CHAPTER 4

# Welding and Cutting Processes


Miller Electric Mfg. LLC.

## Learning Objectives

After studying this chapter, you will be able to:

- Explain the basic process, controls, AWS abbreviation, and key safety concerns for arc welding processes.
- Explain the basic process, controls, AWS abbreviation, and key safety concerns for oxyfuel joining and cutting processes.
- Explain the basic process, controls, AWS abbreviation, and key safety concerns for resistance welding processes.
- Explain the basic process, controls, AWS abbreviation, and key safety concerns for arc cutting and specialized arc welding processes.
- Explain the basic process, controls, AWS abbreviation, and key safety concerns for solid state welding processes.
- Explain the basic process, controls, AWS abbreviation, and key safety concerns for other welding processes.



Welding is a general term for a number of ***processes*** (methods) used to fuse metallic or nonmetallic materials together. The American Welding Society (AWS) defines ***welding*** as "a joining process that produces coalescence of materials by heating them to the welding temperature, with or without the application of pressure or by the application of pressure alone, and with or without the use of filler metal."

The most common welding processes join metals by heating relatively small areas of the materials to their ***welding temperature***. The welding temperature is above the melting temperature of the material being welded. ***Filler material*** is normally added to the weld area while the materials are molten. However, welds can be made without adding filler material. Other welding processes join the base material using heat and pressure; some processes use only pressure. Not all materials can be welded, but most metals and a number of plastics are weldable.

The American Welding Society recognizes 11 major categories for welding, cutting, and allied processes, **Figure 4-1**. This section introduces many welding and cutting processes used in modern industry. Later chapters explain these welding and cutting processes in detail.

AWS standard terminology is used in the descriptions of welding processes in this textbook. Drawings showing the parts and materials used in each process are color-coded for clarity. (Refer to the color code in the front matter of the book.) The welding stations are diagrammed in figures showing the various welding processes. In some cases, details have been enlarged to help explain the process. To understand the material in this chapter more easily, refer to the drawings frequently while reading the text.

Welding process descriptions include the following information:

- The energy source used to produce heat.
- Controls used in the process.
- An overview of how the process works.
- Safety considerations involved in using the process.
- References to other chapters in the book where more detailed information and many additional illustrations are provided.

