepare the work area as previously described, stationing a fire watch.

Step 10 Put on the appropriate personal protective equipment (hood, gloves, and ear protection).

Step 11 Hold the torch at the recommended standoff distance above the point where the cut is to begin, lower your hood, and press the torch arc start button or foot peddle. As soon as cutting begins, move the torch at a 0° travel angle with the recommended speed along the cutting line.

6.1.0 Square-Cutting Metal

Square edges are cut with PAC by holding the torch at 90° (0° work angle) to the metal surface while it is advanced smoothly with no side-to-side movement. A straightedge or metal angle can be used to guide and steady the torch end. When cutting thicker metals, the cut does taper slightly as it narrows with depth. This can result in cuts where one or both faces are not quite square with the plate face. The angle of the face is known as the cut angle. To compensate for the cut angle, the torch should be slightly slanted to produce a square edge on the desired piece. All the taper will then be on the scrap side. *Figure 13* shows how to compensate for the taper in thicker metal cuts.

Standoff Distance

Instead of manually holding the PAC torch, use a drag shield or standoff guide to establish and maintain the correct standoff distance.

Starting the Torch on a Thick Workpiece

Like oxyfuel cutting of thick workpieces, it is easier to begin a manual cut at the edge by rotating the PAC torch slightly so that the plasma cutting jet begins cutting at the top edge only. The torch is then rotated vertically so that the cutting jet slices into the remaining thickness before the torch is moved along the cutting line.

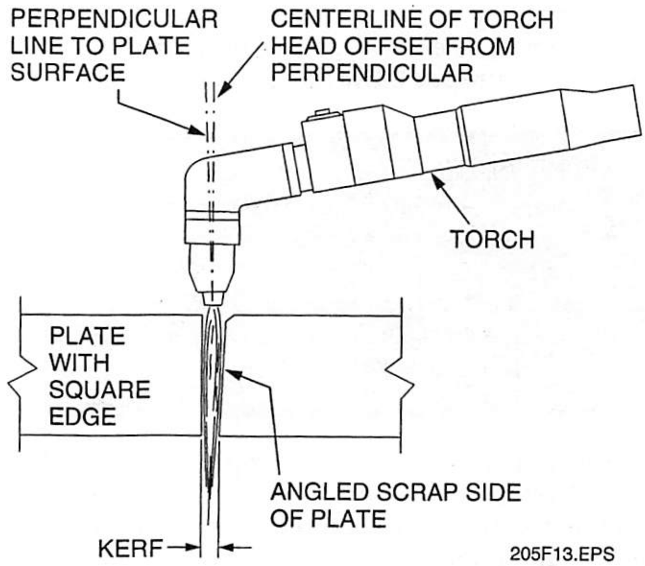

Figure 13 ◆ Compensating for taper in thicker metal cuts.

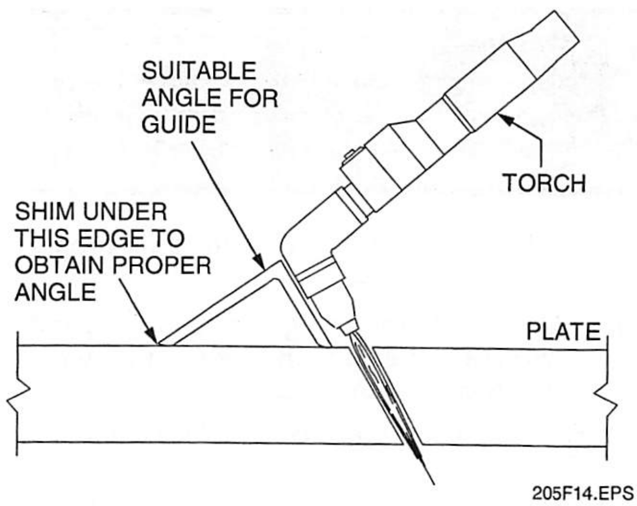

Figure 14 ◆ Using angle iron to set and hold a bevel angle.

6.2.0 Bevel-Cutting Metal

Bevel cuts are made with the same technique as for square cuts, except that the torch is held at the required bevel angle. A length of angle iron laid on its open face and shimmed as necessary can be used to support the torch's side at the required angle. *Figure 14* shows how to use a metal angle to hold a bevel angle.

6.3.0 Piercing and Slot-Cutting in Metal

PAC can be used to pierce and cut slots in metal in any position. Full fire-resistant body protection, including ear protection, is recommended when piercing or cutting metal where out-of-position orientations could cause the metal splash to fall on the torch operator.

To pierce very thin metal, hold the torch directly over the point to be pierced at a 0° work angle and press the arc button. As soon as the jet passes completely through the workpiece, move the torch head in a smooth circle (or other pattern) to produce the desired diameter or shape hole. When piercing thicker materials, rotate the torch to a 10° work angle to prevent metal from splashing directly up into the torch. When the jet passes through the workpiece, rotate the torch to a 0° work angle and complete the cut.

When cutting slots, a template or straightedge can be used to precisely guide the torch tip.

7.0.0 ◆ PROPER EQUIPMENT STORAGE AND HOUSEKEEPING

Proper equipment storage and housekeeping are essential for work efficiency and safety. When finished using the PAC equipment, follow these steps to store the equipment and for good housekeeping:

Step 1 Turn off the power source.

Step 2 Unplug and coil the power source cable.

Step 3 Coil the torch cable.

Step 4 Close the cylinder valves and/or disconnect and coil the compressed air line.

Hot Tip

Swirl Ring Torches

On PAC torches equipped with swirl rings, most swirl rings produce a clockwise tangential plasma swirl as viewed from the torch to the work surface. If the torch is at a 0° work angle, the clockwise swirl causes the right side to the kerf to be essentially square and the left side to be angled. For a counterclockwise swirl, the opposite is true.

> **WARNING!**
> If cylinders are to be removed, be sure to remove the pressure regulators and replace the cylinder caps before releasing and moving them.

Step 5 Return the PAC equipment to its proper storage location.

Step 6 Clean off the welding bench, if used, and sweep up the slag and debris that were blown around the area.

Figure 15 shows a properly stored PAC unit.

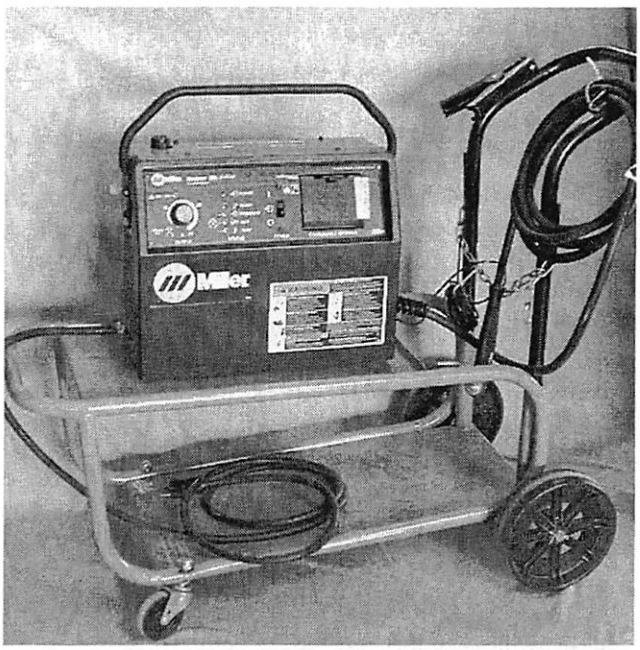

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Figure 15 ◆ Properly stored PAC unit.

8.0.0 ◆ REPAIR OF PLASMA ARC CUTTING (PAC) EQUIPMENT

As with all equipment, regular maintenance should be performed according to the manufacturer's recommendations. The cutting equipment should not be altered or modified in any way, except for those changes identified in the manufacturer's literature. The plasma machine requires relatively little maintenance, but its consumables must be inspected regularly and replaced as needed. Minor external repairs usually involve these basic parts only.

8.1.0 Understanding Basic Operating Concerns

If compressed air is used with a PAC unit, shop air may be used as long as it is dry and free of oil. When properly set, the air pressure regulator and filter/dryer on the power source will maintain the correct pressure and flow rate for the system.

> **WARNING!**
> Always switch off the machine power and unplug the power cord before changing consumable parts or performing any repairs on the power source. If the power source is directly connected to a line disconnect switch, move the line disconnect switch to the OFF position.

Your ability to change and replace parts will depend on your knowledge of the procedures contained in the manufacturer's literature for the equipment in question.

Follow the manufacturer's guidelines for removal and replacement of worn or damaged parts:

- Check the shield for any signs of wear.
  - The shield should be clean and clear of metal debris.
  - Unscrew the shield and check the inside for wear. If the holes are blocked, attempt to clean the holes using a tip cleaner.
  - If the shield cannot be cleaned, replace it.
- Inspect the retaining cup for damage. Replace the retaining cup as necessary.
- Inspect the nozzle for wear or damage. If the hole in the nozzle is worn or oval-shaped, replace the nozzle.
- Inspect the electrode. Remove the electrode and check the tip for pitting. If pits exist and are more than 1/16" deep, replace the electrode.
- Inspect the swirl ring. It should be clean, and the holes on the sides should not be clogged. If the swirl ring is damaged, replace it.
- Inspect the O-ring. Apply a small amount of lubricant (provided in a repair kit) to the O-ring before reinstalling it. The O-ring should make a firm seal when all parts are assembled and tight.

8.2.0 Moisture

A significant concern when using PAC equipment is that moisture may enter the unit through the air line. This can cause the torch to sputter or hiss. If your PAC equipment experiences moisture problems, you must do the following:

- Drain the filter bowl.
- Replace the filter element, if the unit has one. Refer to the manufacturer's literature for cleaning and replacing this filter.

8.3.0 Cooling Filter

Some power sources contain a cooling air filter located in the back of the unit. Refer to the manufacturer's literature and clean the filter regularly as required. A cooling air filter that is neglected may cause the PAC unit to overheat and shut down.

Summary

Plasma arc cutting is very useful for cutting and piercing many types of metals. Unlike oxyfuel cutting, it can be used to cut aluminum, magnesium, copper, nickel, and stainless steel. It is usually much faster than oxyfuel cutting and produces little or no distortion or alteration zone changes. The cuts are fast and clean, with little or no dross. There is no chance of carbon inclusions as can happen with carbon arc cutting. Cut surfaces are usually ready for welding without further preparation. However, because the torch jet produces metal spray, good site fire-prevention practices and the wearing of the appropriate personal protective equipment are essential. Ear protection is important when cutting out of position to prevent sparks or molten metal from entering the ears.

Review Questions

1. Plasma arc cutting uses a jet of plasma that can reach temperatures as high as _____.
   a. 10,000°F
   b. 20,000°F
   c. 25,000°F
   d. 30,000°F

2. There are _____ types of plasma arc cutting.
   a. two
   b. three
   c. four
   d. five

3. In the transferred arc process, the pilot arc is used to _____.
   a. cut the metal
   b. ionize the air jet
   c. establish contact with the metal
   d. keep the torch heated

4. In a nontransferred arc process, the material being cut is _____ the arc circuit.
   a. adjacent to
   b. dependent on
   c. electrically connected to
   d. not electrically connected to

5. Nontransferred arc is not normally found in facilities that cut _____.
   a. non-metal materials
   b. only metal materials
   c. non-conducting materials
   d. insulating materials

6. Light-duty PAC power supplies typically require a single-phase, _____ outlet.
   a. 115VAC only
   b. 220VAC only
   c. 115VAC or 230VAC
   d. 280VAC or 440VAC

7. The heaviest duty PAC torches are usually _____.
   a. water cooled
   b. 115V systems
   c. used for cutting thin materials
   d. handheld

8. Mechanized PAC torches are designed to be _____.
   a. handheld
   b. mounted in a vise
   c. used at a slow speed
   d. mounted on automated carriers

9. The size of a workpiece clamp is the rated _____ that it can carry without overheating.
   a. voltage
   b. capacitance
   c. amperage
   d. power

10. Severe damage from arcing and overheating can be caused by cutting current that passes through a _____.
    a. workpiece
    b. cable
    c. cutting table
    d. bearing

11. Gases other than compressed air are normally supplied in high-pressure cylinders at _____.
    a. 200 psi to 400 psi
    b. 800 psi to 1,000 psi
    c. 1,000 psi to 1,500 psi
    d. 1,500 psi to 2,000 psi

12. If site ventilation is not adequate to keep fumes away from the operator, a(n) _____ must be used.
    a. fan
    b. respirator
    c. fire watch
    d. air line

13. Light-gauge sheet steel may require a cutting amperage as low as _____ amps.
    a. 7
    b. 10
    c. 15
    d. 20

14. Square edges are cut with PAC by holding the torch at _____ to the metal surface.
    a. 30°
    b. 45°
    c. 75°
    d. 90°

15. If cylinders are removed from the system, the _____ must also be removed.
    a. cylinder caps
    b. workpiece clamp
    c. pressure regulators
    d. power source

GMAW and FCAW – Equipment and Filler Metals

Objectives

When you have completed this module, you will be able to do the following:

1. Explain gas metal arc welding (GMAW) and flux cored arc welding (FCAW) safety.
2. Explain the characteristics of welding current and power sources.
3. Identify and explain the use of GMAW and FCAW equipment:
   - Spray transfer
   - Globular
   - Short circuiting
   - Pulse
4. Identify and explain the use of GMAW and FCAW shielding gases and filler metals.
5. Set up GMAW and FCAW equipment and identify tools for weld cleaning.

Prerequisites

Before you begin this module, it is recommended that you successfully complete the following: Core Curriculum; Welding Level One; Welding Level Two, Modules 29201-03 through 29205-03.

Required Trainee Materials

1. Pencil and paper
2. Appropriate personal protective equipment

1.0.0 ◆ INTRODUCTION

Gas metal arc welding (GMAW) uses an electric arc to melt a consumable wire electrode and fuse it with the base metal. The arc generates an intense heat of 6,000 to 10,000 degrees Fahrenheit (°F). The arc is stabilized and the molten filler and base metals are protected from oxidation by a shielding gas dispensed from a GMAW gun nozzle. The wire is automatically fed into the weld puddle as it melts. The process usually operates with direct current electrode positive (DCEP). *Figure 1* shows the basic GMAW process.

Flux cored arc welding (FCAW) uses an electric arc to melt a flux cored (tubular) wire electrode and fuse it with the base metal to form a weld. A wire feeder automatically feeds the flux cored wire as it is being consumed in the arc. The equipment used for FCAW is basically the same as that used for GMAW. The main difference between the two processes is that GMAW uses solid wire or composite core wire electrodes with a shielding gas, while FCAW uses a tubular flux-cored wire electrode with or without shielding gas.

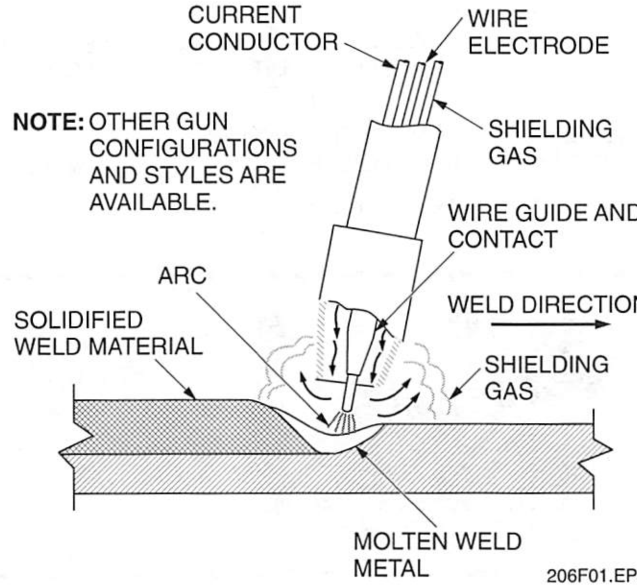

Figure 1 ◆ Basic GMAW process.

In the two basic FCAW processes, one uses an external shielding gas while the other is self-shielding. Whether a shielding gas is used is determined by the type of flux cored wire that is used. When the flux cored wire does not require an external shielding gas, the process is called self-shielding FCAW or FCAW-*S*. When an external shielding gas is required, the process is called gas-shielded FCAW or FCAW-*G*. Equipment specifically designed for self-shielding FCAW does not have provisions for shielding gas (gas connections, solenoids, and gas pre-flow and post-flow timers), and the guns do not have gas nozzles. Equipment used for gas-shielded FCAW welding is the same as that used for GMAW except that the wire feed drive assemblies have to be able to handle the core wire, which is softer and generally larger in diameter than solid wire. *Figure 2* shows the basic FCAW process.

This module provides an overview of the different items of equipment required for gas metal arc welding. Topics include safety and equipment, power sources, wire feeders, guns, equipment setup, and filler metals. Upon completion of this unit, trainees will be aware of the safety concerns associated with both GMAW and FCAW. They will be able to select and set up both GMAW and FCAW equipment safely and efficiently.

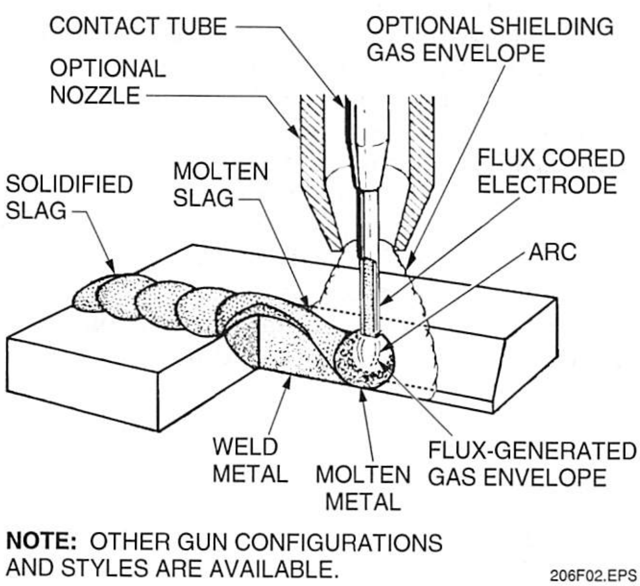

Figure 2 ◆ Basic FCAW process.

2.0.0 ◆ SAFETY PRACTICES

The following is a summary of safety procedures and practices that must be observed while cutting or welding. Keep in mind that this is just a summary. Complete safety coverage is provided in the Level One module, *Welding Safety*. If you have not completed that module, do so before continuing. Above all, be sure to wear appropriate protective clothing and equipment when welding or cutting.

2.1.0 Protective Clothing and Equipment

- Always use safety goggles with a full face shield or a helmet. The goggles, face shield, or helmet lens must have the proper light-reducing tint for the type of welding or cutting to be performed. Never directly or indirectly view an electric arc without using a properly tinted lens.
- Wear proper protective leather and/or flame retardant clothing along with welding gloves that will protect you from flying sparks and molten metal, as well as heat.
- Wear 8" or taller high-top safety shoes or boots. Make sure that the tongue and lace area of the footwear will be covered by a pant leg. If the tongue and lace area is exposed or the footwear must be protected from burn marks, wear leather spats under the pants or chaps and over the front top of the footwear.
- Wear a solid material (non-mesh) hat with a bill pointing to the rear or, if much overhead cutting or welding is required, a full leather hood with a welding face plate and the correct tinted lens. If a hard hat is required, use a hard hat that allows the attachment of rear deflector material and a face shield.

Hot Tip

FCAW

FCAW is presently limited to the welding of ferrous metals. These include low- and medium-carbon steels, some low-alloy steels, cast irons, and some stainless steels. When critical welds are required, the gas-shielded FCAW process is often used because the combination of flux and separate shielding gas produces welds of very high quality.

- If a full leather hood is not worn, wear a face shield and snug-fitting welding goggles over safety glasses for gas welding or cutting. Either the face shield or the lenses of the welding goggles must be an approved shade 5 or 6 filter. For electric arc welding or cutting, wear safety goggles or a welding hood with the correct tinted lens (shade 5 to 14).
- If a full leather hood is not worn, wear earplugs to protect your ear canals from sparks.

2.2.0 Fire/Explosion Prevention

- Never carry matches or gas-filled lighters in your pockets. Sparks can cause the matches to ignite or the lighter to explode, causing serious injury.
- Never perform any type of heating, cutting, or welding until a hot-work permit is obtained and an approved fire watch is established. Most work-site fires caused by these types of operations are started by cutting torches.
- Never use oxygen to blow off clothing. The oxygen can remain trapped in the fabric for a time. If a spark hits the clothing during this time, the clothing can burn rapidly and violently out of control.
- Make sure that any flammable material in the work area is moved or shielded by a fire-resistant covering. Approved fire extinguishers must be available before attempting any heating, welding, or cutting operations.
- Always comply with any site requirement for a hot-work permit and/or fire watch.
- Never release a large amount of oxygen or use oxygen as compressed air. Its presence around flammable materials or sparks can cause rapid and uncontrolled combustion. Keep oxygen away from oil, grease, and other petroleum products.
- Never release a large amount of fuel gas, especially acetylene. Methane and propane tend to concentrate in and along low areas and can ignite at a considerable distance from the release point. Acetylene is lighter than air but is even more dangerous than methane. When mixed with air or oxygen, it will explode at much lower concentrations than any other fuel.
- To prevent fires, maintain a neat and clean work area and make sure that any metal scrap or **slag** is cold before disposal.
- Before cutting or welding containers such as tanks or barrels, check to see if they have contained any explosive, hazardous, or flammable materials, including petroleum products, citrus products, or chemicals that decompose into toxic fumes when heated. As a standard practice, always clean and then fill any tanks or barrels with water or purge them with a flow of inert gas to displace any oxygen.