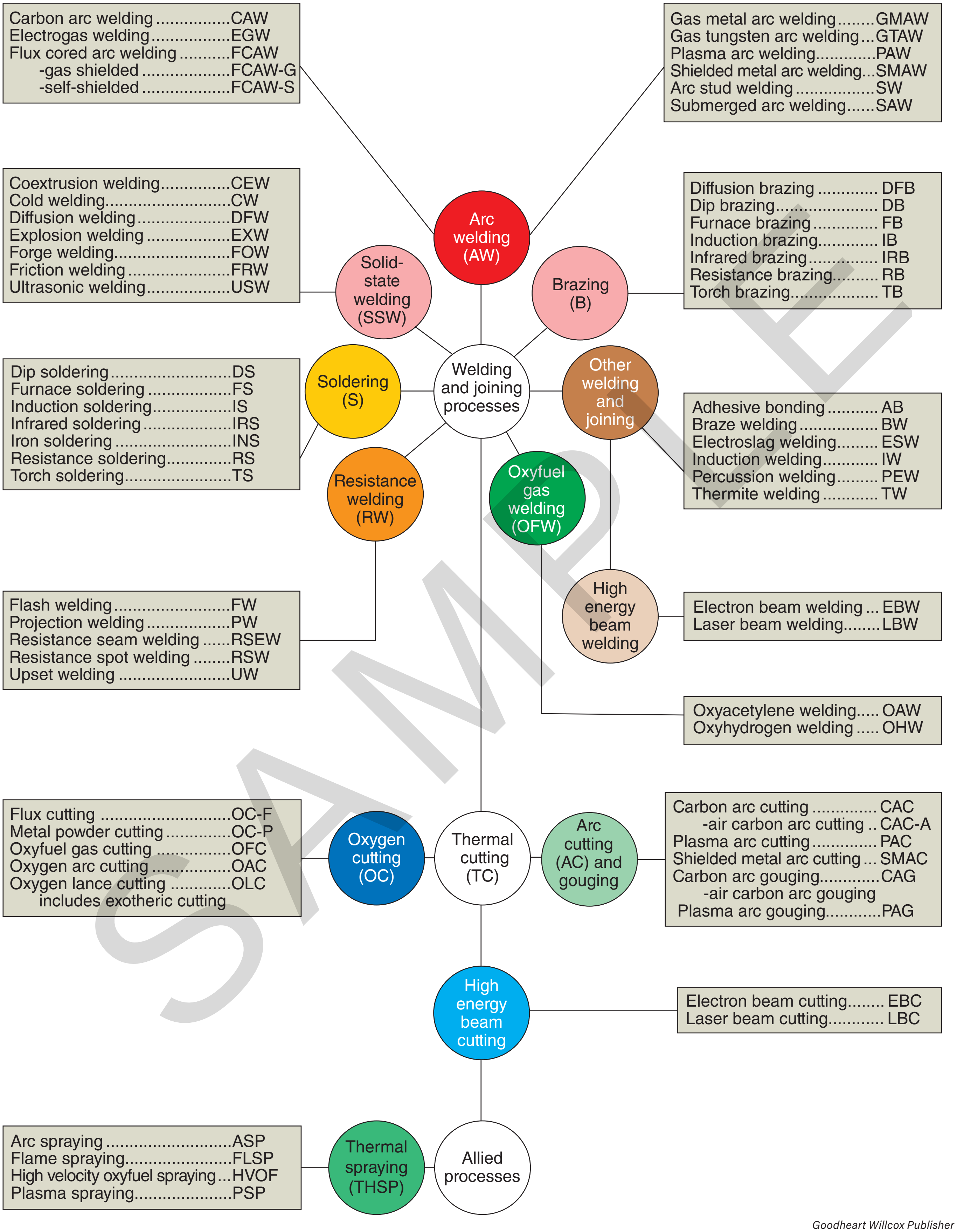


**Figure 4-1.** Some of the welding, cutting, and joining processes recognized by the American Welding Society.

## 4.1 Arc Welding Processes

Arc welding processes covered in this section include shielded metal arc welding, gas metal arc welding, flux cored arc welding, and gas tungsten arc welding. In these processes, an electric arc is struck between an electrode and the ***base metal*** (metal being welded). The heat from the arc melts the base metal and the welding electrode or welding rod. The molten base metal plus additional filler metal flow together. Once the molten material solidifies, the metals are joined and the weld has been made. Not every process can weld every type of base metal, but as a group, these arc welding processes can be used to weld all base metals.

### 4.1.1 Shielded Metal Arc Welding (SMAW)

The ***shielded metal arc welding*** process creates an electric arc between a consumable flux-covered metal electrode and the base metal. Heat from the electric arc melts both the end of the electrode and the base metal to be joined. This process is often used for structural welding, maintenance work, and small production welding. Pipe is frequently welded with shielded metal arc welding.

**Nonstandard Terminology**

**Shielded metal arc welding** is often referred to by the nonstandard term *stick welding*.

Equipment used in the SMAW process provides an electric current for welding. The electric current may be either alternating current (AC) or direct current (DC). Current adjustment controls on the welding machine allow the welder to set the desired current. Movement of the handheld electrode holder is controlled by the welder. The electrode is a flux-covered metal wire. An electrical lead (cable) connects the electrode holder to the power source. Another lead connects the work to the power source. An arc is created between the electrode and ***workpiece*** (base metal) to complete the circuit. **Figure 4-2** shows a typical station for shielded metal arc welding.