2.3.0 Work Area Ventilation

- Make sure confined space procedures are followed before conducting any welding or cutting in the confined space.
- Never use oxygen in confined spaces for ventilation purposes.
- Always perform cutting or welding operations in a well-ventilated area. Cutting or welding operations involving zinc or cadmium materials or coatings result in toxic fumes. For long-term cutting or welding of such materials, always wear an approved full-face, supplied-air respirator (SAR) that uses breathing air supplied outside of the work area. For occasional, very short-term exposure, a high-efficiency particulate arresting (HEPA)-rated or metal-fume filter may be used on a standard respirator.
- Make sure confined spaces are ventilated properly for cutting or welding purposes.

3.0.0 ◈ CHARACTERISTICS OF WELDING CURRENT

The current produced by a welding machine has different characteristics than the current flowing through utility power lines. Welding current has low voltage and high amperage, while the power line current has high voltage and low amperage.

3.1.0 Voltage

Voltage is the measure of the electromotive force or pressure that causes current to flow in a circuit. There are two types of voltage associated with welding current: open-circuit voltage and operating voltage. Open-circuit voltage is the voltage present when the machine is on but no welding is being done. There are usually ranges of open-circuit voltages that can be selected, up to about 40 volts. Operating voltage, or arc voltage, is the voltage after the arc is struck.

This voltage is generally slightly lower than the open-circuit voltage. The arc voltage is typically 2 to 3 volts lower than the open-circuit voltage for each 100 amperes of current, but it depends on the range selected.

3.2.0 Amperage

Amperage is the electric current flow in a circuit. The unit of measure for amperage is the ampere (amp).

In welding, the current flows in a closed loop through two welding cables; the ground lead connects the power source to the base metal, and the other cable connects the power source to the wire electrode. During welding, an arc is established between the end of the wire electrode and the work. The arc generates intense heat at 6,000 to 10,000°F, melting the base metal and the wire electrode to form the weld. The amount of amperage produced by the welding machine determines the intensity of the arc and the amount of heat available to melt the work and the electrode.

4.0.0 ◆ WELDING POWER SOURCES

DC power sources are usually designed to produce either constant current (CC) or constant voltage (CV) DC. A constant current machine produces a constant current output over a wide voltage range. This is typical of a SMAW welding machine. A constant voltage machine maintains a constant voltage as the output current varies. This is typical of a GMAW or FCAW machine. The output voltages and output currents of a power source can be plotted on a graph to form a curve. These curves show how the output voltage relates to the output current as either changes. *Figure 3* shows constant current and constant voltage output curves.

4.1.0 Types of Welding Power Sources

Different types of welding machines (power sources) are available for GMAW, including:

- Transformer-rectifier power sources
- Engine-driven generator and alternator power sources
- Inverter power sources

4.1.1 Transformer-Rectifier Power Sources

The transformer-rectifier power source uses a transformer to convert the primary current to welding current and a rectifier to change the current from AC to DC. Transformer-rectifier power sources can be designed to produce either AC and DC or DC only. Transformer rectifiers that produce both AC and DC are usually lighter duty than those that produce DC only. Transformer-rectifier power sources that produce DC only are sometimes called rectifier power sources or just rectifiers. Depending on the size, transformer-rectifier power sources may require 120/240-volt single-phase power, 208-volt three-phase power, or 480-volt three-phase power.

> **WARNING!**
> Coming into contact with the primary voltage of a welding machine can cause shock or electrocution. Ensure that welding machines are properly grounded to prevent injury.

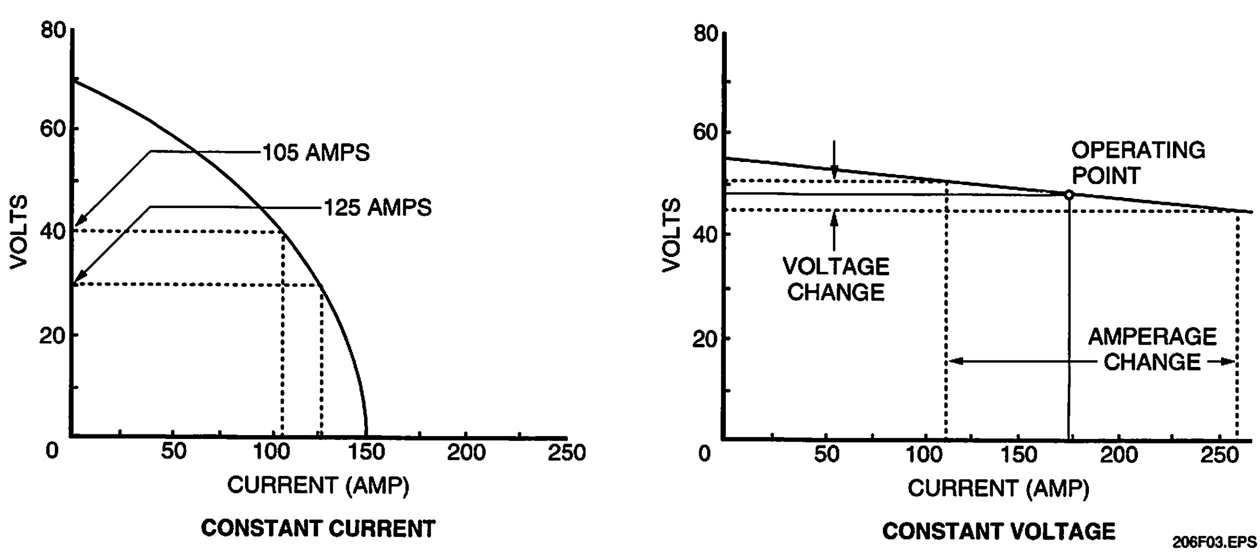

Figure 3 ◆ Constant current and constant voltage output curves.

Hot Tip: *Constant Current/Constant Voltage Power Sources*

Transformer rectifiers can be designed to produce constant current (CC) or constant voltage (CV) DC. Some will produce either variable or constant voltage by setting a switch. These machines are sometimes referred to as multiprocess power sources, since they can be used for any welding process, including GMAW and FCAW.

Transformer rectifiers used for GMAW and FCAW have an on/off switch and a voltage control. If the machine has a CC/CV or mode switch, it also has an amperage control for SMAW or GTAW. When the switch is set to CV for either GMAW or FCAW, the amperage control is disabled or becomes the voltage control. The welding cables (electrode cable and workpiece cable) are connected to terminals marked ELECTRODE and GROUND, or POSITIVE (+) and NEGATIVE (–). They often have selector switches to select direct current electrode negative (DCEN) or direct current electrode positive (DCEP). If there is no selector switch, the cables must be manually changed on the machine terminals to select the type of current desired.

Figure 4 shows a typical industrial transformer-rectifier CC/CV power source. These units usually have a 100% duty cycle at their rated output and a 60% duty cycle at their maximum output. They require a wire feeder and GMAW/FCAW gun or spool gun. These devices are described in a later section.

4.1.2 Engine-Driven Generator and Alternator Power Sources

Power sources can also be powered by gasoline or diesel engines. The engine can be connected to a generator or to an alternator. Engine-driven generators produce DC. Engine-driven alternators produce AC, which is fed through a rectifier to produce DC.

The size and type of engine used depend on the size of the power source. Single-cylinder engines are used to power small rectifier alternators, and multi-cylinder engines are used to power larger generators.

To produce welding current, the generator or alternator must turn at a required number of rpm (revolutions per minute). The engines that power alternators and generators have governors to control the engine speed. Most governors have a welding speed switch. The switch can be set to idle the engine when no welding is taking place. When the electrode is touched to the base metal, the governor automatically increases the speed of the engine to the required rpm for welding. If no welding takes place for about 15 seconds, the engine will automatically return to idle. The switch can also be set for the engine to run continuously at the welding speed.

Figure 5 shows an example of a diesel engine-driven power source. This particular unit can produce CC/AC or DC and CV/DC outputs up to 300 amps at a 100% duty cycle for SMAW, GTAW, GMAW, and FCAW. For GMAW and FCAW, it is available with a companion weatherproof wire

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Figure 4 ◆ Industrial transformer-rectifier CC/CV power source with wire feeder.

feeder and a 24V control module for the wire feeder motor that enables an engine idle mode when no welding is being performed. The wire feeder control operates from the welding circuit voltage of the power source. When welding is started, wire feed speed is ramped up slowly while the engine reaches welding speed. The wire feeder is shown with an FCAW-only (FCAW-S) gun connected; however, it also functions with an external gas supply and gas-shielded GMAW/FCAW-G guns, as well as spool guns.

Engine-driven power sources often have an auxiliary power unit that produces 120 volts alternating current (VAC) for lighting, power tools, and other electrical equipment. When 120 VAC is required, the engine-driven generator or alternator must run continuously at the welding speed.

Engine-driven generators and alternators have engine controls and welding current controls. The engine controls vary with the type and size but normally include the following:

- Starter
- Voltage meter
- Temperature gauge
- Fuel gauge
- Hour meter

Engine-driven generators and alternators have a voltage/amperage control. There may be a polarity or mode selector switch, or you may have to manually change the welding cables at the welding current terminals to change the polarity. If the machine has a CC/CV or mode selector switch, it also has an amperage control. When the switch is set to CV or GMAW/FCAW mode, the amperage control is disabled and becomes a voltage control.

The advantage of engine-driven generators and alternators is that they are portable and can be used in the field where electricity is not available for other types of welding machines. The disadvantage is that engine-driven generators and alternators are costly to purchase, operate, and maintain.

4.1.3 Inverter Power Sources

Inverter power sources (*Figure 6*) increase the frequency of the incoming primary power. This provides a smaller, lighter power source with a faster response time and more control for pulse welding. Inverter welding machines are used where space is limited and portability is important. The controls on these welding machines vary according to size and application.

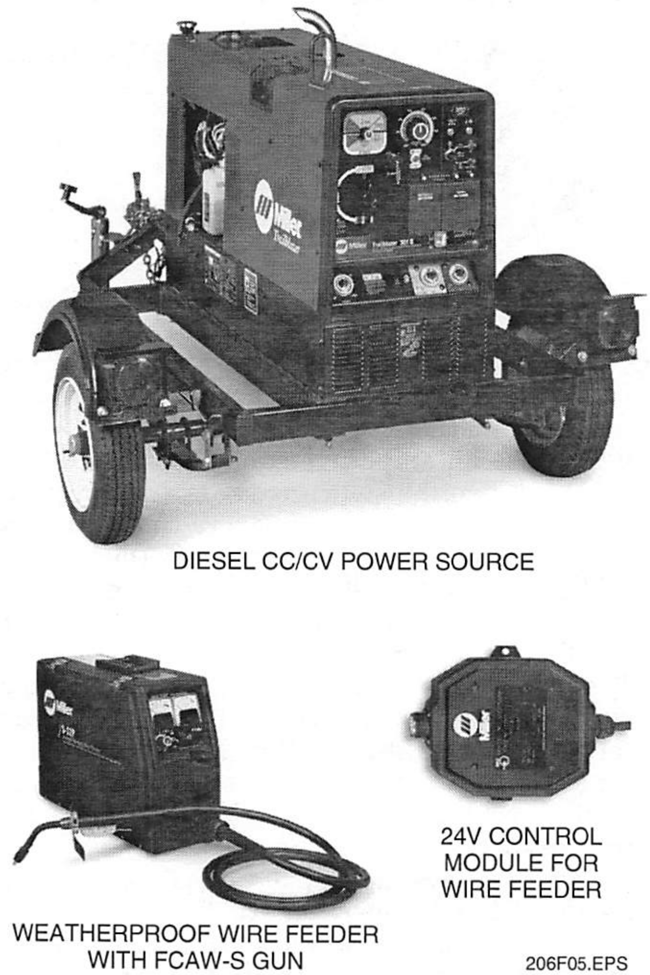

Figure 5 ◆ Diesel engine-driven power source with wire feeder.

> **Hot Tip**
>
> **GMAW/FCAW Feeders for Engine-Driven Power Sources**
>
> If possible, select wire feeders or spool guns that operate from 24VDC battery power and arc voltage. If AC-powered feeder or spool gun controls are used, the power source will have to operate in the continuous run mode to supply AC power to operate the feeder or spool gun.

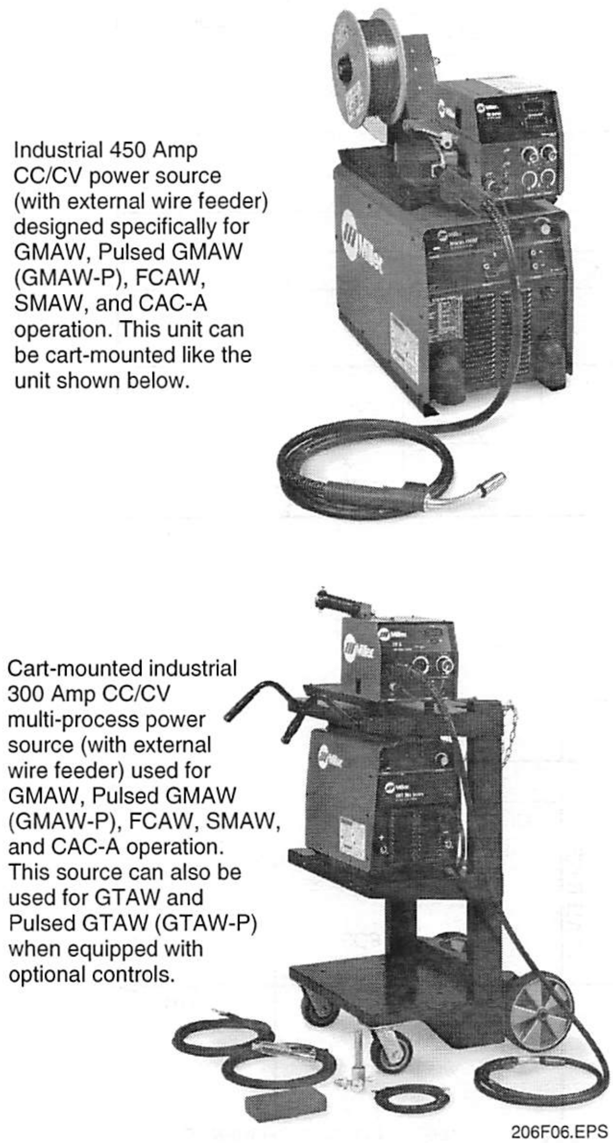

Figure 6 ◆ Inverter power sources.

Typical industrial advanced inverter power sources designed specifically for GMAW or FCAW operations usually have controls similar to those shown in *Figure 7*. These controls can include the following:

- *Power switch* – Applies power to unit.
- *Select pushbutton* – Moves a cursor up each line of 4-line display.
- *Display and change increment/decrement pushbuttons* – Contains up to 4 lines of alphanumeric text. When a line is selected, it can be changed using the increment/decrement pushbuttons.

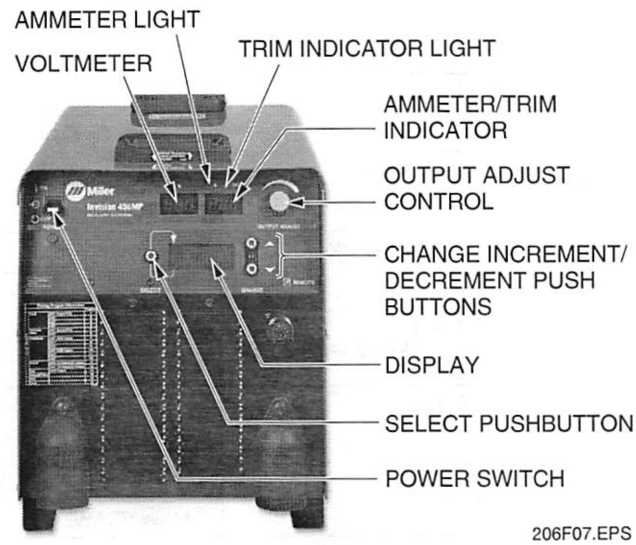

Figure 7 ◆ Typical industrial inverter power source controls.

> **NOTE**
> The display and the select/change increment/decrement pushbuttons are used to change the operational mode of the power source (GMAW, GMAW-P, FCAW, SMAW, Manual Pulse, etc.) and to select among a number of internal preset or programmable welding programs for various metals and shielding gases.

- *Voltmeter* – Indicates voltage during welding and voltage selected by Output Adjust Control for applicable modes or programs.
- *Ammeter/trim indicator* – Indicates amperage during welding and welding amperage or pulse trim amperage (for arc length) as selected by Output Adjust Control for applicable modes or programs.
- *Ammeter/trim indicator lights* – Indicate whether the ammeter/trim indicator is displaying welding amperage or pulse trip amperage.

A typical program sequence for one of the internal welding programs available in an advanced inverter power source is shown in *Figure 8*.

4.2.0 Power Source Ratings

The rating (size) of a welding machine is determined by the amperage output of the machine at a given duty cycle. The duty cycle of a welding

		TRIM 0-99	VOLTS 10.0-38.0	INDUCTANCE 0-99%	IPM 50-780	SECONDS
1. WELD	GMAW-P	X			X	0-100.0
	GMAW/FCAW		X	X	X	
2. CRATER	GMAW-P	X			X	0-5.00
	GMAW/FCAW		X		X	
3. MELTBACK	GMAW-P					0-0.25
	GMAW/FCAW		X			
4. & 5. POSTFLOW/PREFLOW						0-9.9
6. RUN-IN					25-780	
6. START	GMAW-P	X			X	0.00-5.00
	GMAW/FCAW		X		X	

X = Setting Available

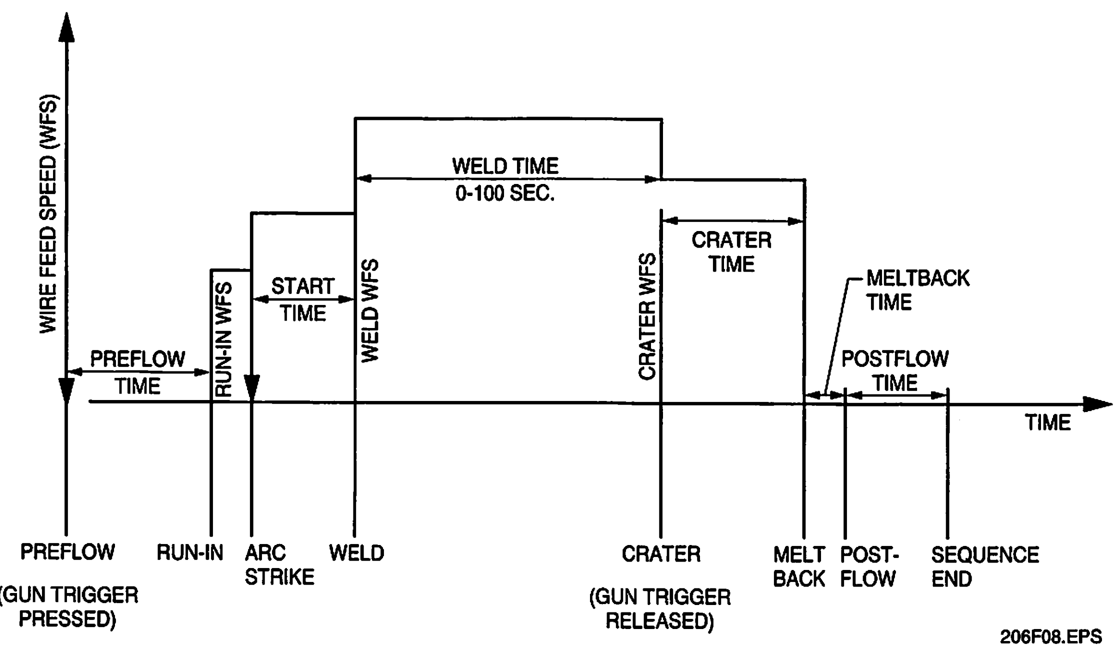

Figure 8 ◇ Typical welding program sequence.

machine is based on a 10-minute period. It is the percentage of 10 minutes during which the machine can continuously produce its rated amperage without overheating. For example, a machine with a rated output of 300 amps at 60% duty cycle can deliver 300 amps of welding current for 6 minutes out of every 10 without overheating.

The duty cycle of a welding machine will be 10%, 20%, 30%, 40%, 60%, or 100%. A welding machine with a duty cycle of 10% to 40% is considered a light- to medium-duty machine. Most industrial, heavy-duty machines for manual welding have 60 to 100% duty cycle ratings. Machines designed for automatic welding operations have 100% duty cycle ratings.

With the exception of 100% duty cycle machines, the maximum amperage that a welding machine can produce is always higher than its rated capacity. A welding machine rated 300 amps at a 60% duty cycle will generally put out a maximum of 375 to 400 amps. But, since the duty cycle is a function of its rated capacity, the duty cycle will decrease as the amperage is raised over 300 amps. Welding at 375 amps with a welding machine rated 300 amps at 60% duty cycle will lower the duty cycle to about 30%. If welding continues for more than 3 out of 10 minutes, the machine will overheat.

If the amperage is set below the rated amperage, the duty cycle increases. Setting the amper-

Hot Tip

All-in-One Welding Machines

Hand portable, light industrial GMAW/FCAW welding machines are also available. The CV/DC machine shown is rated at 130 amps with a 30% duty cycle. It is equipped with an internal wire feeder.

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NOTE

Most welding machines have a heat-activated circuit breaker that shuts off the machine automatically when it overheats. The machine cannot be turned back on until it has cooled.

age at 200 amps for a welding machine rated 300 amps at 60% duty cycle will increase the duty cycle to 100%. *Figure 9* shows the relationship between amperage and duty cycle.

5.0.0 ◆ GMAW AND FCAW EQUIPMENT

Typical GMAW and FCAW systems are made of four interconnected pieces of equipment, including the following:

- DC power source (welding machine)
- Wire feeder (if required)
- Welding gun
- Shielding gas supply (if required)

In some systems, equipment functions may be integrated or combined. For example, the wire feeder can be built into the same cabinet as the power source or it may be incorporated into the welding gun. Welding guns are shown in a later section of this module.

Most systems have a separate wire feeder (push system) that pushes the wire from the feeder through the gun cable and gun. Other systems may incorporate the wire feeder into the welding gun (pull system) or do both (push-pull system). There are some systems that have synchronized wire feeders located at intervals along very long feeder conduits. Various types of wire feeders are covered in a later section. Heavy-duty, water-cooled guns

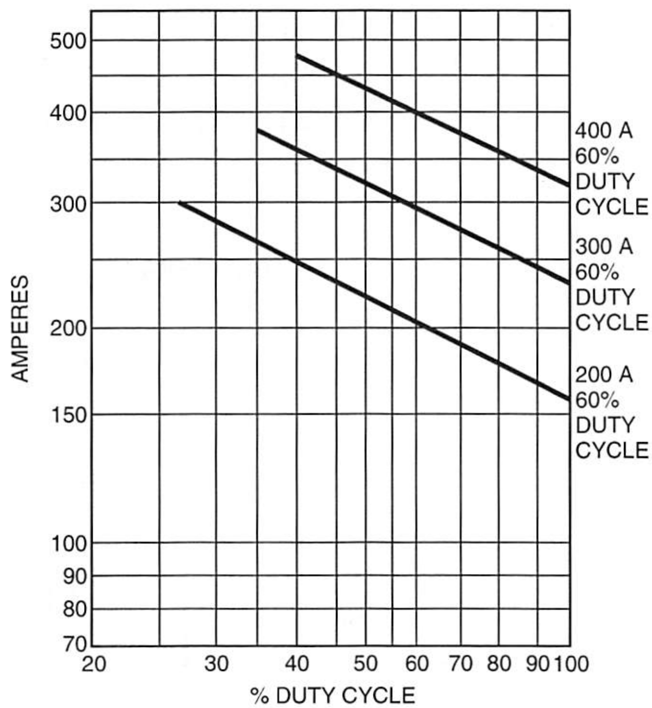

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Figure 9 ◆ Relationship between amperage and duty cycle.

may also be equipped with a closed loop water cooling system. Systems that are used for self-shielding FCAW do not require gas cylinders.

Figure 10 shows a simplified diagram of a typical GMAW/FCAW system.

5.1.0 GMAW Metal Transfer Modes

GMAW can use any of several modes (types of metal transfer) to conduct the filler metal to the molten weld pool. The principal modes follow:

- **Spray transfer**
- **Globular transfer**
- **Short-circuiting transfer**
- **Pulsed transfer**

5.1.1 Spray Transfer

In the spray transfer mode (*Figure 11*), the welding voltage is set in the higher ranges to keep the end of the wire electrode away from the work and to maintain a continuous arc. The high heat of the arc melts the end of the wire electrode, and fine droplets are carried by the arc **axially** to the molten weld puddle on the base metal. The spray transfer deposits filler metal at a high rate and produces very little spatter. However, the weld puddle is relatively large, and the mode works best in the flat or horizontal fillet positions. Also, only certain shielding gases or gas combinations can be used with spray transfer. Shielding gases are covered later in this module.

5.1.2 Globular Transfer

In the globular transfer mode, the welding voltage is set lower than it is for spray transfer. The end of the wire electrode remains a short distance from the work to maintain a continuous arc. Because of

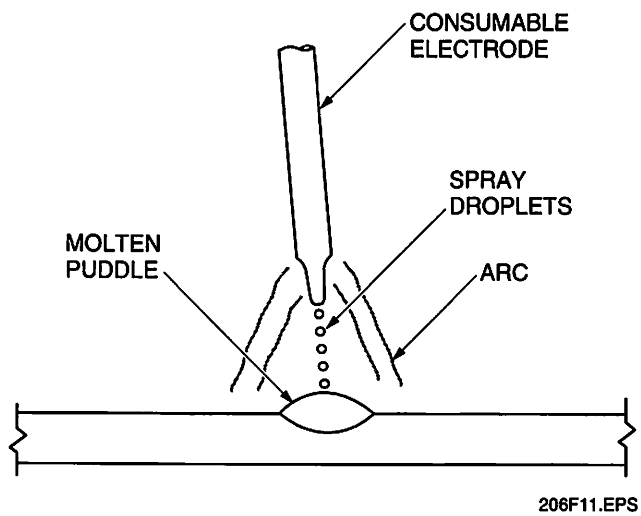


Figure 11 ◆ Spray transfer.

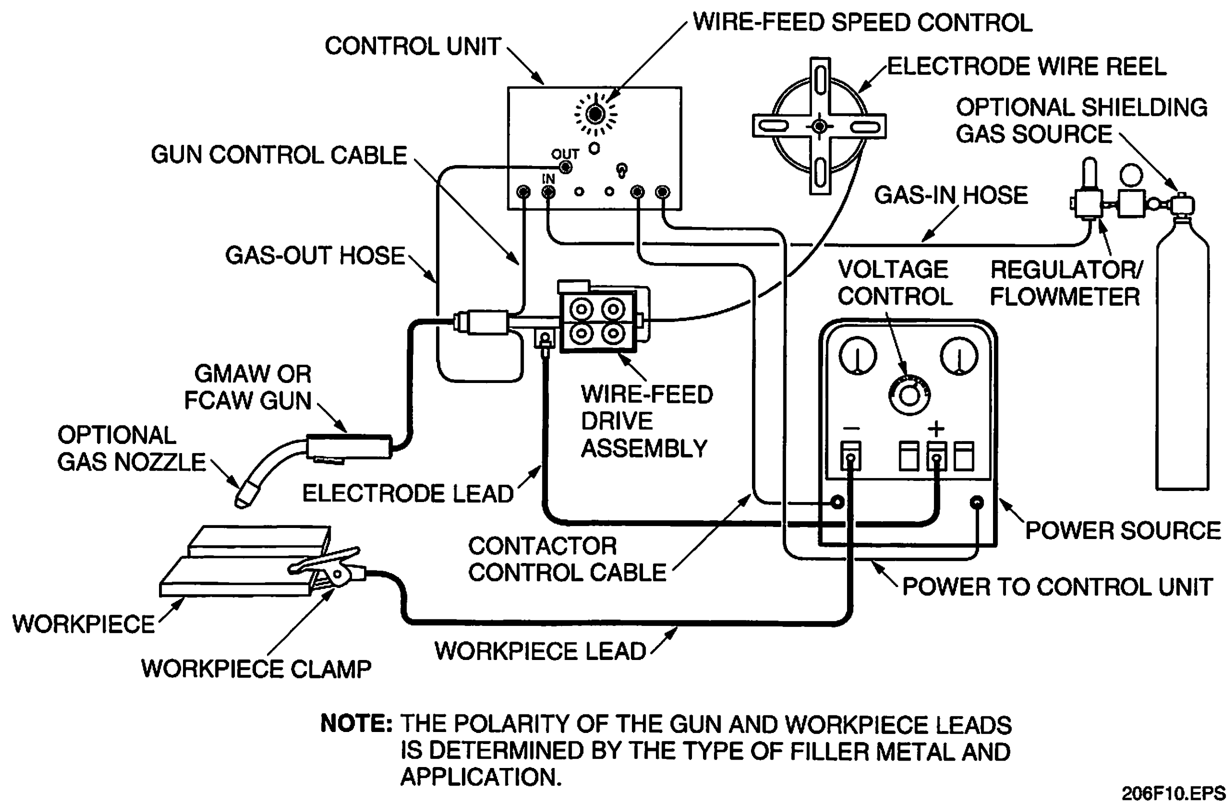


Figure 10 ◆ Simplified GMAW/FCAW system diagram.

the weight, the electrode wire tip periodically melts off in a large glob, which the arc then carries to the workpiece, where it mixes with the weld puddle. Globular transfer can be used to deposit filler metal at high rates and is capable of producing high-quality welds in all positions. However, bead appearance can be rough, and spatter may be heavy in some applications. *Figure 12* shows globular transfer.

5.1.3 Short-Circuiting Transfer

Short-circuiting transfer (GMAW-S) uses the lowest voltage settings of the three modes. It is the best mode for welding light-gauge sheet metal. The wire electrode is fed against the workpiece; when contact is made, current flow heats the wire electrode until it melts enough for a droplet to separate and mix with the weld puddle. When the droplet separates, a gap is formed and an arc is initiated. The continuously feeding wire closes the gap and contacts the workpiece, shorting out the arc. The current again heats the wire until another droplet separates, and the arc is again established. This process repeats many times each second. The short-circuiting process can be used to weld thin materials and is suitable for all positions. However, it does not penetrate deeply and may produce incomplete fusion on thicker materials because of the low heat input. *Figure 13* shows short-circuiting transfer.

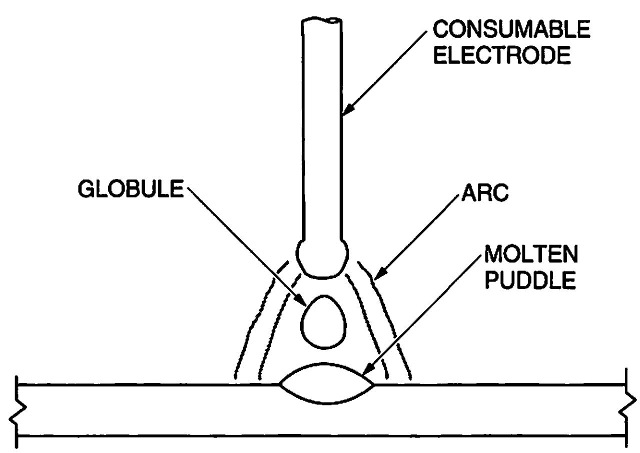


Figure 12 ◆ Globular transfer.

5.1.4 Pulsed Transfer

Pulsed transfer (GMAW-P) welding is a modified combination of spray transfer welding and short-circuit transfer arc welding. The process transfers molten metal in droplets while maintaining an arc with the base metal. The pulsed GMAW process also allows the transfer action to occur while using lower current levels. The advantages of the lower current levels are less spatter and better penetration without melting through the base metal.

In pulsed transfer welding, the welding power is electronically controlled by a special power source that pulses the output power to the consumable electrode (wire). Although different GMAW machines may have different types of special power sources, the results are the same for each. The welding current is generated in pulses of high current at specified periods of time. The frequency of these pulses varies from one power source to the next, but some power sources are capable of producing pulses over a wide range. During the period of time between each pulse, the welding current is reduced but is still maintained at a high enough level to keep the wire heated and an arc established. This lowered current level is called the background current. *Figure 14* shows output pulses of high welding current occurring over time.

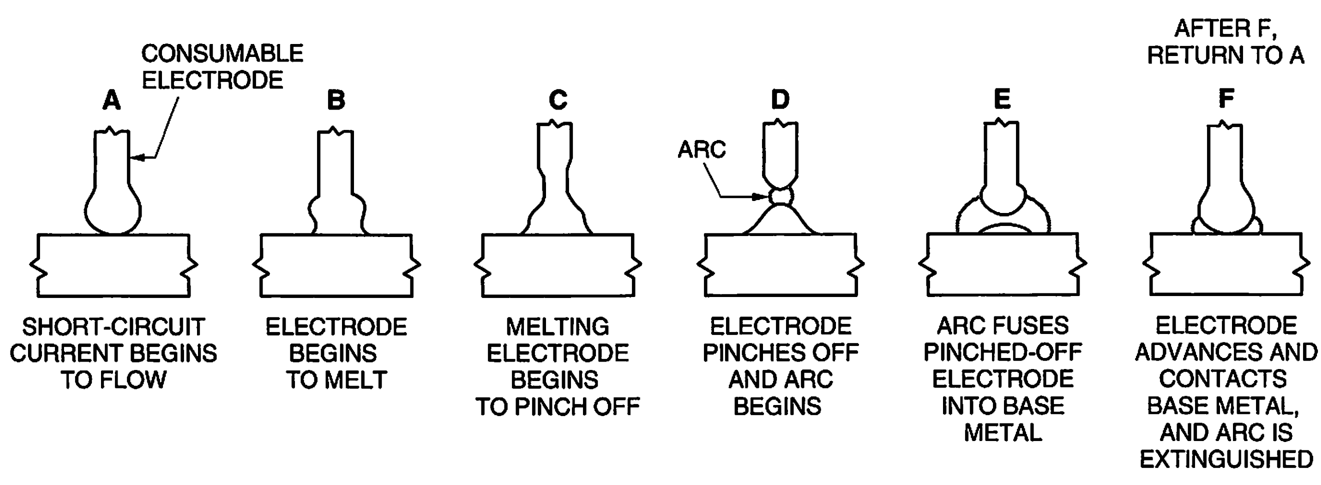


Figure 13 ◆ Short-circuiting transfer.

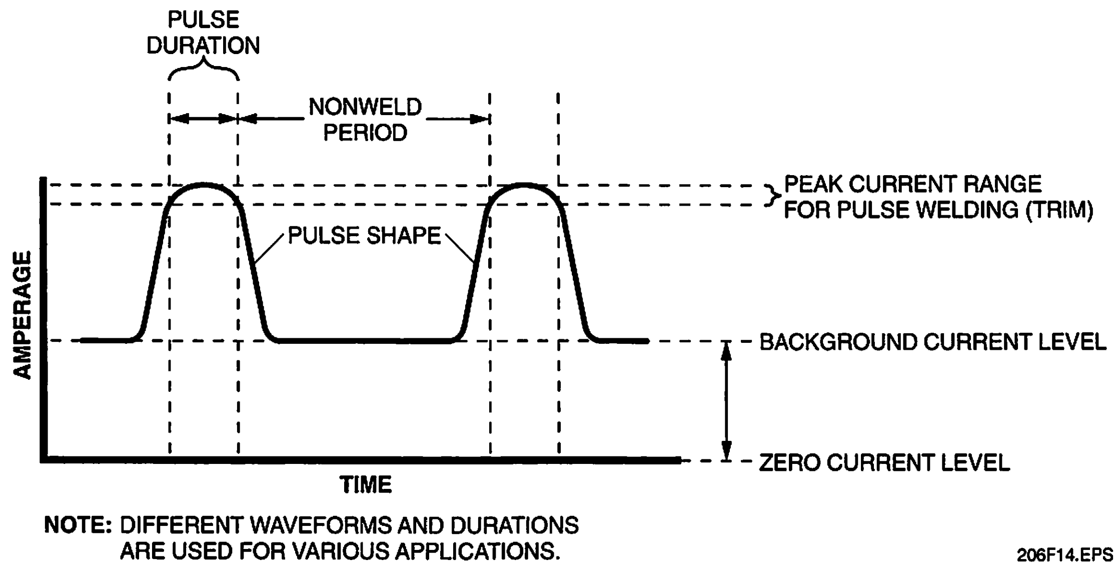


Figure 14 ◆ Output pulses of high welding current occurring over time.

After an arc is established and maintained between the consumable electrode (wire) and the base metal, the welding current to the electrode is momentarily increased to form a pulse and then returns to its lower background level. Each pulse of welding current must peak strongly enough, and have enough duration, to make a single drop of molten metal separate from the wire that is maintaining an arc with the base metal.

Figure 15 shows the pulsed welding process as associated with one of the pulse shapes. Points A through E on the diagram relate to the electrode arc illustrations, labeled A through E, above the diagram.

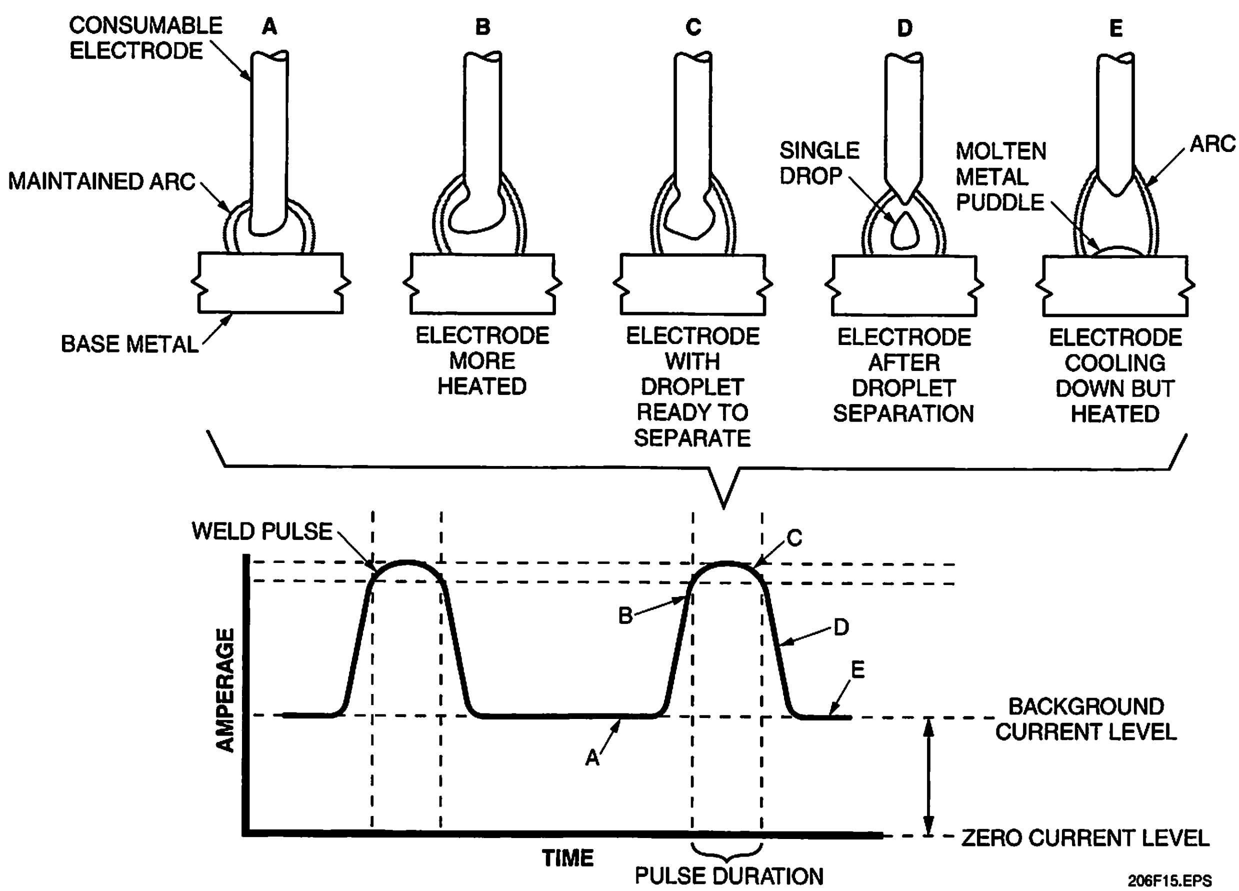


Figure 15 ◆ Typical pulsed welding process associated with one pulse shape.

Hot Tip: *Adaptive Control Welding*

Some newer inverter power sources are capable of using adaptive control welding during pulse transfer. These units sense and alter the frequency of the pulse, its width, the peak current, and wire speed automatically to maintain optimum welding characteristics during welding.