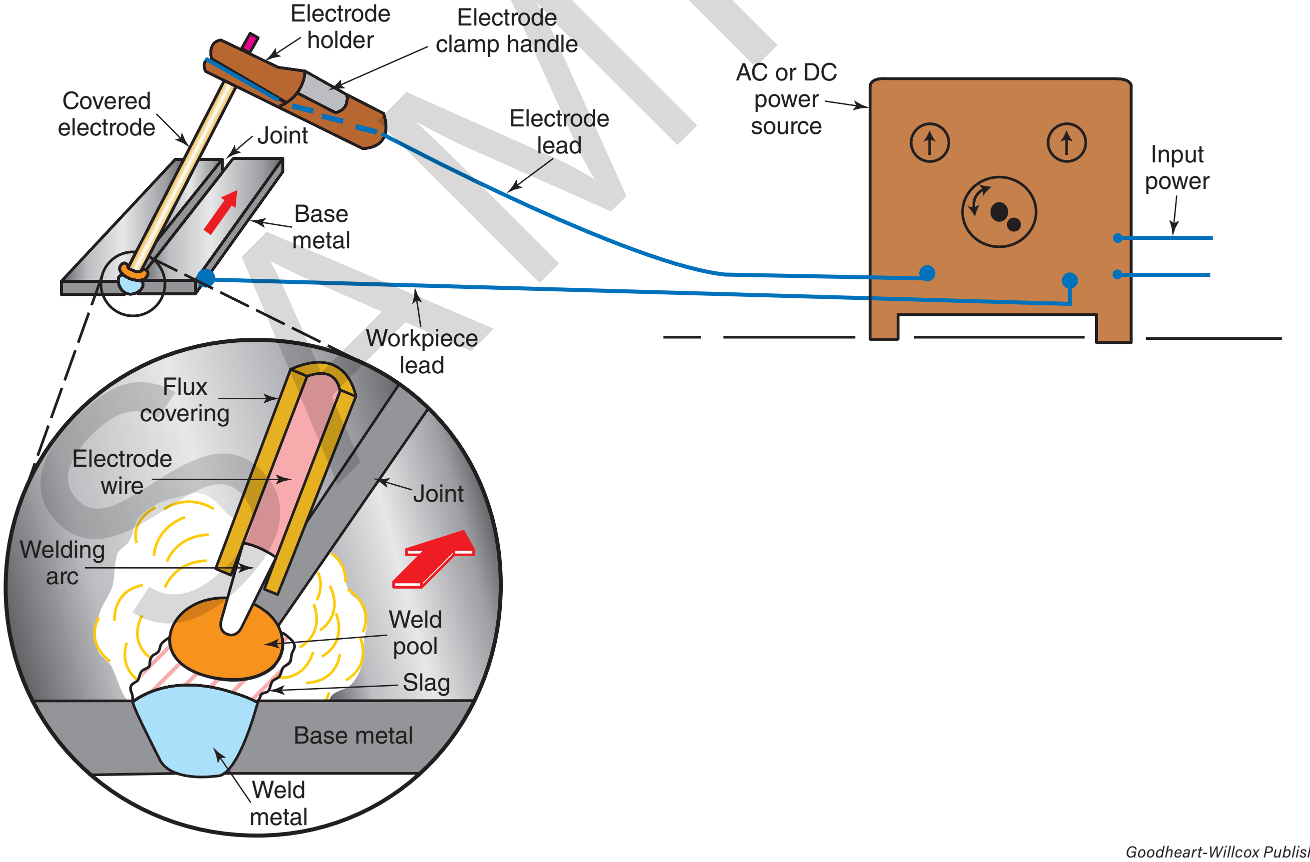


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**Figure 4-2.** Shielded metal arc welding (SMAW). An electric arc is created between the covered electrode and the base metal. The heat of the arc melts the end of the electrode and an area of the base metal where the arc is directed. The metal from the electrode provides the filler metal for the weld.