When the single drop of molten metal separates from the electrode, it is transferred across the arc to form the molten puddle on the base metal. This transfer process creates less spatter and reduces the chances of melt-through. When these pulses are repeated many times per second, the result is a high-quality weld with minimal heat affecting the welding zone.

5.2.0 FCAW Metal Transfer Process

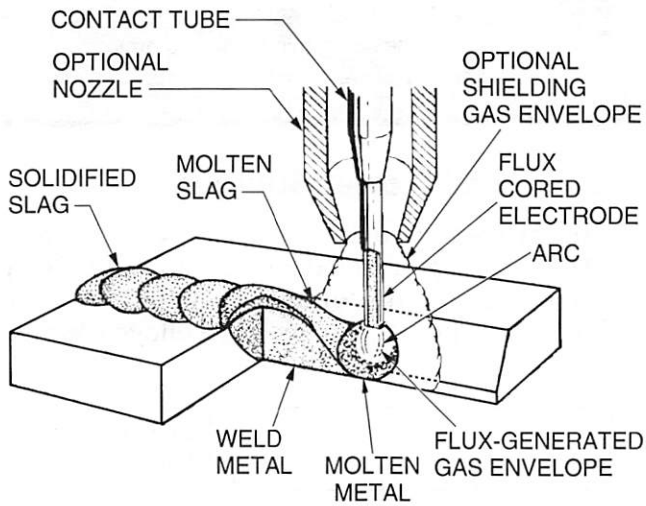
Currently, the FCAW process is only used for ferrous base metals. The FCAW process uses an electric arc to melt the filler and base metals and to transfer fine droplets of filler metal to the weld puddle. The electromagnetic force that propels the metal spray is strong, but the process produces very little spatter. The flux inside the core contains ingredients to perform several functions:

- Ionizers to stabilize the arc
- Deoxidizers to purge the weld of gases and slag
- Additional metals and elements to enhance the quality of the weld metal
- Ingredients to generate shielding gas
- Ingredients to form a protective slag over the weld bead

The gas shield generated by flux in the wire core as well as that of the external gas shield protects the arc and molten weld metal. The slag cover produced by the flux helps to support the weld metal, permitting the process to be used for making high-quality welds in all positions. With larger diameter flux cored wires, deposition rates of 25 pounds per hour can be achieved. *Figure 16* shows the FCAW process.

5.2.1 FCAW Weld Penetration

FCAW welds made with carbon dioxide (CO_2) shielding have much deeper penetration than either SMAW or FCAW without shielding gas. For this reason, edge preparation is often not needed for double-welded butt joints on plate up to ⅜-inch thick. When making FCAW fillet welds using CO_2 shielding, a smaller size fillet weld will have as much strength as a larger fillet made with SMAW because of the deep penetration achieved with FCAW and the carbon dioxide shielding.



NOTE: OTHER GUN CONFIGURATIONS AND STYLES ARE AVAILABLE.

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Figure 16 ◆ FCAW process.

Hot Tip: *Pulse Transfer Advantages*

The following are advantages of pulsed transfer welding over welding processes using continuous currents:

- Rivals GTAW for weld quality.
- Permits all-position welding.
- Allows smooth welds to be made on thin materials without melt-through.
- Controls thick plate weld pool more easily.
- Reduces cost because larger diameter electrode wire can be used.
- Can be used on base metals such as aluminum, stainless steel, copper alloy, and nickel steels as well as carbon steels.
- Reduces weld contamination from surface oxides because less surface area is exposed during the weld.

5.2.2 FCAW Joint Design

FCAW uses the same basic joint designs as SMAW. However, when making groove welds with FCAW and CO_2 shielding gas, the square groove (square butt) joint can be used for plate thicknesses up to ⅜ of an inch. Above this thickness, beveled joints should be used.

Because FCAW electrode wire is much thinner than comparable SMAW electrodes, and FCAW penetration with carbon dioxide is superior to SMAW, the included angles of V joints can be reduced to half the angle required for SMAW. For example, a SMAW included angle of 60° can be reduced to 30° when using FCAW with CO_2 shielding. This can save approximately 50 percent on filler metal and considerable welding time when compared with using SMAW. *Figure 17* shows joint designs for FCAW with CO_2 shielding.

CAUTION
Always refer to your WPS or Site Quality Standards for specific information on joint requirements. Information in this manual is provided as a general guideline only.

5.3.0 GMAW Power Sources

As described in earlier sections, GMAW and FCAW are best performed with a constant-voltage (CV) or constant voltage/constant current (CV/CC) DC power. In constant-voltage welding machines, the open-circuit voltage and the welding voltage are nearly the same. Constant-current variable voltage DC welding machines, the type used for SMAW, in which the output voltage varies between high open-circuit voltage and lower arc voltage, are sometimes used but require specially designed voltage-sensing wire feeders. CV/CC welding machines are required for GMAW-P operation.

Power sources usually contain controls for adjusting arc voltage, slope, and inductance and have meters to monitor amperage and voltage. The simplest machines are power sources with built-in wire feeders. A simple combination welder-wire feeder may have only a wire-feed speed control and a voltage control.

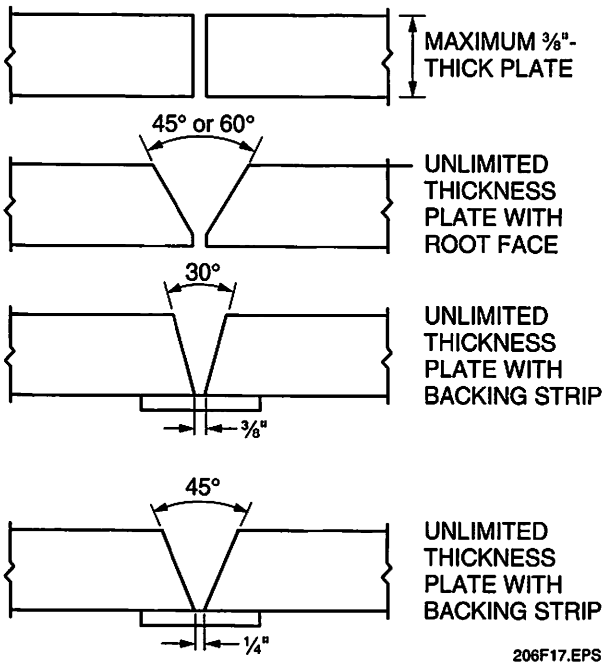

Figure 17 ◆ Joint designs for FCAW with CO_2 shielding.

5.3.1 Slope

The constant voltage power sources used for GMAW and FCAW are not truly constant in their voltage output, because the voltage always drops a little as the current (amperage) increases. This voltage-to-amperage relationship forms a slight curve when plotted as a graph. The general angle of the volt-ampere curve is known as the slope. This slope is adjustable on some power sources. A flatter (more horizontal) slope is better for spray transfer welding, while a steeper slope is better for short-circuiting welding. *Figure 18* shows flat slope and steep slope volt-ampere curves for GMAW.

5.3.2 Pinch Effect and Inductance

When using short-circuiting welding in GMAW, the current passing through the wire electrode heats and then melts the wire. This is sometimes

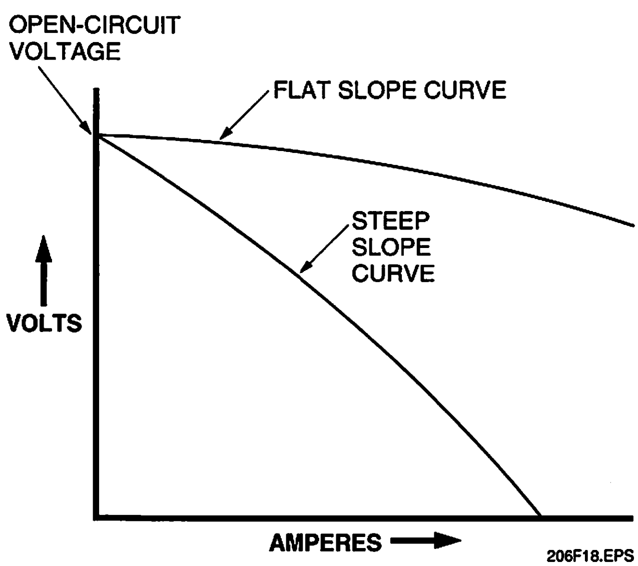

Figure 18 ◆ Flat slope and steep slope volt-ampere curves for GMAW.

called the pinch effect because the molten wire appears to be pinched off, forming a droplet of molten metal. *Figure 19* shows the pinch effect.

Low inductance produces high pinch effect, and high inductance produces low pinch effect. With low circuit inductance, the current rise is very fast, and the high pinch effect can cause the wire droplet to explode or spatter. When the circuit inductance is high, the current rises more slowly, decreasing the number of short circuits per second and extending the arc duration. The pinch effect forms the droplet more gently, which results in a more fluid puddle, smoother weld, and less spatter.

Constant voltage power sources are self-regulating in that they automatically produce current as it is required. Inductance controls the rate at which the current output rises. Some inductance is desirable in FCAW because it prevents explosive arc starts by slowing down the current rise rate. Many FCAW power sources have a control to adjust the inductance.

5.3.3 Arc Blow

When operating in GMAW spray transfer mode or in FCAW, arc blow can sometimes be a problem. Arc blow is the deflection of the arc from its normal course because of the attraction or repulsion of the arc's magnetic field with the weld current's magnetic field in the base metal. The amount and direction of arc deflection depend upon the relative position, direction, and density of the base metal's magnetic field. Arc blow can result in excess spatter and weld defects. It can be minimized by relocating the workpiece clamp or changing the weld angle of the gun.

5.4.0 Welding Cable

Cables used to carry welding current are designed for maximum strength and flexibility. The conductors inside the cable are made of fine strands of copper wire. The copper strands are covered with layers of rubber reinforced with nylon or dacron cord. *Figure 20* shows a cutaway section of welding cable.

The size of a welding cable is based on the number of copper strands it contains. Large-diameter cable has more copper strands and can carry more welding current. Typical welding cable sizes (*Appendix, Table 1*) range from #4 to #3/0 (3 aught).

When selecting welding cable size, the amperage load as well as the distance the current will travel must be considered. The longer the distance the current has to travel, the larger the cable must be to reduce voltage drop and heating caused by the electrical resistance in the welding cable. When selecting welding cable, use the rated capacity of the welding machine for the cable amperage requirement. For the distance, measure

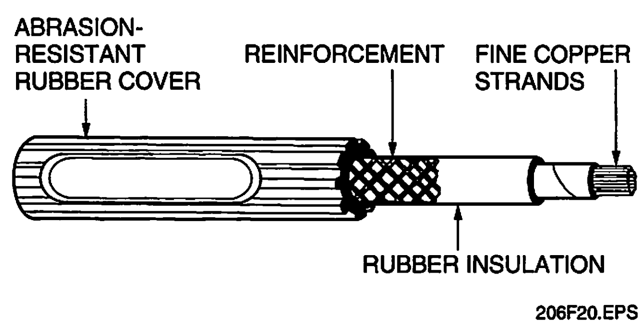

Figure 20 ◆ Cutaway section of welding cable.

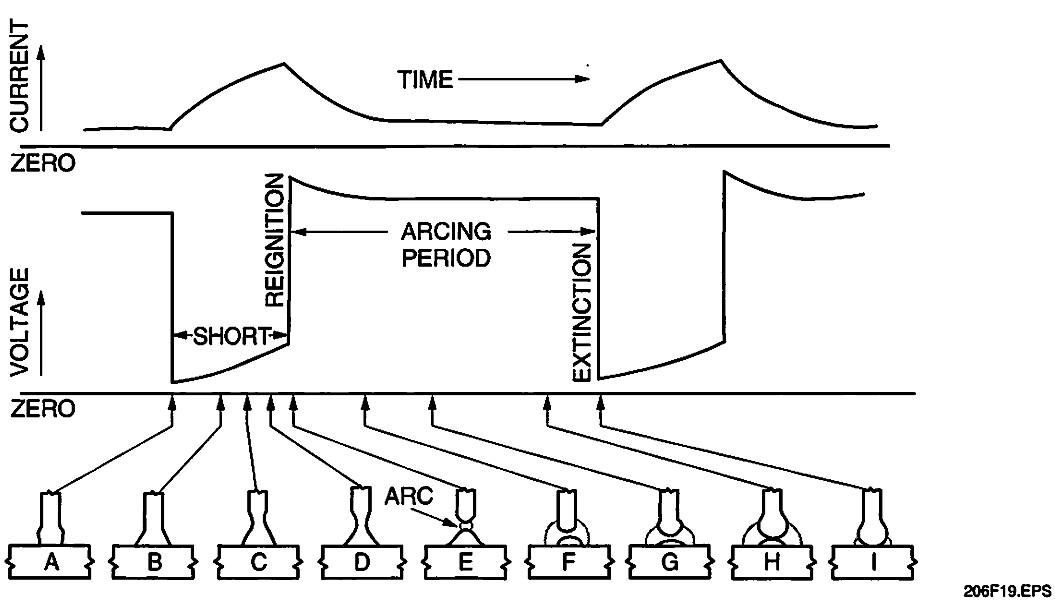

Figure 19 ◆ Pinch effect.

both the electrode and the workpiece leads, and add the two lengths together. To identify the welding cable size required, refer to a recommended welding cable size table, furnished by most welding cable manufacturers.

5.4.1 Welding Cable End Connections

For efficient use, welding cables must be equipped with the proper end connections or terminals.

> **CAUTION**
> If the end connection is not tightly secured to the cable, the connection will overheat and oxidize. An overheated connection will cause variations in the welding current and permanent damage to the connector and/or cable. Check connections for tightness and repair loose or overheated connections.

Lugs are used at the end of the welding cable to connect the cable to the welding machine current terminals. The lugs come in various sizes to match the welding cable size and are mechanically connected onto the welding cable.

Quick disconnects are also mechanically connected to the cable ends. They are insulated and serve as cable extensions for splicing two lengths of cable together. Quick disconnects are connected or disconnected with a half twist. When using quick disconnects, care must be taken to ensure that they are tightly connected to prevent overheating or arcing in the connector. *Figure 21* shows typical lugs and quick disconnects used as welding cable connectors.

The workpiece clamp (see *Figure 22*) provides the connection between the end of the workpiece lead and the workpiece. Workpiece clamps are mechanically connected to the welding cable and come in a variety of shapes and sizes. The size of a workpiece clamp is the rated amperage that it can carry without overheating. Workpiece clamps must be rated at least the same as the rated capacity of the power source on which they will be used.

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Figure 22 ◆ Workpiece clamps.

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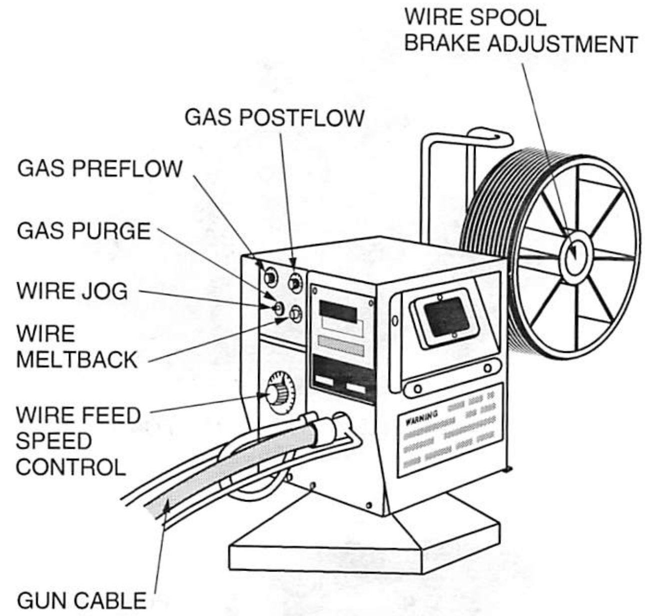
Figure 21 ◆ Lugs and quick disconnects.

5.5.0 External Wire Feeders

An external wire feeder pulls the electrode wire from a spool and pushes it through the gun cable and the gun. It consists of a wire spool holder with a drag brake, an electric motor that drives either one or two sets of opposing slotted rollers, and various controls. The wire feeder also usually contains the shielding gas connections, the gas control solenoid, and (optionally) the cooling-water flow-control solenoid. Some controls that may be located on a wire feeder include the following (not all these controls are present, and other controls may exist, on some wire feeders):

- *Spool drag* – This is a manual adjustment used to adjust the drag on the wire spool to prevent the uncontrolled unwinding of the wire.
- *Wire feed speed control* – This is a variable control used to set the wire feed speed. Since GMAW power sources are self-regulating (they produce the required current on demand), increasing or decreasing the wire feed speed will cause the welding machine to automatically increase or decrease its current output.
- *Voltage control* – This control is used to set the welding voltage.
- *Wire jog* – The manual wire jog switch is used to start and stop the wire feeder without energizing the welding current.
- *Wire meltback timer (burnback)* – This is an adjustable time delay that causes the welding current to continue after the trigger is released. This consumes the length of wire that continues to feed after the trigger is released so that the proper **stickout** is maintained to start the next weld.
- *Gas purge* – The manual gas purge switch is used to operate the gas solenoid to purge the shielding gas system prior to actual welding. It is also used to adjust the flowmeter.
- *Trigger hold* – This switch enables or disables a trigger hold function activated by the gun trigger. This function enables welding without holding the trigger.
- *Gas preflow timer* – This is an adjustable time delay that prevents the welding current contactor from closing until the shielding gas is flowing.
- *Gas postflow timer* – This is an adjustable time delay that is used to keep shielding gas flowing for a short period after the gun trigger is released.

Figure 23 shows typical basic wire feeder units, and *Figure 24* shows other types of wire feeders.



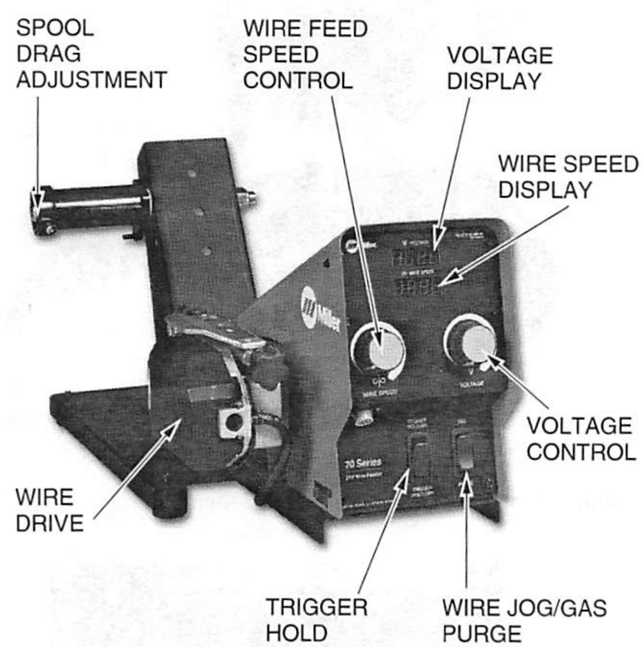


Figure 23 ◆ Basic GMAW/FCAW wire feeder units.

The wire feeder grips the wire in the grooves of opposing grooved rollers. There can be one or two sets of opposed rollers (*Figure 25*). The grooves can be V-grooved or U-grooved in cross section. V grooves are used for hard wire. One roller slot in each V-groove set may be serrated for better gripping. U-groove rollers are used for soft wire or soft-shelled cored wire. For extremely soft wire or soft-shelled cored wire, cogged U-groove rollers are used.

Figure 24 ◆ Various types of wire feeders.

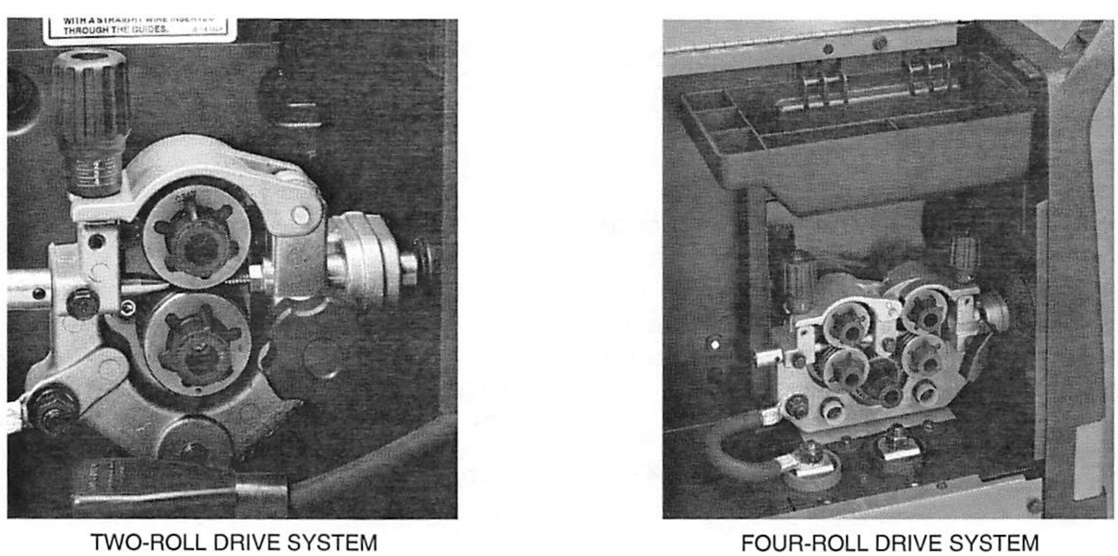


Figure 25 ◆ Wire feeder drive roll systems.

Some rollers are made in two pieces with different-size half-grooves formed on the outside edges of each half-roller. The half-rollers are assembled to fit two different ranges of wire size. *Figure 26* shows groove styles and combination rollers.

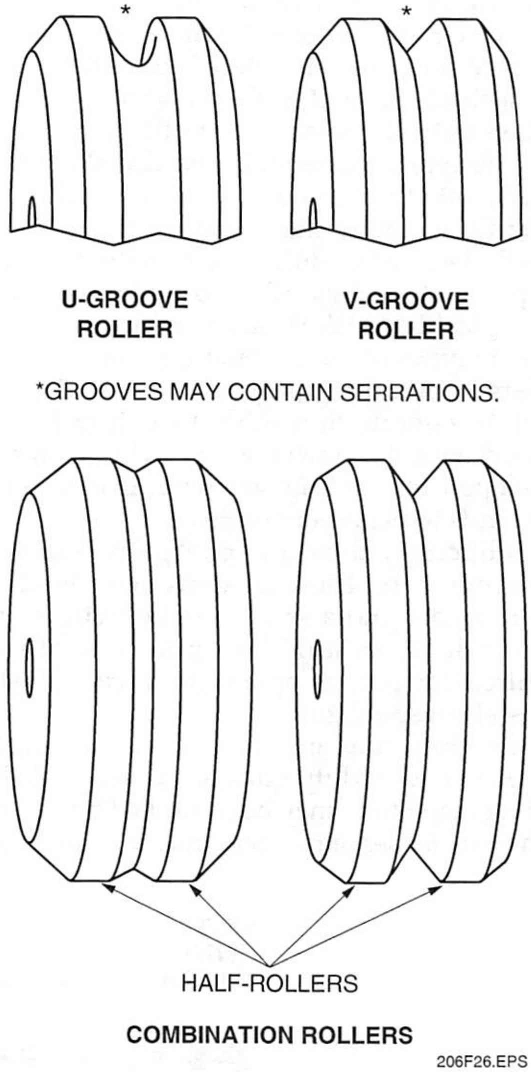


Figure 26 ◆ Groove styles and combination rollers.

When dust or dirt is a problem, a felt wiper can be added to the wire between the spool and the inlet guide to the feed rollers. The felt wipers are treated with a silicone lubricant that cleans and lubricates the wire. Special liquid silicone cleaner/lubricants can be added to the felt wiper occasionally.

CAUTION

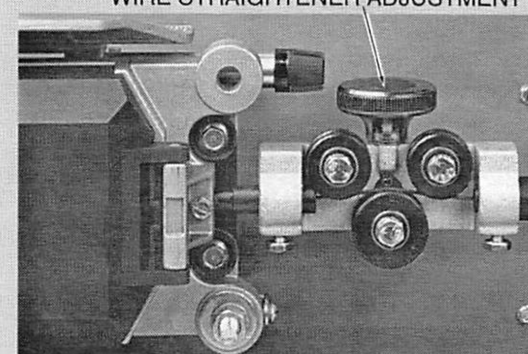
Use only special cleaner/lubricants made specifically for wire feed wipers. Use of other cleaners or lubricants may cause porosity in the weld.

Hot Tip

Wire Straighteners

A wire straightener can be added to some wire feeders. This device can be adjusted to remove the spool cast (curl) imparted to solid wire or hard-shelled cored wire to prevent wire jams and wear in the gun cable.

WIRE STRAIGHTENER ADJUSTMENT



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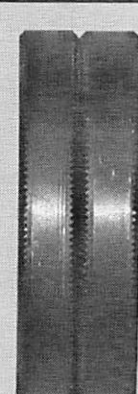
Hot Tip

Knurled Roller

In addition to the U-groove rollers, knurled V-groove rollers are used for hard-shelled cored wire. Knurled rollers have small serrations formed into the edge of the groove to help the roller grab the wire and push it out to the gun without crushing it.



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5.6.0 GMAW/FCAW-G Guns

The GMAW/FCAW-G gun supports and guides the wire electrode and provides the electrical contact between it and the welding machine electrode lead. The gun also contains a remote switch to start and stop the welding current and the shielding gas flow. The gun tip contains a nozzle to direct the shielding gas around the arc. The tip of the electrode wire extends through the contact tube, located within the center of the nozzle. The contact tube is replaceable and must be matched to the electrode wire size. Because the contact tube is the welding current's electrical connection with the electrode wire, it is also subject to wear from friction with the wire and electrical erosion and must be replaced periodically. GMAW guns are usually rated for amperage at a 100% duty cycle using CO_2 and are derated from 10% to 50% for mixed gases, depending on gas mixture and welding parameters. *Figure 27* shows the construction of a typical GMAW/FCAW-G gun.

Some types of guns contain motor-driven wire pullers within the gun handle (*Figure 28*). These work in conjunction with a push wire feeder located with the power source. This system was developed for feeding soft wire, like aluminum, that tends to bend very easily.

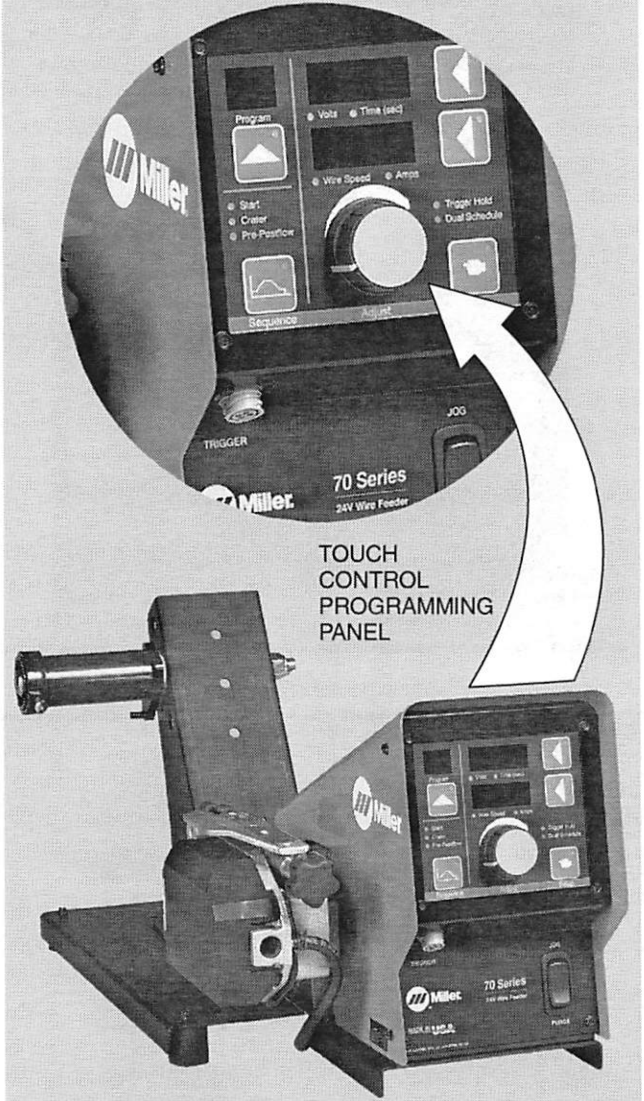
Additionally, there are spool guns designed for aluminum wire. These are guns that contain both a wire feeder and a small spool of wire. In some applications, an auxiliary gun control unit is required for proper operation. *Figure 29* shows one style of spool gun.

Light-duty guns are gas-cooled by the shielding gas flow. Heavy-duty guns are water cooled. The cooling water flow may be controlled by a solenoid in the wire feeder or by a separate dedicated cooling

Hot Tip

Programmable Wire Feeders

Programmable wire feeders are normally used with compatible CC/CV power sources for GMAW-P applications. Custom welding programs can be created, or preset welding programs can be stored in the feeder or in the power source. The program can be activated by the various controls and displays on the feeder.



PROGRAMMABLE WIRE FEEDER

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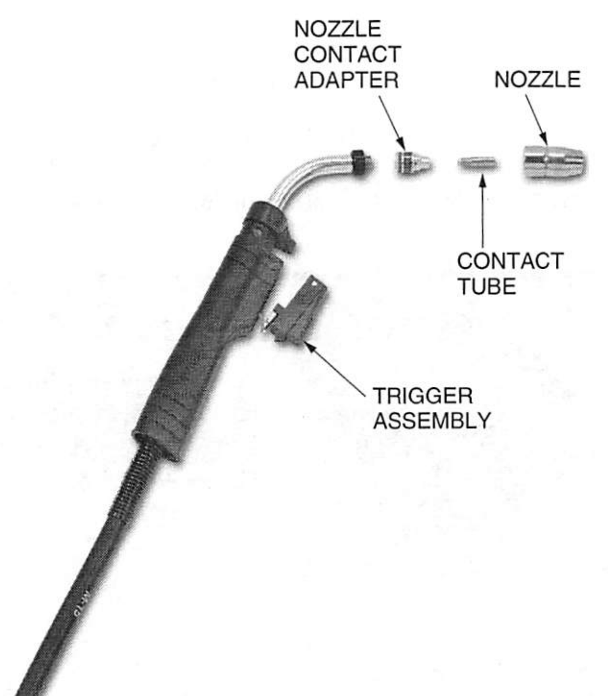

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Figure 27 ◆ Construction of a typical GMAW/FCAW-G gun.

system. Cooling water is piped to and from the gun through flexible tubing integrated into the gun cable. Some cooling systems use domestic water to cool the gun. Others use a closed-loop system (see *Figure 30*) that circulates de-mineralized water or special cooling fluid that will not corrode internal gun surfaces or plug the cooling passages with mineral scale.

5.7.0 FCAW-S Guns

FCAW-S guns are similar to GMAW/FCAW-G guns but are often designed to handle larger diameter wire. The FCAW gun supports and guides the wire electrode. It also contains a remote switch for starting and stopping the welding current. The electrode wire extends through the contact tube located at the end of the gun. The contact tube provides the electrical connection from the welding machine electrode lead to the electrode wire. The contact tube is replaceable and must always be matched to the electrode wire size. If it is too small, the wire will jam; if it is too large, poor contact will cause damaging arcing between the tip and the wire. The contact tube is subject to wear from sliding friction and electrical erosion caused by the wire and must be replaced periodically.

Guns designed for self-shielded FCAW do not have provisions to deliver shielding gas. This makes the gun nozzles smaller in diameter. To protect the contact tube, these guns have a fiber insulator that threads onto the end of the gun nozzle.

FCAW-S generates smoke, which can be removed at the gun tip with a special smoke extraction nozzle. The nozzle is connected to a vacuum pump or blower by a flexible tube to draw off the smoke and thereby improve visibility. *Figure 31* shows an FCAW-S gun without the smoke extractor.

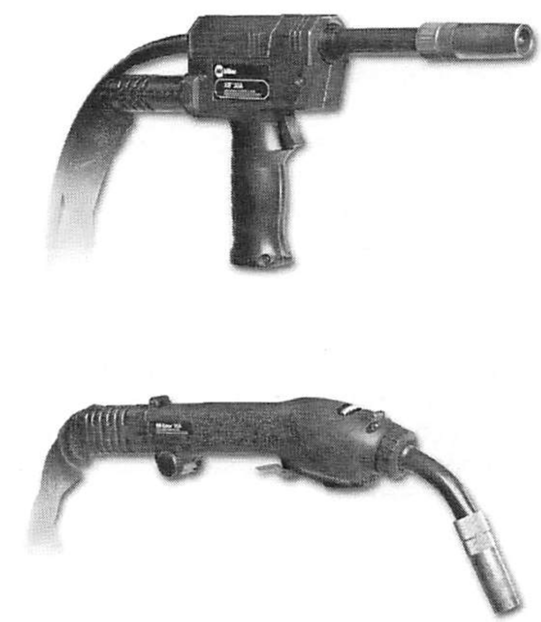

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Figure 28 ◆ Pull guns for push-pull wire feeders.

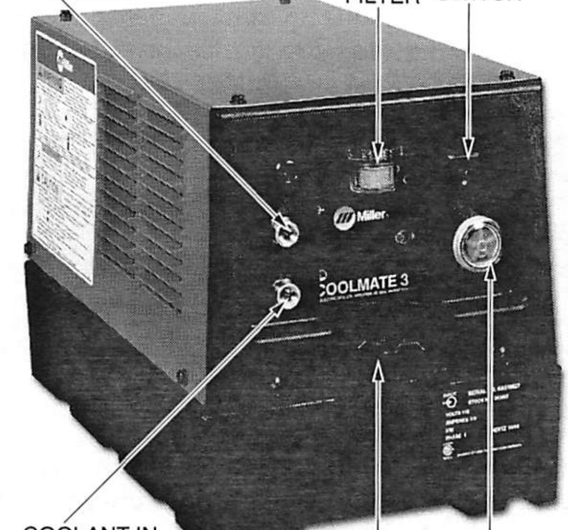

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Figure 30 ◆ Typical closed-loop cooling unit.

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Figure 29 ◆ Spool gun.

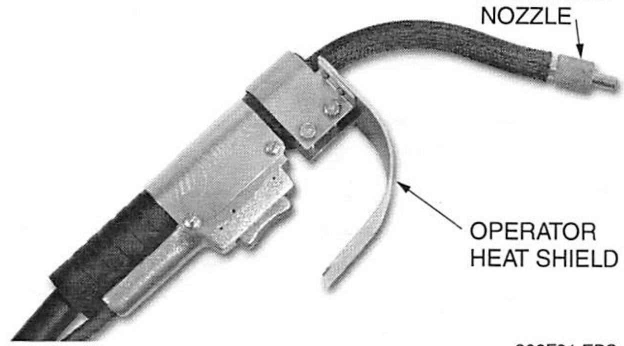

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Figure 31 ◆ FCAW gun without smoke extractor.

5.8.0 Shielding Gas Supply

The GMAW/FCAW-G process always uses shielding gas to protect the welding electrode (wire) and the weld from contamination. The shielding gas is directed around the electrode end and the weld zone by the nozzle of the gun. The most common shielding gases are argon (Ar), helium (He) and carbon dioxide (CO_2). These may be used alone or mixed. A small amount of oxygen (O_2) is often added to argon to stabilize the arc, increase the filler transfer rate, and improve wetting and bead shape.

Some FCAW core wires require the use of a shielding gas. The shielding gas is directed around the electrode end and the weld zone by the nozzle of the gun. The shielding gas used depends on the filler wire and base metal being welded. The most common shielding gases for FCAW carbon and low-alloy steels are carbon dioxide (CO_2) or an argon-carbon dioxide mix. For FCAW high-alloy or stainless steels, argon or an argon-carbon dioxide mixture is generally used. These gases are available in pressurized cylinders of various sizes and in bulk liquid.

CAUTION

Check your WPS or Site Quality Standards for the type of shielding gas to use. If these are not available, refer to the filler metal supplier's specifications.

5.8.1 Cylinder Safety

Cylinders must always be handled with great care because of the extremely high-pressure gases they contain. When a valve is broken off a high-pressure cylinder, the gas escapes with explosive force and can severely injure personnel with the blast and blown debris. The cylinder itself can become a powerful uncontrolled missile. When transporting and handling cylinders, always observe the following rules:

- The safety cap should always be installed over the valve except when the cylinder is connected for use.

WARNING!

Do not remove the protective cap unless the cylinder is secured. If a cylinder falls over and the nozzle breaks off, the cylinder will shoot like a rocket, causing severe injury or death to anyone in its way.

- When in use, the cylinder must always be secured to prevent it from falling. It should be chained or clamped to the welding machine or to a post, beam, or pipe.
- A cylinder cart should be used to transport a cylinder.
- Cylinders should never be hoisted by slings or magnets. They can slip out of the sling or fall from the magnets. Always use a hoisting basket or similar device.
- Always open the cylinder valve slowly. Once pressure is applied to the system, the valve should be completely opened to prevent leakage from around the valve stem.

5.8.2 Gas Regulators/Flowmeters

A gas regulator/flowmeter is required to meter the shielding gas to the gun at the proper flow rate. A typical regulator/flowmeter consists of a preset pressure regulator with a cylinder valve spud, a flowmetering (needle) valve, and a flow-rate gauge. The pressure regulator is usually equipped with a tank pressure gauge to show cylinder pressure. The metering valve is used to adjust the gas flow to the gun nozzle. The flow gauge indicates the gas flow rate in cubic feet per hour (cfh) or liters per minute as shown by a ball-type flow indicator. *Figure 32* shows a shielding gas regulator/flowmeter.

Gas flow to the gun is started and stopped by an electric solenoid valve that is usually located inside the control unit or the wire feeder unit. The solenoid is controlled by the operator with the trigger switch on the gun. The same trigger switch simultaneously starts and stops the wire feeder and welding current.

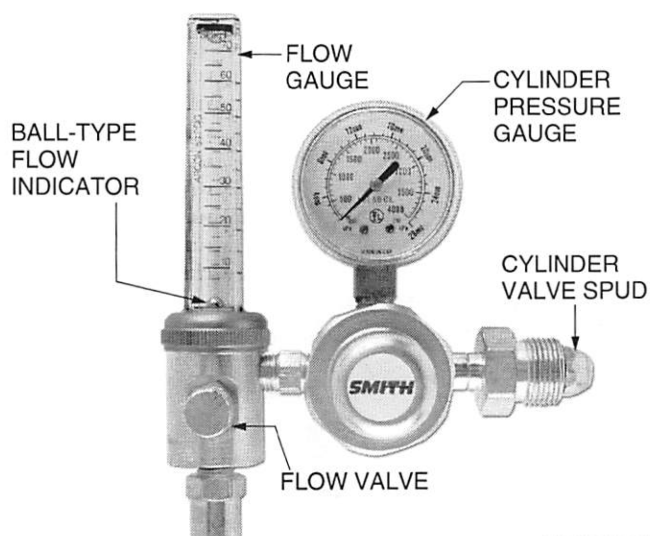


Figure 32 ◆ Shielding gas regulator/flowmeter.

6.0.0 ◆ SHIELDING GASES

Shielding gases are used to displace atmosphere from the weld zone to prevent contamination of the weld puddle by oxygen, nitrogen, and moisture. The three principal shielding gases are argon (Ar), helium (He), and carbon dioxide (CO_2). These gases are often mixed in various proportions for specific applications.

6.1.0 Shielding Gas Characteristics

Each of the shielding gases has distinctive individual performance characteristics. Each welds differently and works differently with different arc modes and base metals. Mixtures of gases often have the best features of the individual constituents. The following sections explain some of the features of the principal gases and their primary uses.

6.1.1 Argon

Argon (Ar), an inexpensive, inert gas, is the most commonly used shielding gas. Because of its current transfer and ionization properties, argon can be used alone or in combination with other shielding gases. It forms a tight arc column with high current density, concentrating the arc in a small area and producing deep penetration.

Pure argon is used with aluminum, nickel-based alloys, copper alloys, and the reactive metals zirconium, titanium, and tantalum. It provides excellent arc stability, penetration, and bead shape. For ferrous metals, argon is usually mixed with oxygen, helium, hydrogen, carbon dioxide, and/or nitrogen.

6.1.2 Helium

Because of thermal conductivity (heat transfer), helium is used when deeper penetration and higher travel speed are required.

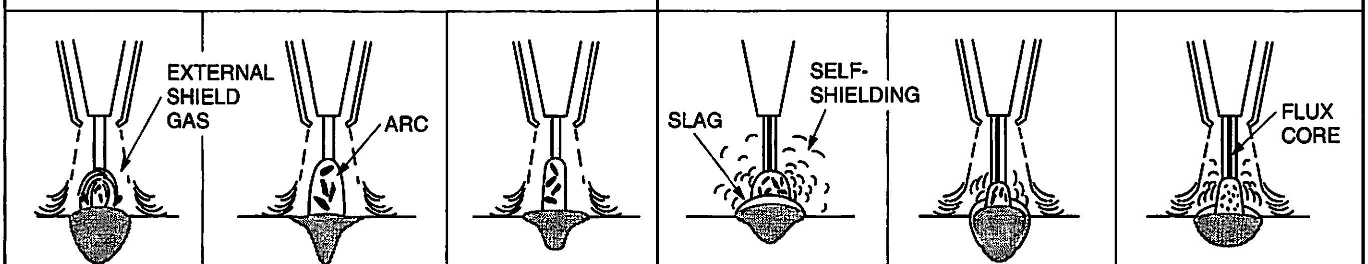
Arc stability with helium is not as good as it is with argon. The helium arc column is wider than the argon arc column, resulting in reduced current density. It is better for welding aluminum, magnesium, and copper alloys because of better puddle fluidity and bead wetting. Some mixtures of helium and argon have the beneficial characteristics of both gases. Helium mixtures of 90% helium, 7.5% argon, and 2.5% carbon dioxide are widely used for short-circuit GMAW of stainless steel in all positions.