The heat of the electric arc can be controlled by the current setting and by the arc length. Electrode diameter and flux material determine the amount of welding current and the type of current (AC or DC) required. The arc between the welding electrode and the base metal is struck (initiated) by the welder. The welder must keep the electrode positioned the proper distance from the workpiece (arc length) to maintain the arc.

The covering on the electrode burns off while welding. Some of the covering melts and forms a protective gas shield that surrounds the arc as the electrode melts. Some of the covering melts to form a slag that covers the completed weld. The slag layer protects the hot metal from oxidizing (or rusting) while it cools.

The term ***oxidation*** refers to oxygen chemically combining with a metal. Oxidation should be avoided in welding operations. Oxidation can be avoided by preventing oxygen from coming into contact with the metal during the welding process.

**Welders must wear an approved helmet with proper lenses for shielded metal arc welding, gloves, and protective clothing. The welding workstation must be well ventilated.**

Chapter 5, *Shielded Metal Arc Welding Equipment and Supplies*, and Chapter 6, *Shielded Metal Arc Welding*, provide more detailed information about shielded metal arc welding.

### 4.1.2 Gas Metal Arc Welding (GMAW)

In ***gas metal arc welding***, an electric arc between a continuously fed metal electrode and the base metal produces heat. The heat melts the base metal and the electrode, creating the weld. The arc is shielded by a gas that is supplied through the welding gun. This process is popular in production, robotic welding, and repair shops.

#### Nonstandard Terminology

**Gas metal arc welding** is often referred to by the nonstandard term *MIG (metal inert gas) welding*.



## Employability

### Communication and Welding Terms

In any occupation, the ability to communicate effectively and to be clearly understood by one's coworkers is an important factor in working successfully. Many specialized terms identify equipment and processes in the welding industry. Standard terminology and informal jargon are both encountered in the workplace.

The American Welding Society has established standard terminology to promote effective communication in the welding industry. AWS publishes a document, titled *Standard Welding Terms and Definitions*, that contains standard terms and definitions related to welding, brazing, soldering, and other processes. In the welding industry, standard terms should be used in oral and written communications to refer to equipment and processes. Aspiring welders should learn these terms because use of standard terminology projects professionalism and ensures technical accuracy.

However, in shops, in factories, on construction sites, and in other welding environments, nonstandard terminology is frequently spoken and written. These terms must also be understood by welders.

Some welding terms even evolve over time. For example, in the 1940s, the developer of the GTAW process named it Heliarc because helium shielding gas was used to protect a tungsten electrode arc. Later, when other inert gases were used for shielding, the process became known as tungsten inert gas welding (TIG). As the welding process evolved, small quantities of hydrogen were occasionally added to the shielding gas to speed up production. Since hydrogen is *not* an inert gas, the standardized term for the process was changed to *gas tungsten arc welding (GTAW)*.

Employers value good communication skills in employees. A clear understanding of welding terminology contributes to clear communication and is a positive factor in gaining and keeping employment.

A shielding gas cylinder, regulator, flowmeter, and hose provide a flow of shielding gas to the arc. See **Figure 4-3**. Shielding gases such as carbon dioxide, argon, or helium are used. An electrode-feeding device called a *wire feeder* continuously supplies metal electrode. GMAW electrode comes in the form of wire on a large spool. A cable carries the electrode wire, current, and shielding gas to the welding gun and arc. The welding gun has a trigger switch for starting and stopping the electrode feed and gas flow.

The desired voltage is set on the welding machine. Current is changed by adjusting the feed speed of the wire. Wire speed controls are on the wire feeder or the power source. The GMAW gun has a trigger. When the trigger is squeezed, the arc, wire feeder, and gas are started. Shielding gas volume adjustments are made using a gas flowmeter. The type of shielding gas used depends on the metals being welded and a few other factors.