6.1.3 Carbon Dioxide

Carbon dioxide is commonly used to weld mild steel because of its low cost and weld performance. In the welding arc it is not an inert gas, because it breaks down into carbon monoxide and free oxygen. The oxygen combines with elements in the weld puddle to form slag. Carbon dioxide does not support spray transfer, so short circuiting transfer and globular transfer must be used. Carbon dioxide provides good penetration. However, the weld surface is heavily oxidized and has high weld spatter. Normally, argon is mixed with no more than 25% carbon dioxide to improve the performance characteristics. *Figure 33* shows the effects of shield gas on the welding arc.

6.1.4 Gas Mixtures

The principal shielding gases are often mixed to improve their overall welding characteristics. For



GMAW			FCAW		
CO_2	Ar-O_2	Ar-CO_2	SELF-SHIELDING	DUAL-SHIELDING with CO_2	DUAL-SHIELDING with Ar-CO_2
Shorter, Colder Arc	Hotter Arc Narrow Penetration	Eliminates Under Cutting	Better Arc Ionization Provides Covering (Slag)	Increases Penetration	Increases Arc Length, Improves Spray, and Decreases Penetration

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Figure 33 ◆ Effects of shield gas on the welding arc.

steel, small amounts of oxygen added to argon stabilize the arc, increase filler metal deposition rate, and improve wetting and bead shape. Small percentages of oxygen added to carbon dioxide improve arc characteristics. Helium is added to argon to increase the arc voltage and heat for welding nonferrous metals. Small amounts of nitrogen and oxygen are added to argon for welding stainless steel when the austenitic characteristics should be preserved. Helium and carbon dioxide are added to argon to improve arc stability, wetting, and bead profile. *Table 2* (see *Appendix*) shows some examples and uses of gas mixtures. Many other typical gas mixtures are available as shown in *Table 3* (see *Appendix*). The AWS classification for gases and gas mixtures is covered in *ANSI/AWS 5.32/A5.32M*.

6.2.0 Shielding Gas Selection

Selecting the best shielding gas for a particular welding task involves the consideration of many factors. The shielding gas selected will affect arc shape, arc density, arc temperature, arc stability, rate of filler metal transfer, degree of spatter, weld penetration, weld bead shape, weld bead appearance, weld porosity, weld chemistry, and weld quality.

Shielding gases affect the welding process in three ways:

- Gas thermal conductivity affects arc voltage and heat delivered to the weld. The thermal conductivity of both helium and carbon dioxide is much higher than that of argon; both helium and carbon dioxide supply more heat to the weld. Because of this, they also require more voltage and power to maintain a stable arc.
- Some gases can react with the filler and base metals and also affect arc stability. Carbon dioxide and most oxygen-bearing gases cannot be used with aluminum, because they form oxides. However, they provide better fusion and arc stability when used with steels.
- Gases affect the mode of metal transfer and penetration depth. Mixtures containing more than 15% carbon dioxide do not allow true spray transfer.

Table 4 (see *Appendix*) lists common short-circuiting shielding gases and their applications in short-circuiting transfer welding. *Table 5* (see *Appendix*) lists common shielding gases and their applications in spray transfer welding.

6.3.0 Shielding Gas Flow Rate

Gas flow rate from the gun tip is important because it affects the quality and the cost of a weld. Too low a flow rate will not shield the weld zone adequately and will result in a poor-quality weld; excessive gas flow wastes expensive gases and can cause turbulence at the weld. The turbulence can pull atmosphere into the weld zone, causing porosity in the weld. Welding specifications specify shielding gas flow rates. *Table 6* (see *Appendix*) lists typical shielding gas flow rates for various metals and wire sizes.

7.0.0 ◆ FILLER METALS

Filler metals are explained in two sections:

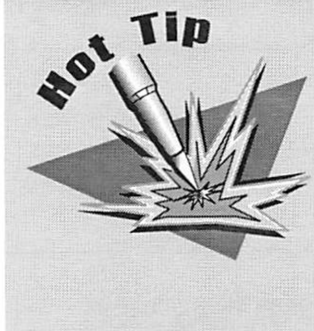
- GMAW filler metals
- FCAW filler metals

7.1.0 GMAW Filler Metals

GMAW uses a continuous solid wire electrode for filler material. This filler wire is drawn from high-grade pure alloys compounded for different applications. During manufacture, the wire is drawn, cleaned and inspected for defects several times. Standard wire diameters are 0.023, 0.030, 0.035, 0.045, 0.052, and 0.062 inches. The finished wire is wound on spools 4, 8, 12, or 14 inches in diameter. The most common spool is 12 inches in diameter and weighs 30 pounds (mild steel wire). Reels up to 30 inches in diameter and weighing up to 1,000 pounds are also available for stationary production welding.

Several industry organizations and the U.S. government publish specification standards for welding wire. The most common are the American Welding Society (AWS) specifications. The purpose of the AWS specifications is to set standards that all manufacturers must follow when manufacturing welding consumables. This ensures consistency for the user regardless of who manufactured the product. The specifications set standards for the following:

- Classification system, identification, and marking
- Chemical composition of the deposited weld metal
- Mechanical properties of the deposited weld metal



Filler Wire and Filler Metal

The terms filler wire and filler metal are both used to describe the filler materials used in GMAW. Filler metal is also referred to as filler rod when used for (GTAW).

The following AWS specifications pertain to gas metal arc welding wires and rods:

- *A5.7, Specification for Copper and Copper Alloy Bare Welding Rods and Electrodes*
- *A5.9, Specification for Bare Stainless Steel Welding Electrodes and Rods*
- *A5.10, Specification for Bare Aluminum and Aluminum Alloy Welding Electrodes and Rods*
- *A5.14, Specification for Nickel and Nickel Alloy Bare Welding Electrodes and Rods*
- *A5.16, Specification for Titanium and Titanium Alloy Welding Electrodes and Rods*
- *A5.18, Specification for Carbon Steel Filler Metals for Gas Shielded Arc Welding*
- *A5.19, Specification for Magnesium Alloy Welding Rods and Electrodes*
- *A5.28, Specification for Low-Alloy Steel Electrodes for Gas Shielded Metal Arc Welding*

NOTE

The specification number is generally followed by a dash and a two-digit number, such as *A5.18-93* or *A5.28-96*. The dash and the following number indicate the year that the specification was last revised.

Filler wire is graded for three major areas of use:

- *General use* – Wire meets specifications. No record of chemical composition, strength, or similar factors is supplied to the user with the wire purchase.
- *Rigid control fabrication* – A Certificate of Conformance is supplied with the wire at purchase. The stock is identified by code numbers located on the roll package.
- *Critical use* – A Certified Chemical Analysis report is supplied, and records are kept by the fabricator of welds and processes for later reference on aircraft, nuclear reactors, and pressure vessels.

The following factors affect the selection of a GMAW filler wire:

- Base metal chemical composition
- Base metal mechanical properties
- Weld joint design
- Service or specification requirements
- Shielding gas used

Commonly used filler wire types include:

- Carbon steel
- Stainless steel
- Aluminum and aluminum alloy
- Copper and copper alloy
- Low-alloy steel

Table 7 (see *Appendix*) summarizes the GMAW filler metal specifications and the major AWS class covered by each specification.

7.1.1 Carbon Steel Filler Metals

Carbon steel filler metals are identified by specification *ANSI/AWS A5.18*. The filler metal is available in wire reels and rod form. The wire classification (number) is located on a label on the side of the reel or container. *Figure 34* shows a typical AWS classification for carbon steel filler metal.

All carbon steel filler metals contain alloys such as silicon, manganese, aluminum, and carbon. Other alloys such as nickel, chromium, and molybdenum are also often added. The purpose of the alloys is as follows:

- *Silicon (Si)* – Concentrations of 0.40–1.00% are employed to deoxidize the puddle and to strengthen the weld. Silicon above 1% may make the welds crack-sensitive. Silicon also lowers the melting temperature of the wire and promotes wetting.
- *Manganese (Mn)* – Concentrations of 1–2% are also employed as a deoxidizer and to strengthen the weld. Manganese also decreases hot-crack sensitivity.
- *Aluminum (Al), titanium (Ti) and zirconium (Zr)* – One or more may be added in very small amounts for deoxidizing. Strength may also be increased.
- *Carbon (C)* – Concentrations of 0.05–0.12% are employed to add strength without adversely affecting ductility, porosity, or toughness.
- *Nickel (Ni), chromium (Cr), and molybdenum (Mo)* – May be added in small amounts to improve corrosion resistance, strength, and toughness.

Rod and Electrode Designations

The letter R that follows the E in an AWS classification number indicates that the classification is used as a metal filler rod as well as an electrode. GMAW and GTAW filler metals are both labeled the same way when used for gas tungsten arc welding (GTAW).

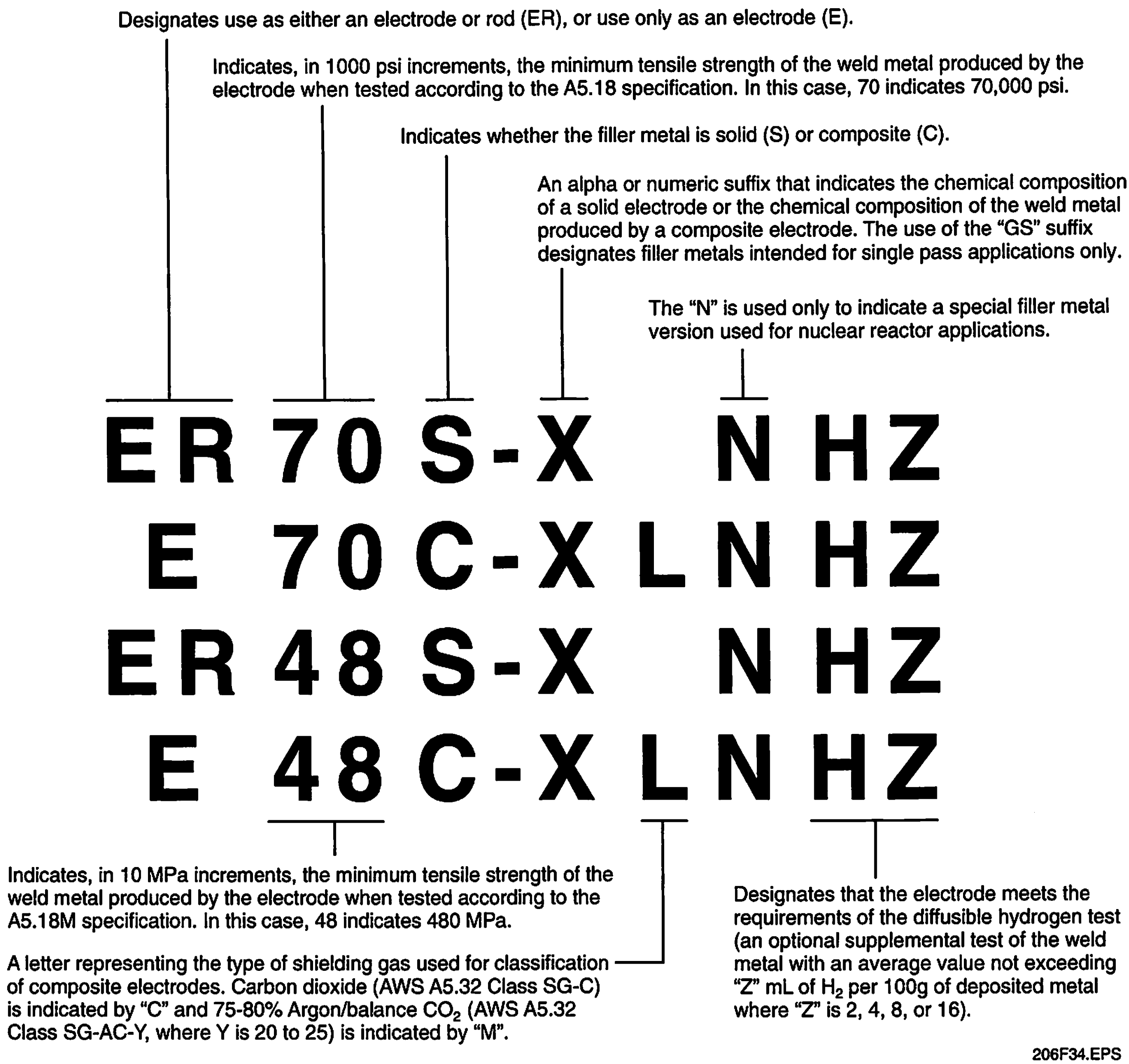


Figure 34 ◆ AWS classification for carbon steel filler metal.

In many cases, carbon steel filler metal wire is copper coated. The copper coating protects the filler metal wire from corrosion and makes electrical contact easier as the wire passes through the copper contact tube at the end of a gun.

Table 8 (see *Appendix*) lists AWS carbon steel filler metal wire classifications and their uses.

7.1.2 Low-Alloy Steel Filler Metals

Low-alloy steel filler metals are identified by *ANSI/AWS Specification A5.28*. The filler metal is available in wire reel and rod form. The wire classification (number) is located on a label on the side of the reel or container. The classification is similar to the carbon steel filler metal classification except that there is a letter in the suffix at the end of the classification. The letter suffix indicates that the filler metal contains alloys (nickel, manganese, molybdenum, etc.) that give the deposited weld metal special properties. Also, the tensile strength of low-alloy filler metals is often higher than that of carbon steel filler metals. For specific information on low-alloy filler metal composition and intended use, refer to the manufacturer's specifications. *Figure 35* shows the AWS classification for low-alloy steel filler metal. *Table 9* (see *Appendix*) provides some uses and characteristics for each AWS class of filler metal.

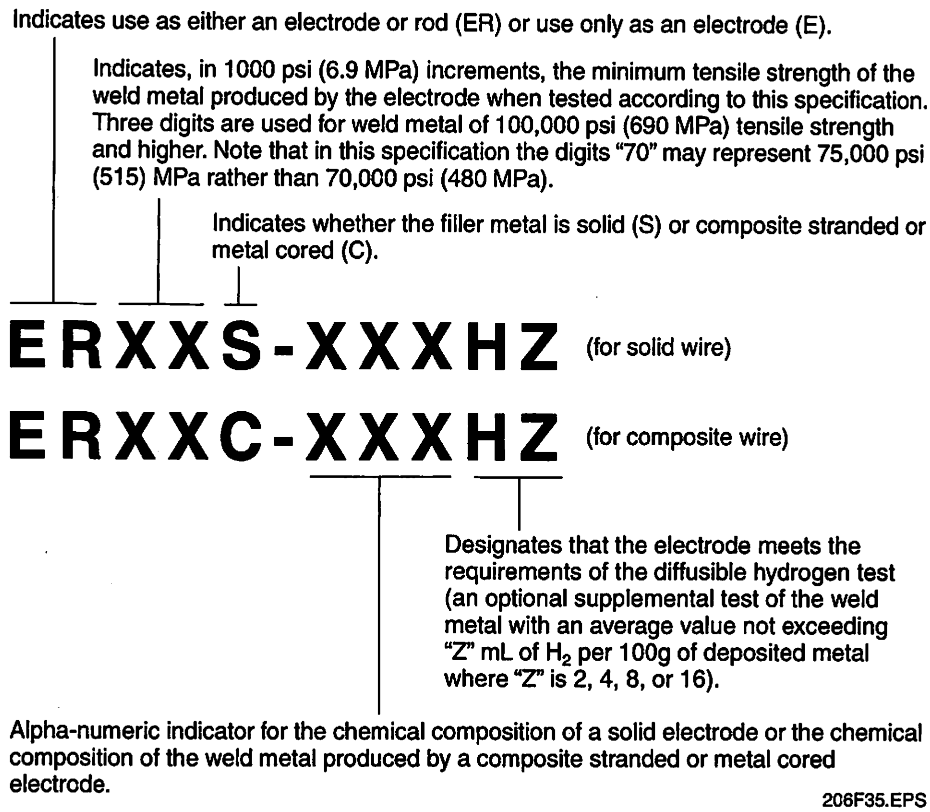


Figure 35 ◆ AWS classification for low-alloy steel filler metal.

7.1.3 Stainless Steel Filler Metals

Stainless steel filler metals are identified by specification *ANSI/AWS A5.9*. The filler metal is available in wire reel, flat strip, and rod form. The wire identifier (number) is located on a label on the side of the reel or container. *Figure 36* shows the AWS classification for stainless steel filler metal.

Stainless steel filler metal should be selected to closely match the alloy composition of the base metal. Stainless steel filler metals also require specific shielding gases or gas mixtures. *Table 10* (see *Appendix*) lists AWS stainless steel filler metal classifications and uses.

7.1.4 Aluminum and Aluminum Alloy Filler Metals

Aluminum filler metals are covered by *ANSI/AWS Specification A5.10*. Aluminum filler metals usually contain magnesium, manganese, zinc, silicon, or copper for increased strength. Corrosion resistance and weldability are also considerations. Aluminum filler metals are designed to weld specific types of aluminum and should be selected for compatibility. The most widely used aluminum filler metals are ER4043 (contains silicon) and ER5356 (contains magnesium). The filler metal

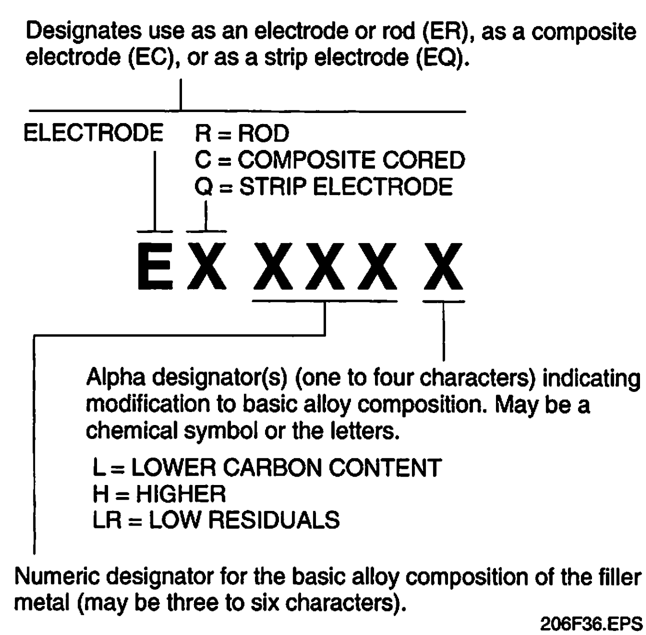


Figure 36 ◆ AWS classification for stainless steel filler metal.

identifier (number) is located on a label on the side of the reel or container. *Figure 37* shows the AWS classification for aluminum filler metal.

Table 11 (see *Appendix*) lists recommended filler metals for common aluminum alloys.

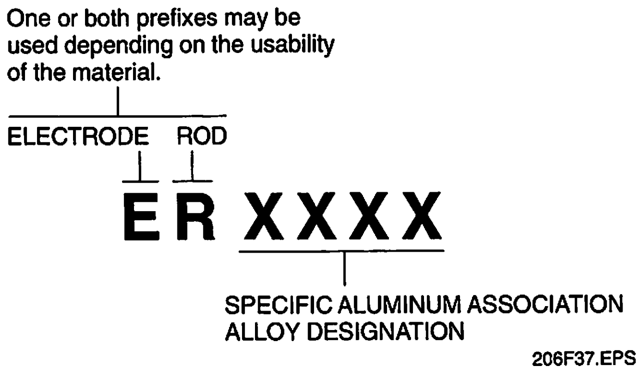


Figure 37 ◈ AWS classification for aluminum filler metal.

7.1.5 Copper and Copper Alloy Filler Metals

Copper filler metals are covered by *ANSI/AWS Specification A5.7*. Most copper filler metals contain other elements that increase strength, deoxidize the weld metal, and match the base metal composition. *Figure 38* shows the AWS classification for copper filler metal.

Table 12 (see *Appendix*) lists AWS copper filler metal classifications and uses.

7.1.6 Nickel and Nickel Alloy Filler Metals

Nickel-based filler metals are covered by *ANSI/AWS Specification A5.14*. These filler metals contain other elements to match base metal applications and to increase the strength and quality of the weld metal. For GTAW, DCEN is used with high-purity argon, helium or both used as a shielding gas. For GMAW, DCEP is used. Argon shielding gas is often used, but mixtures of argon and helium are also used. *Figure 39* shows the AWS classification for nickel filler metals.