**The welder must wear an approved helmet, gloves, and welder's clothing. The welding area must have good ventilation.**

Chapter 7, *Gas Metal and Flux Cored Arc Welding Equipment and Supplies*, and Chapter 8, *Gas Metal and Flux Cored Arc Welding*, explain the GMAW process in more detail.

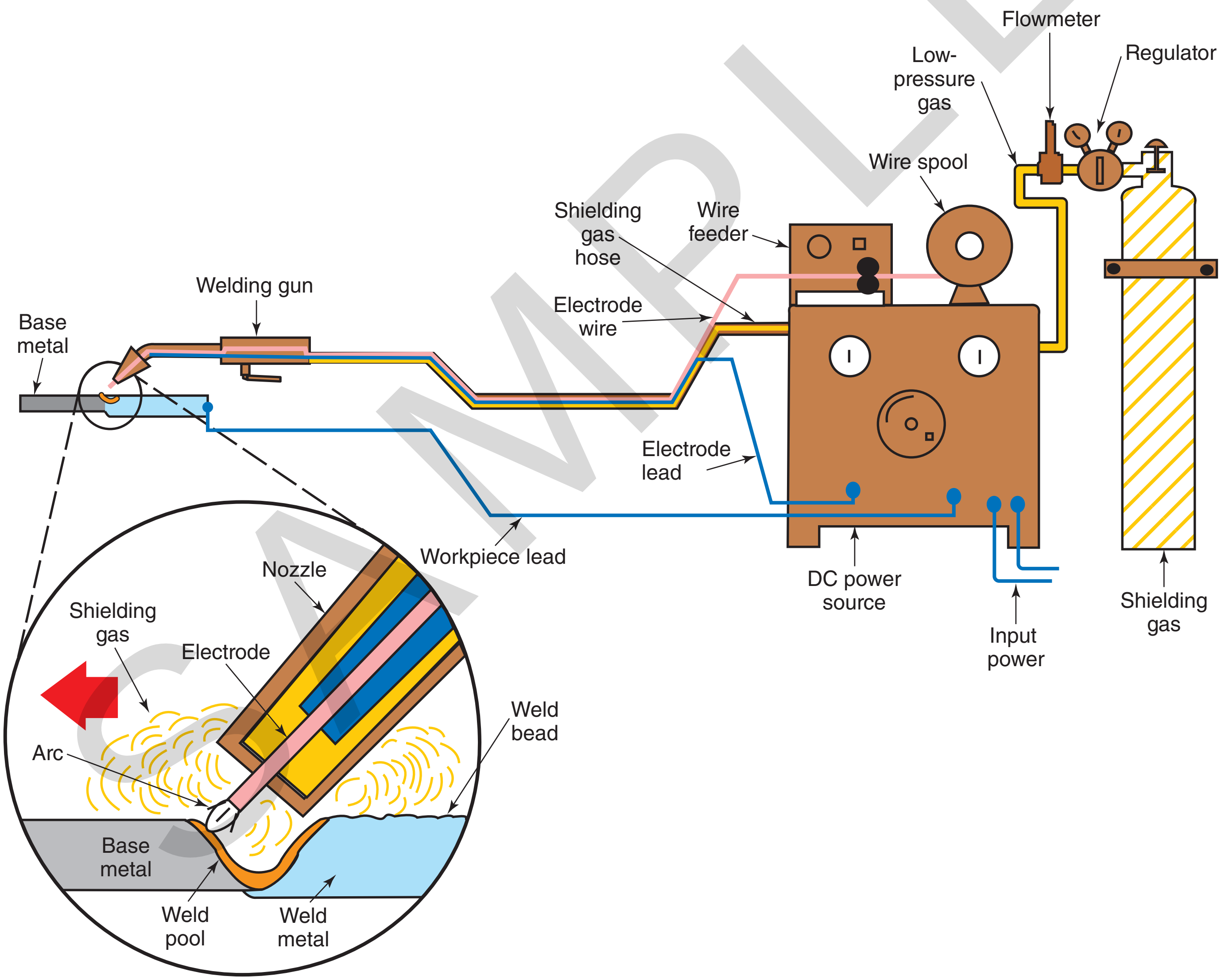




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**Figure 4-3.** Gas metal arc welding (GMAW). An electric arc is created between a metal electrode and the base metal. Heat from the arc melts the end of the electrode wire and a spot on the base metal. Shielding gas flows out of the nozzle. This gas keeps the oxygen and impurities in the air from contacting the weld.