Table 13 (see *Appendix*) lists AWS nickel filler metal classifications and uses.

7.1.7 Magnesium Alloy Filler Metals

Magnesium alloy filler metals are covered by *ANSI/AWS Specification A5.19*. These filler metals are usually used with GTAW, GMAW, and PAW processes. Oxyfuel welding should be used only for temporary repair work. For GTAW welding, the techniques and equipment is similar to those for aluminum. Argon, helium, or both are used for shielding. Alternating current is preferred for arc cleaning and penetration. Direct current is also employed with DCEP used for thin materials and DCEN used for mechanized welding with helium for deep penetration. GTAW is recommended for the defect repair of clean magnesium castings. GMAW of magnesium alloys is the same as for other metals. Argon is generally used for shielding; however, mixtures of argon and helium are occasionally used. Pulsed and short-circuit GMAW are used for magnesium alloys. Spray transfer without pulsing is also used. Globular transfer is not suitable. *Figure 40* shows the AWS classification for magnesium filler metals

Table 14 (see *Appendix*) lists recommended filler metals for common magnesium alloys. Note that the prefix ER and R has been removed from the filler metal designations to reduce the size of the table.

7.1.8 Titanium and Titanium Alloy Filler Metals

Titanium and titanium alloy filler metals are covered by *ANSI/AWS Specification A5.16*. These filler metals are generally used with GTAW, GMAW, SAW, and PAW processes. Titanium is sensitive to embrittlement by oxygen, nitrogen, and hydrogen at temperatures above 500°F. Like aluminum, titanium requires weld cleaning and high-purity gas shielding, and especially adequate postflow

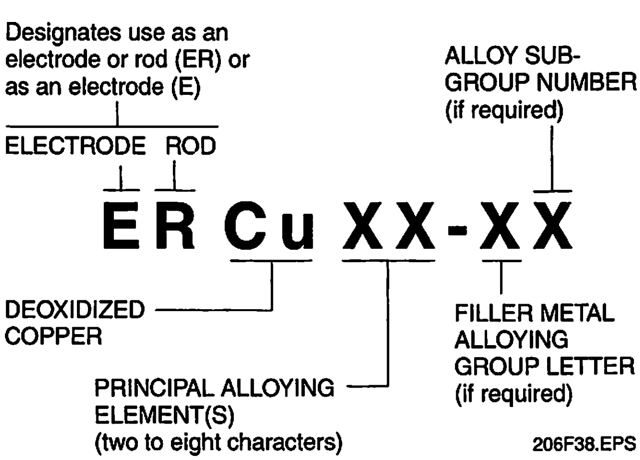


Figure 38 ◈ AWS classification for copper filler metal.

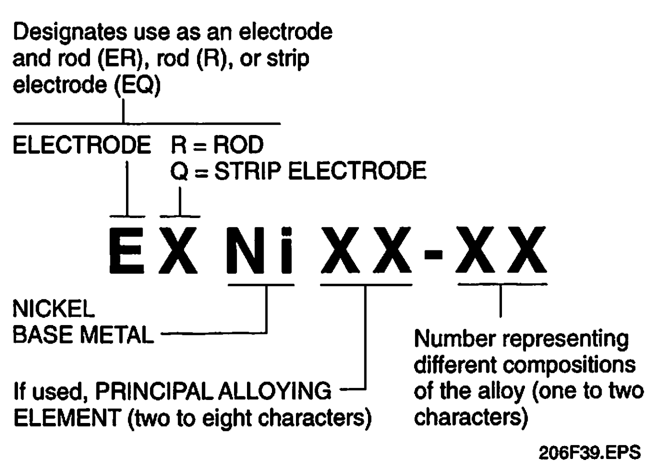


Figure 39 ◈ AWS classification for nickel filler metals.

shielding to avoid embrittlement. Titanium can be successfully fusion welded to zirconium, tantalum, niobium, and vanadium. Titanium should not be fusion welded to copper, iron, nickel, and aluminum. *Figure 41* shows the AWS classification for titanium filler metals.

Table 15 (see *Appendix*) lists AWS titanium filler metal classifications and uses.

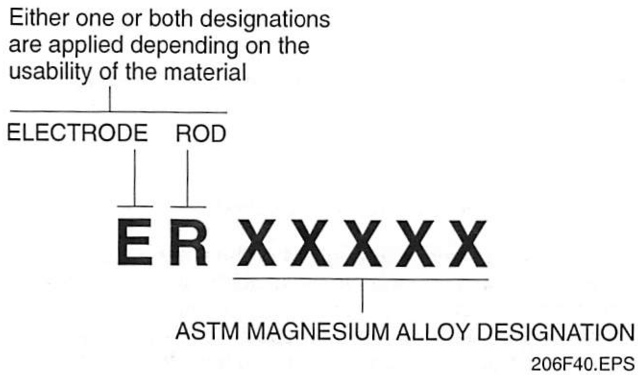


Figure 40 ◆ AWS classification for magnesium filler metals.

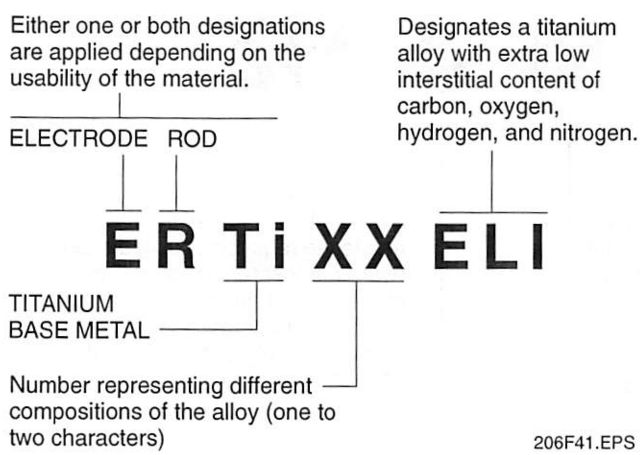


Figure 41 ◆ AWS classification for titanium filler metals.

7.2.0 FCAW Filler Metals

FCAW is presently limited to the welding of ferrous metals. These include low- and medium-carbon steels, some low-alloy steels, cast irons, and some stainless steels.

The FCAW electrode is a continuous flux cored wire electrode. The wire is made by forming a thin filler metal strip into a U shape, filling the U with the flux material, squeezing the strip shut around the flux, and then drawing the tube through dies to size the wire and compact the flux. During manufacture, the wire is carefully inspected for defects. Flux cored wires are manufactured in a range of sizes from 0.030 inch to 5⁄32 inch. The finished flux cored wire is coiled on all the standard spool sizes and forms.

NOTE

All flux cored wires are considered to be low hydrogen. For this reason, proper electrode control procedures must be followed to keep the wire dry.

By varying the power settings on the welding machine, smaller size electrode wire (0.045 and 1⁄16 inch) can be used both for thin metals and for multipass welds on metals of unlimited thickness in all positions.

There are three AWS specifications presently available for flux cored electrodes:

- *ANSI/AWS A5.20 Specification for Carbon Steel Electrodes for Flux Cored Arc Welding*
- *ANSI/AWS A5.22 Specification for Stainless Steel Electrodes for Flux Cored Arc Welding and Stainless Steel Flux Cored Rods for Gas Tungsten Arc Welding*
- *ANSI/AWS A5.29 Specification for Low-Alloy Steel Electrodes for Flux Cored Arc Welding*

Magnesium Fires

While ignition of magnesium is a very remote possibility while welding, the ignition will cease when the heat source is removed. Ignition of the weld pool is also prevented by the gas shielding used in GTAW, GMAW and PAW processes. Most magnesium fires occur with accumulations of fines from grinding or filing or chips from machining. Accumulations of fines on clothing should be avoided. Graphite-base or salt-base powders recommended for extinguishing magnesium fires should be stored in the work area. If large amounts of fines are produced, they should be collected in a waterwash-type dust collector designed for use with magnesium. Special precautions pertaining to the handling of wet magnesium fines should be followed.

Each specification defines standards for the following:

- Classification, identification, and marking of the electrode wire
- Chemical composition of the deposited weld metal
- Chemical composition of the flux filling
- Mechanical properties of the deposited weld metal

7.2.1 Carbon Steel Flux Cored Electrodes

Figure 42 shows the *ANSI/AWS A5.20* specification format for carbon steel flux cored electrodes.

Table 16 (see *Appendix*) shows the carbon steel flux cored electrode welding characteristics as indicated by the AWS classification.

Table 17 (see *Appendix*) lists carbon steel flux cored electrode classes and uses.

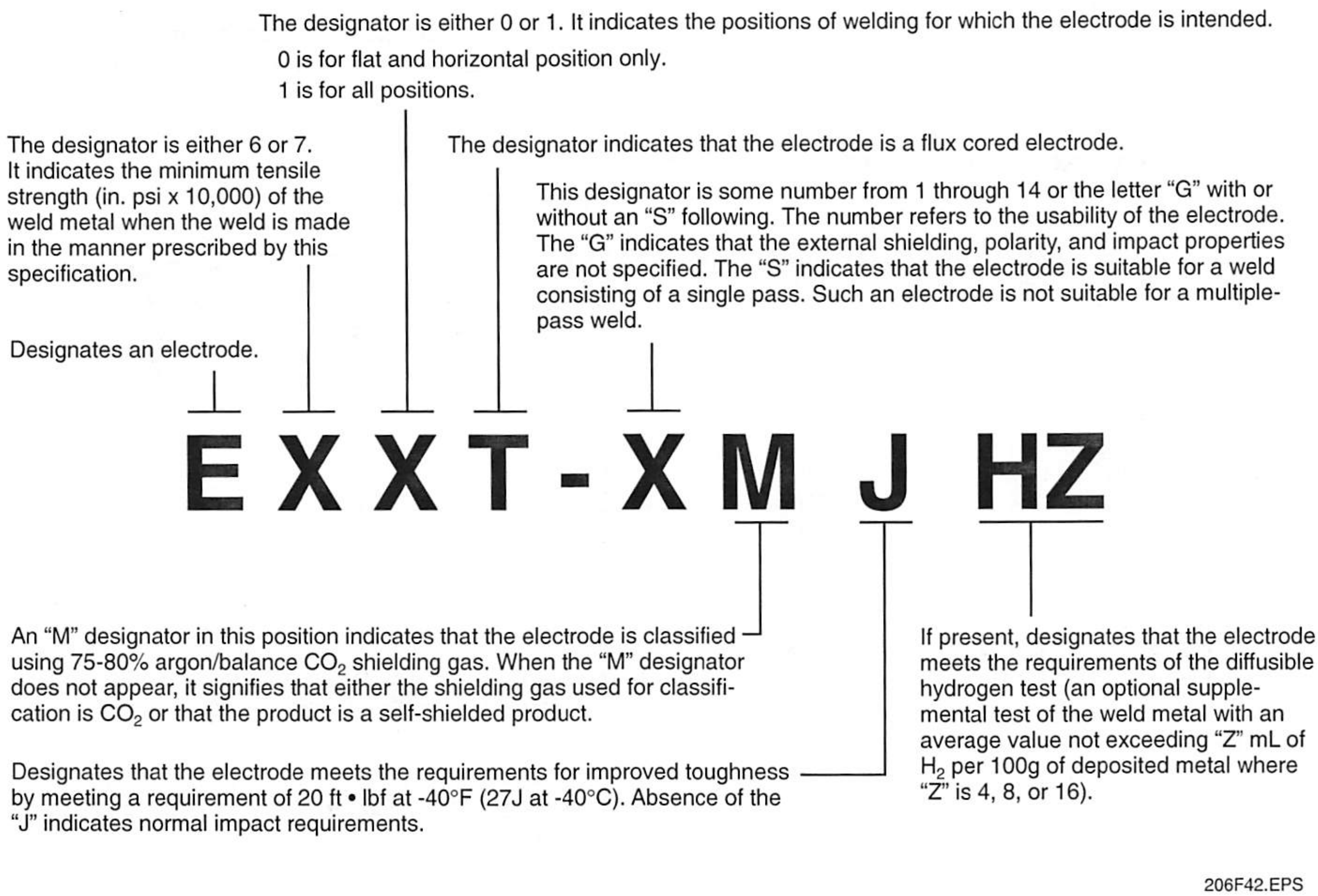


Figure 42 ◆ AWS specification format for carbon steel flux cored electrodes.

Hot Tip

FCAW of Structural Steel

For large structural welding projects such as bridges and skyscrapers, many construction companies prefer carbon (or low-alloy) steel FCAW to meet the toughness requirements for new construction using the newer self-shielding E71T-8 or gas-shielded E71T-1 electrodes. Many ironworkers that use SMAW are reluctant to use FCAW, and those that have used FCAW predominantly relied upon E71T-11 for structural welds because it was easy to use in all positions. However, welds with –11 wire sometimes had cracking problems and had to be rewelded. Once welders are properly retrained for FCAW using the newer electrodes, the cracking problems are eliminated and the deposition rates are higher because the newer electrodes run hotter and faster than the –11 electrodes or SMAW electrodes.

7.2.2 Low-Alloy Steel Flux Cored Electrodes

Figure 43 shows the *ANSI/AWS A5.29* specification format for low-alloy steel flux cored electrodes

Table 18 (see *Appendix*) shows the low-alloy steel flux cored electrode welding characteristics as indicated by the AWS classification.M

Table 19 (see *Appendix*) lists the AWS low-alloy steel flux cored electrode classes and uses.

7.2.3 Stainless Steel Flux Cored Electrodes and Rods

Figure 44 shows the *ANSI/AWS A5.22* specification format for stainless steel flux cored electrodes and rods.

Table 20 (see *Appendix*) shows stainless steel flux cored electrode and rod characteristics as indicated by the AWS classification.

Table 21 (see *Appendix*) lists AWS stainless steel flux cored electrode classifications and uses. The table only includes electrodes for FCAW applications because the rods are used for GTAW.

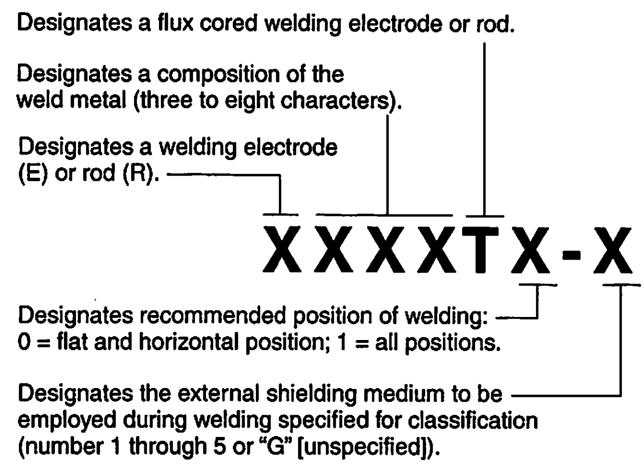


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Figure 44 ◆ AWS specification for stainless steel flux cored electrodes and rods.

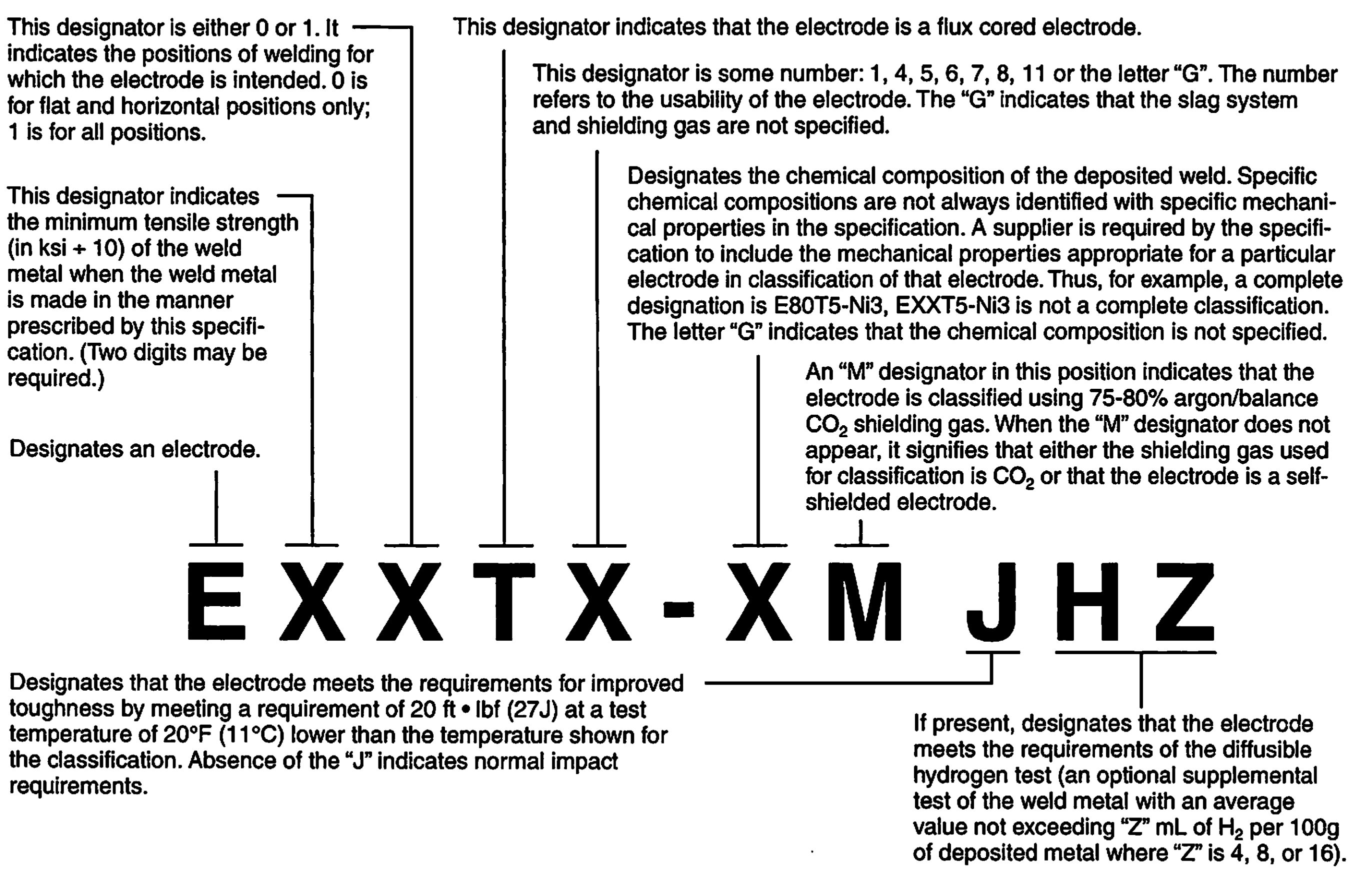

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Figure 43 ◆ AWS specification for low-alloy steel flux cored electrodes.

8.0.0 ◈ WELDING EQUIPMENT SETUP

In order to weld safely and efficiently, the welding equipment must be properly set up. The following sections explain the steps for setting up welding equipment. *Figure 45* shows a diagram of a GMAW or FCAW system.

8.1.0 Selecting a GMAW Power Source

To select a power source (welding machine), several factors must be considered.

- GMAW requires a constant-voltage or constant voltage/constant current power source.
- A DCEP-type welding current is required.
- The maximum amperage required must be available.
- Consider the primary power requirements. For example, are there electrical receptacles to plug a welding machine into, or do engine-driven generators/alternators need to be used?

8.2.0 Selecting an FCAW Power Source

To select an FCAW welding machine, the following factors must be considered:

- FCAW requires a constant-voltage power source.
- The welding current required for FCAW is DC.
- The required operating amperage ranges from 150 amps with a 0.045-inch electrode to 650 amps or more with a ⅛-inch electrode; larger electrodes require even higher amperage.
- Consider whether the primary power source is adequate. Are there enough AC electrical receptacles to plug a welding machine into, or do engine-driven generators/alternators need to be used?

8.3.0 Positioning the Equipment

Because of the short length of the gun cables, the wire feeder must be positioned near the work to be performed. The power source must also be located near the wire feeder because of the limited length of the contactor/control cable that runs from the power source to the wire feeder. Normally the wire feeder is located either on top of the power source or on the floor or a cart near the power source.

Select a site where the equipment will not be in the way but will be protected from welding or cutting sparks. There should be good air circulation to keep the machine cool. The environment should be free from explosive or corrosive fumes and as free as possible from dust and dirt. Welding machines have internal cooling fans that will pull these materials into the welding machine if they are present. Also, dust and dirt can collect on the wire, causing weld contamination and clogging of

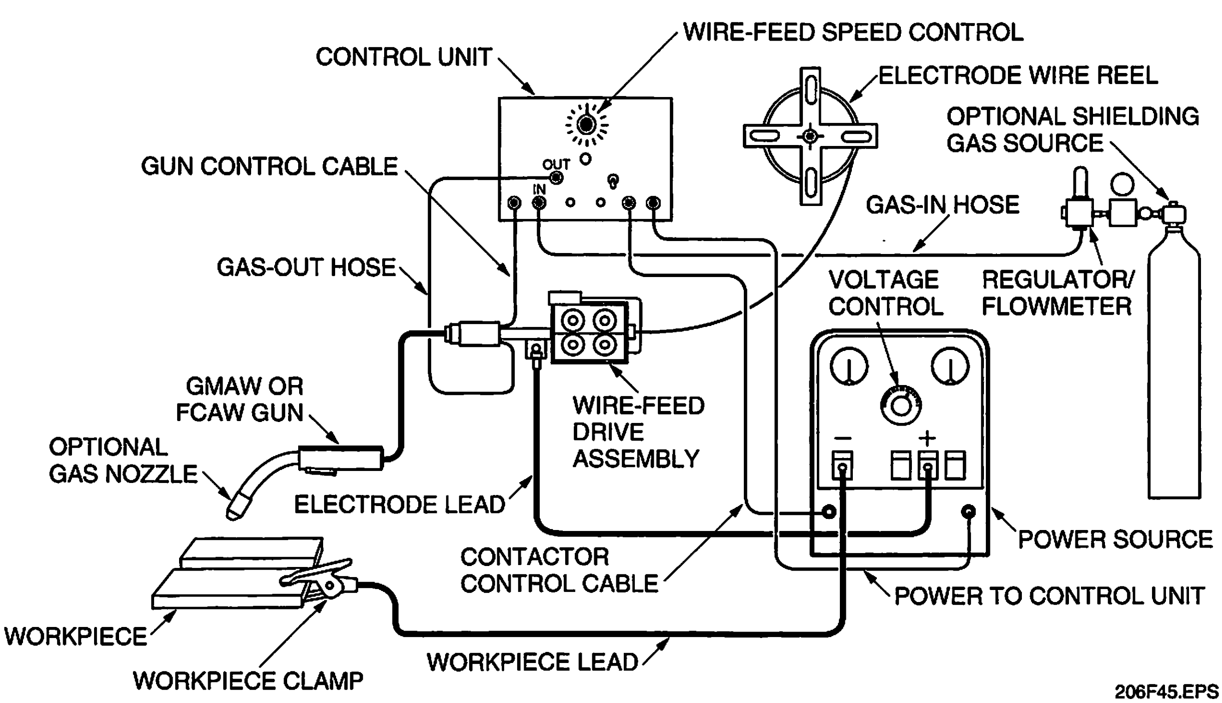


Figure 45 ◈ Diagram of a GMAW/FCAW system.

the liner in the gun cable. The site should also be free of standing water or water leaks. If an engine-driven generator or alternator is used, position it so that it can be easily refueled and serviced.

There should also be easy access to the site so the equipment can be started, stopped, or adjusted as needed. If the machine is to be plugged into an outlet, be sure the outlet has been properly installed by a licensed electrician to ensure it is grounded. Also, be sure to identify the location of the electrical disconnect for the outlet before plugging the welding machine into it.

8.4.0 Moving Welding Power Sources

Large engine-driven generators are mounted on a trailer frame and can easily be moved by a pickup truck or tractor with a trailer hitch. Other types of welding machines may have a skid base or be mounted on steel or rubber wheels. When moving wheel-mounted welding machines by hand, use care. Some machines are top-heavy and could fall over in a tight turn or if the floor or ground is uneven or soft.

CAUTION

Secure or remove the wire feeder and gas cylinder before attempting to move the power source.

WARNING!

If a welding machine starts to fall over, do not attempt to hold it. Welding machines are very heavy, and severe crushing injuries can occur if a welding machine falls on you.

Most welding machines have a lifting eye, which is used to move machines mounted on skids or to lift any machine. Before lifting a welding machine, check the equipment specifications for the weight. Be sure the lifting device and tackle can handle the weight of the machine. Always use a sling and/or a shackle. Never attempt to lift a machine by placing the lifting hook directly in the machine's lifting eye because the safety latch on the hook cannot be closed. Also, before lifting or moving a welding machine, be sure the welding cables are secure. *Figure 46* shows the proper way to lift a welding machine.

8.5.0 Connecting the Shielding Gas

The shielding gas connects to the wire feeder unit or to the power source if the wire feeder is integrated with the power source.

Follow these steps to connect the shielding gas:

Step 1 Identify the required shielding gas by referring to the WPS or Site Quality Standards.

Step 2 Locate a cylinder of the correct gas or mixture, and secure it near the wire feeder.

CAUTION

Be sure to secure the cylinder so that it cannot fall over.

Step 3 Remove the cylinder's protective cap and momentarily crack open the cylinder valve to blow out any dirt, then close it again.

WARNING!

Even though available, do not use an adapter to connect a regulator/flowmeter equipped with one type of CGA (Compressed Gas Association) connection to a gas cylinder that has a different CGA connection. The CGA connections are specific to the types of gas and cylinder pressures permitted for the connection.

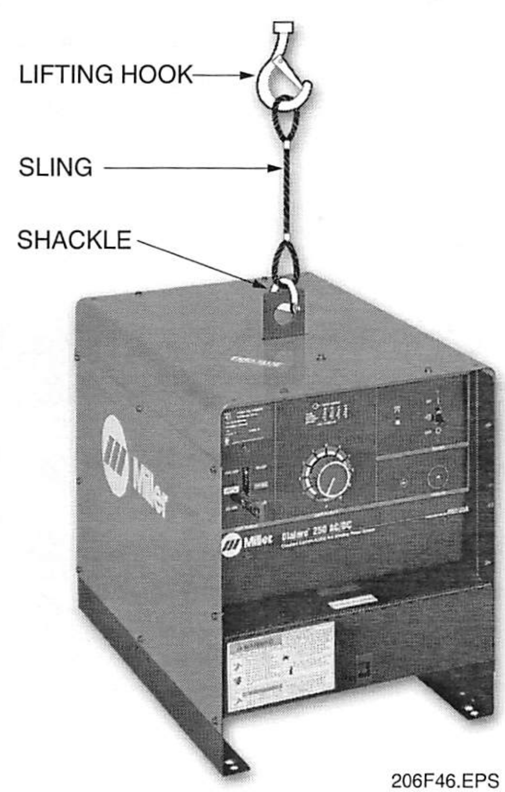


Figure 46 ◆ Lifting a welding machine.

Step 4 Using a regulator/flowmeter with the correct CGA connection for the cylinder, install the pressure regulator/flowmeter on the cylinder.

Step 5 Connect the gas hose to the flowmeter and to the gas connection on the wire feeder (or power source).

Step 6 Slowly crack open the cylinder valve and then open it completely.

Step 7 Adjust the gas flow, using the flowmeter valve, to the specified flow rate.

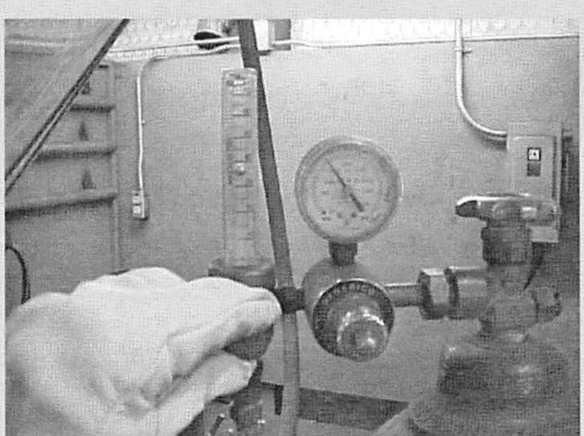
NOTE

Some flowmeters are equipped with several scales of different calibrations around the same sight tube, for monitoring the flows of different types (densities) of gases. Be sure to rotate the scales or read the correct side for the type of gas in use.

Hot Tip

Adjusting Flowmeters

In most cases, the top of the floating flowmeter ball is used as the reference point for setting the gas flow. However, always check the manufacturer's instructions to determine the correct adjustment method.



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8.6.0 Selecting and Installing Filler Wire

Follow these steps to select and install the filler wire:

Step 1 Identify the filler wire required by referring to the WPS or Site Quality Standard.

Step 2 Locate a spool of the wire, and mount it on the wire feeder spool holder. Lock the holder and set the drag brake for a slight drag. The brake control is usually located on the end of the spool axle.

Step 3 Check (and change if necessary) the wire feed drive wheels, liner, and gun contact tube to make sure they are the correct size for the wire selected. Adjust the wheel tension if necessary. For detailed instructions on changing or adjusting the wire feeder drive wheels or changing the gun's contact tube or liner, refer to the specific manufacturer's instructions.

Step 4 Feed the wire into the feeder wheels, and then use the JOG control to feed it through the gun cable and the gun contact tube.

8.7.0 Placing the Workpiece Clamp

The workpiece clamp must be properly placed to prevent damage to surrounding equipment. If the electrical welding current travels through a bearing, seal, valve, or contacting surface, it could cause severe damage through heat and arcing, which would require that these items be replaced. Carefully check the area to be welded, and position the workpiece clamp so the welding current will not pass through any contacting surface. If in doubt, ask your supervisor for assistance before proceeding.

Hot Tip

Gas Flow Rates

More gas flow is not always better. Too much flow can deflect off the workpiece. The resultant swirling gas can create turbulence that pulls in air, which contaminates the weld and creates pinholes. If black flecks occur in the weld puddle, or pinholes occur in the weld, try reducing gas flow.

CAUTION
Welding current passing through electrical or electronic equipment will cause severe damage. Before welding on any type of mobile equipment, the ground lead at the battery must be disconnected to protect the electrical system. If welding is near the battery, the battery must be removed. Batteries produce hydrogen gas, which is extremely explosive. A welding spark could cause the battery to explode.

WARNING!
Do not weld near batteries. A welding spark could cause a battery to explode, showering the area with battery acid.

Workpiece clamps must never be connected to pipes carrying flammable or corrosive materials. The welding current could cause overheating or sparks, resulting in an explosion or fire.

The workpiece clamp must make a good electrical contact when it is connected. Dirt and paint will inhibit the connection and cause arcing, resulting in overheating of the workpiece clamp. Dirt and paint also affect the welding current and can cause defects in the weld. Clean the surface before connecting the workpiece clamp. If the workpiece clamp is damaged and does not close securely onto the surface, replace it.

8.8.0 Energizing the Power Source

Electrically powered welding machines are energized by plugging them into an electrical outlet. The electrical requirements (primary current) will be located on the equipment specification tag displayed prominently on the machine. Most machines require single-phase 240-volt power, 208-volt three-phase power, or 460-volt three-phase power. Most machines requiring single-phase 240-volt power have a three-pronged plug. Machines requiring three-phase 208- or 460-volt power will have a four-pronged plug. Both types of plugs are shown in *Figure 47*.

If a welding machine does not have a power plug, an electrician must connect it. The electrician will add a plug or hard-wire the machine directly into an electrical box.

WARNING!
Never use a welding machine until you identify the electrical disconnect for that machine. In the event of an emergency, you must be able to quickly turn off the power to the welder at the disconnect.

8.9.0 Starting Engine-Driven Generators and Alternators

Before welding can take place with an engine-driven generator or alternator, the engine must be checked and then started. As with a car engine, the engine powering the generator or alternator must also have routine maintenance performed.

8.9.1 Performing Pre-Start Checks

Many sites have pre-start checklists that must be completed and signed prior to starting or operating an engine-driven generator or alternator. Check with your supervisor. If your site has such a checklist, complete and sign it. If your site does

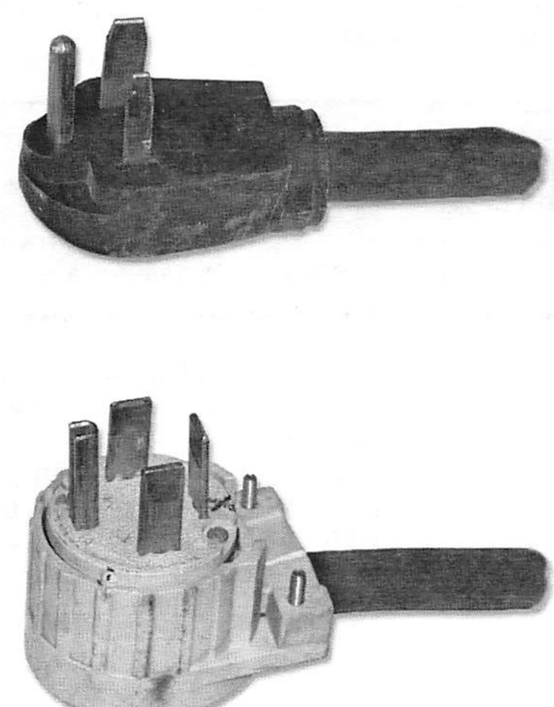

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Figure 47 ◆ Typical three- and four-pronged plugs.

not have a pre-start checklist, perform the following checks before starting the engine:

- Check the oil, using the engine oil dipstick. If the oil is low, add the appropriate grade of oil for the time of year.
- Check the coolant level in the radiator if the engine is liquid-cooled. If the coolant level is low, add coolant.

CAUTION

Do not add plain water to radiators that contain antifreeze. Antifreeze not only protects radiators from freezing in cold weather, it also has rust inhibitors and additives to aid cooling. If the antifreeze is diluted, it will not function properly. If the weather turns cold, the system may freeze, causing damage to the radiator, engine block, and water pump.

- Check the fuel. The unit may have a fuel gauge or a dipstick. If the fuel is low, add the correct fuel (diesel or gasoline) to the fuel tank. The type of fuel required should be marked on the fuel tank. If it is not marked, contact your supervisor to verify the fuel required and have the tank marked.

CAUTION

Adding gasoline to a diesel engine or diesel to a gasoline engine will cause severe engine problems. It can also cause a fire hazard. Always be sure to add the correct fuel to the fuel tank.

- Check the battery water level unless the battery is sealed. Add demineralized water if the battery water level is low.
- Check the electrode holder to be sure it is not grounded. If the electrode holder is grounded, it will arc and overheat the welding system when the welding machine is started. This is a fire hazard and will cause damage to the equipment.
- Open the fuel shut-off valve if the equipment has one. If there is a fuel shut-off valve, it should be located in the fuel line between the fuel tank and the carburetor.
- Record the hours from the hour meter if the equipment has one. An hour meter records the total number of hours the engine runs. This information is used to determine when the engine needs to be serviced. The hours will be displayed on a gauge similar to an odometer.
- Clean the unit. Use a compressed air hose to blow off the engine and generator or alternator. Use a rag to remove heavier deposits that cannot be removed with the compressed air.

WARNING!

Always wear eye protection when using compressed air to blow dirt and debris from surfaces. Never point the nozzle at yourself or anyone else.

NOTE

Cleaning may not be required on a daily basis. Clean the unit as required.

8.9.2 Starting the Engine

Most engines have an on/off ignition switch and a starter. They may be combined into a key switch similar to the ignition on a car. To start the engine, turn on the ignition switch and press the starter. Release the starter when the engine starts. The engine speed is controlled by the governor. If the governor switch is set for idle, the engine will slow to an idle after a few seconds. If the governor is set to welding speed, the engine will continue to run at the welding speed.

Small engine-driven alternators may have an on/off switch and a pull cord. These are started by turning on the ignition switch and pulling the cord, in much the same way as a lawn mower is started.

Engine-driven generators and alternators should be started about 5 to 10 minutes before they are needed for welding. This will allow the engine to warm up before a welding load is placed on it.

8.9.3 Stopping the Engine

If no welding is required for thirty or more minutes, stop the engine by turning off the ignition switch. If you are finished with the welding machine for the day, close the fuel valve (if there is one).

8.9.4 Performing Preventive Maintenance

Engine-driven generators and alternators require regular preventive maintenance to keep the equipment operating properly. Most sites have a preventive maintenance schedule based on the hours that the engine operates. In severe conditions, such as very dusty or cold weather, maintenance may have to be performed more frequently.

CAUTION

In order to prevent damage to the equipment, perform preventive maintenance as recommended by the site procedures or by the manufacturer's maintenance schedule in the equipment manual.

The responsibility for performing preventive maintenance varies by site. Check with your supervisor to determine who is responsible for performing preventive maintenance.

When performing preventive maintenance, follow the manufacturer's guidelines in the equipment manual. Typical items to be performed as a part of preventive maintenance include the following:

- Changing the oil
- Changing the gas filter
- Changing the air filter
- Checking/changing the antifreeze
- Greasing the undercarriage
- Repacking the wheel bearings

Hot Tip — *Dust Removal*

Blow out the welding machine and drive unit with compressed air occasionally to remove dust. A significant buildup of dust inside the machine will provide an alternate path for the electricity and could result in some of the components shorting out.

9.0.0 ◆ HAND TOOLS FOR WELD CLEANING

The tools used for weld cleaning include handheld tools such as chipping hammers, wire brushes, and pliers, and power tools such as pneumatic weld-flux chippers and needle scalers.

Wire brushes are used to clean welds and to remove paint or surface corrosion. Wire brushing removes light to medium corrosion, but does not remove tight corrosion. Tight corrosion must be removed by filing, grinding, or sandblasting.

Chipping hammers are used to remove cutting and welding slag. The head of a chipping hammer has a point at one end and a chisel at the other. When chipping hammers become dull, they can be sharpened on a grinder. When sharpening chipping hammers, use care not to overheat the head. The head is hardened by tempering, and overheating removes the temper, causing the head to become soft. If the temper is removed from a chipping hammer head, it will mushroom and wear out much faster than a tempered head. Prevent overheating by plunging the head of the chipping hammer into a pail of water every few seconds while grinding.

Welders should also have clamping pliers to handle hot metal or hold and align metal to be welded. Hot metal should not be handled with leather welding gloves. The heat will cause the leather to shrivel and become hard. *Figure 48* shows a wire brush, chipping hammers, various clamping pliers, and a common file. Before use, files should have handles installed on the tang to prevent injury.

Figure 48 ◆ Wire brush, chipping hammers, clamping pliers, and file.

Summary

Both gas metal arc welding (GMAW) and flux cored arc welding (FCAW) can be dangerous if the proper safety precautions are not followed. Before proceeding, be sure you understand the equipment and filler metals required and the safety precautions presented in this module. Before GMAW or FCAW can take place, the appropriate equipment and filler metals must be selected and the equipment must be set up. By following the recommendations in this module, you will be able to select and safely set up the appropriate welding equipment and understand the types of filler metals used for GMAW and FCAW.

Review Questions

1. In gas metal arc welding, the arc is stabilized and the molten filler and base metals protected from oxidation by _____.

a. the application of pressure
b. use of self-fluxing alloy
c. shielding gas
d. use of intense heat

2. Of the two basic FCAW processes, one is self-shielding and one uses _____ shielding gas.

a. nonself-
b. internal
c. external
d. constant

3. When mixed with air or oxygen, _____ will explode at much lower concentrations than any other fuel.

a. propylene
b. propane
c. methane
d. acetylene

4. Depending on the range selected, for each 100 amperes of current the arc voltage of a welding machine is typically _____ volt(s) lower than the open-circuit voltage.

a. 0–1
b. 1–2
c. 2–3
d. 4–5

5. In welding, the current flows through two welding cables; the ground welding leads connect the power source to the _____.

a. base metal
b. wire electrode
c. welding machine
d. work table

6. The advantage of engine-driven generators and alternators is that they are _____.

a. portable and can be used in the field
b. easy to operate
c. less expensive
d. require little maintenance

7. In FCAW, the flux inside the filler core contains ingredients that _____.

a. cause arc flutter
b. oxidize the weld
c. generate shielding gas
d. prevent slag from forming

8. For FCAW, edge preparation is seldom needed for double-welded butt joints on plate up to ⅜-inch thick, because of the _____ of welds made with CO_2 shielding.

a. smooth profile
b. lower temperature
c. deionization
d. deeper penetration

9. When using short-circuiting welding in GMAW, the current passing through the wire electrode heats and then melts the wire in a process called _____.

a. inductance
b. slope
c. pinch effect
d. arc blow

10. GMAW guns are usually rated for amperage at a _____ duty cycle using CO_2.

a. 25%
b. 50%
c. 75%
d. 100%

11. Light-duty GMAW guns are cooled by ______.
    a. domestic water
    b. special cooling fluid
    c. shielding gas flow
    d. demineralized water

12. To meter the shielding gas to the welding gun at the proper flow rate, a(n) ______ is required.
    a. gate valve
    b. gas regulator/flowmeter
    c. auxiliary gun control unit
    d. cylinder valve

13. Because of its current transfer and ionization properties, ______ can be used alone or in combination with other gases to weld both ferrous and non-ferrous materials.
    a. helium
    b. carbon dioxide
    c. nitrogen
    d. argon

14. FCAW is limited to the welding of ______.
    a. aluminum
    b. copper
    c. ferrous metals
    d. nonferrous metals

15. To lift a welding machine mounted on skids, the welder should ______ the lifting eye.
    a. attach the hook directly to
    b. attach a sling and/or a shackle to
    c. run a stout rope through
    d. attach a heavy-duty chain to