### 4.1.3 Flux Cored Arc Welding (FCAW)

In *flux cored arc welding*, **Figure 4-4**, heat is produced by an arc between a continuous flux cored electrode and the base metal. Heat from the arc melts the electrode and base metal, creating the weld. As the electrode melts, the flux inside burns, creating gas that shields the weld from the atmosphere. This process is particularly desirable for welding structural steel and in other low-carbon steel applications.

The electrode is a hollow metal tube with its center (core) filled with a flux material. The electrode is fed to the welding gun from a wire spool mounted to the wire feeder. Some flux cored wires are used with carbon dioxide ($CO_2$) shielding gas or a combination of argon and $CO_2$ supplied through the welding gun. Others do not require the use of externally provided shielding gas.

The heat of the arc depends on the arc length, voltage setting, and the wire feed speed. The speed of the wire feeder can be adjusted. Adjusting the wire speed varies the current at the arc. The higher the wire feed speed, the higher the current. A higher wire feed speed provides additional penetration for welding thick metal. A lower wire feed speed is used to weld thinner metal without burning through.

**The welder working with FCAW equipment is exposed to heat and light from the arc. An arc welder's helmet, leather gloves, and protective clothing should be worn. Excellent ventilation should also be provided.**

Chapter 7, *Gas Metal and Flux Cored Arc Welding Equipment and Supplies*, and Chapter 8, *Gas Metal and Flux Cored Arc Welding*, provide more detailed information about the FCAW process.

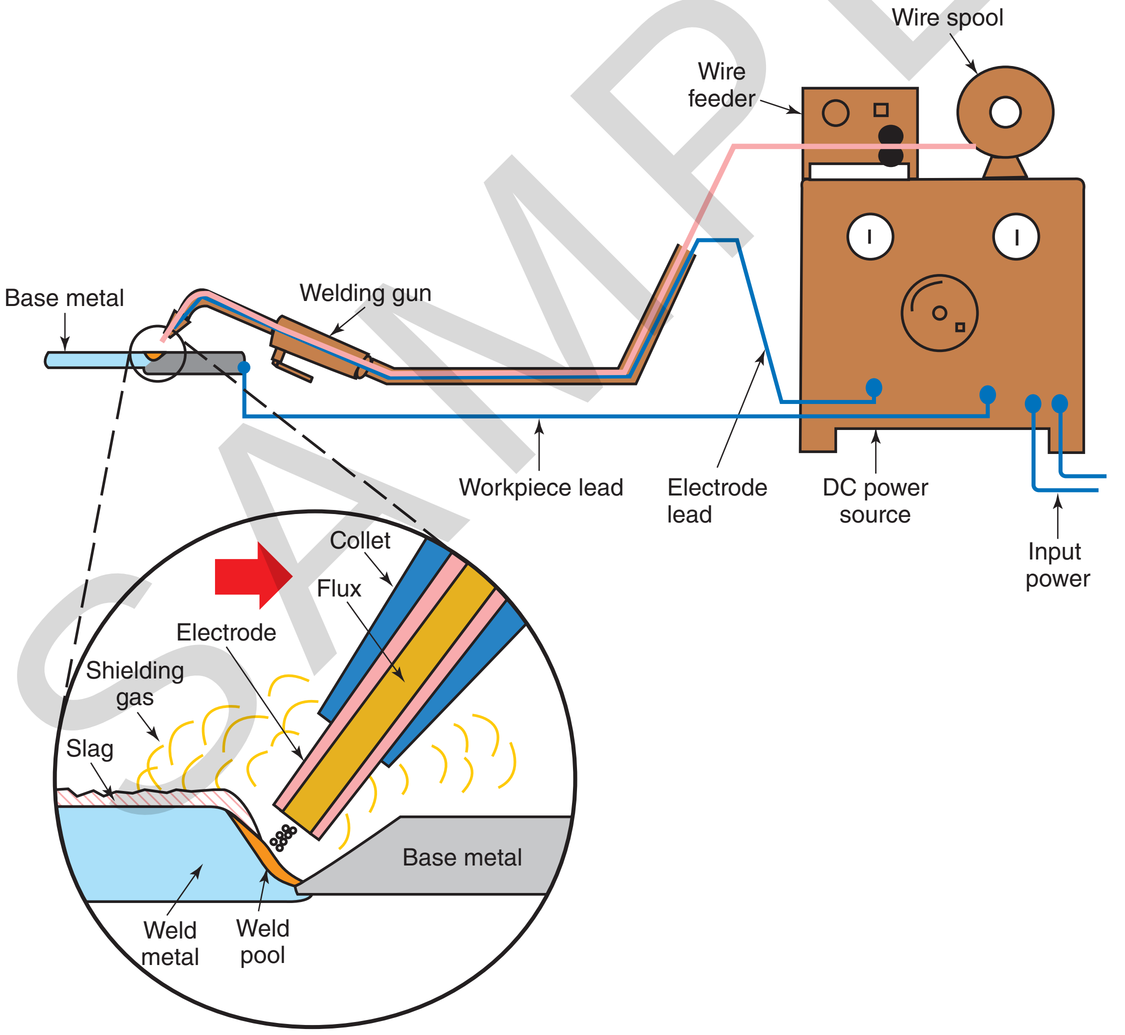


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**Figure 4-4.** Flux cored arc welding (FCAW). An electric arc is created between a flux cored electrode and base metal. The end of the electrode and a spot on the base metal are melted to form the weld. The flux core melts, forms a gaseous shield around the arc, and forms a slag covering to keep air away from the weld until it cools.

### 4.1.4 Gas Tungsten Arc Welding (GTAW)

***Gas tungsten arc welding*** uses the heat of an electric arc between a nonconsumable tungsten electrode and the base metal. A separate welding filler rod is fed into the molten base metal, if needed. A ***shielding gas*** flows around the arc to keep air away from the arc and molten base metal. Gas tungsten arc welding is particularly desirable for welding stainless steel, aluminum, titanium, and many other nonferrous metals. GTAW can be done in any position with excellent results.

**Nonstandard Terminology**

**Gas tungsten arc welding** is often referred to by the nonstandard term *TIG (tungsten inert gas) welding*.

**Figure 4-5** shows a typical station for gas tungsten arc welding. An AC-DC welding machine may be used with a regulated flow of a shielding gas, such as argon or helium. The shielding gas flows from a cylinder through a regulator, a flowmeter, and a hose to the GTAW torch.

The welder manually controls the movement of the torch (tungsten electrode holder) and the filler metal rod. A heat-resistant gas flow cup or nozzle surrounds the electrode. The electrode is held in place by a collet. Some small-capacity torches are air-cooled. Higher amperage torches are water-cooled.

Heating properties of the arc are controlled by changing current and arc length. The diameter of the tungsten electrode and the thickness and kind of base metal determine the required welding amperage.

**Gas tungsten arc welding generates intense heat and light, with no metal spatter. The welder must wear an approved welding helmet, gloves, and welder's clothing.**

Chapter 9, *Gas Tungsten Arc Welding Equipment and Supplies*, and Chapter 10, *Gas Tungsten Arc Welding*, provide additional information about the GTAW process.

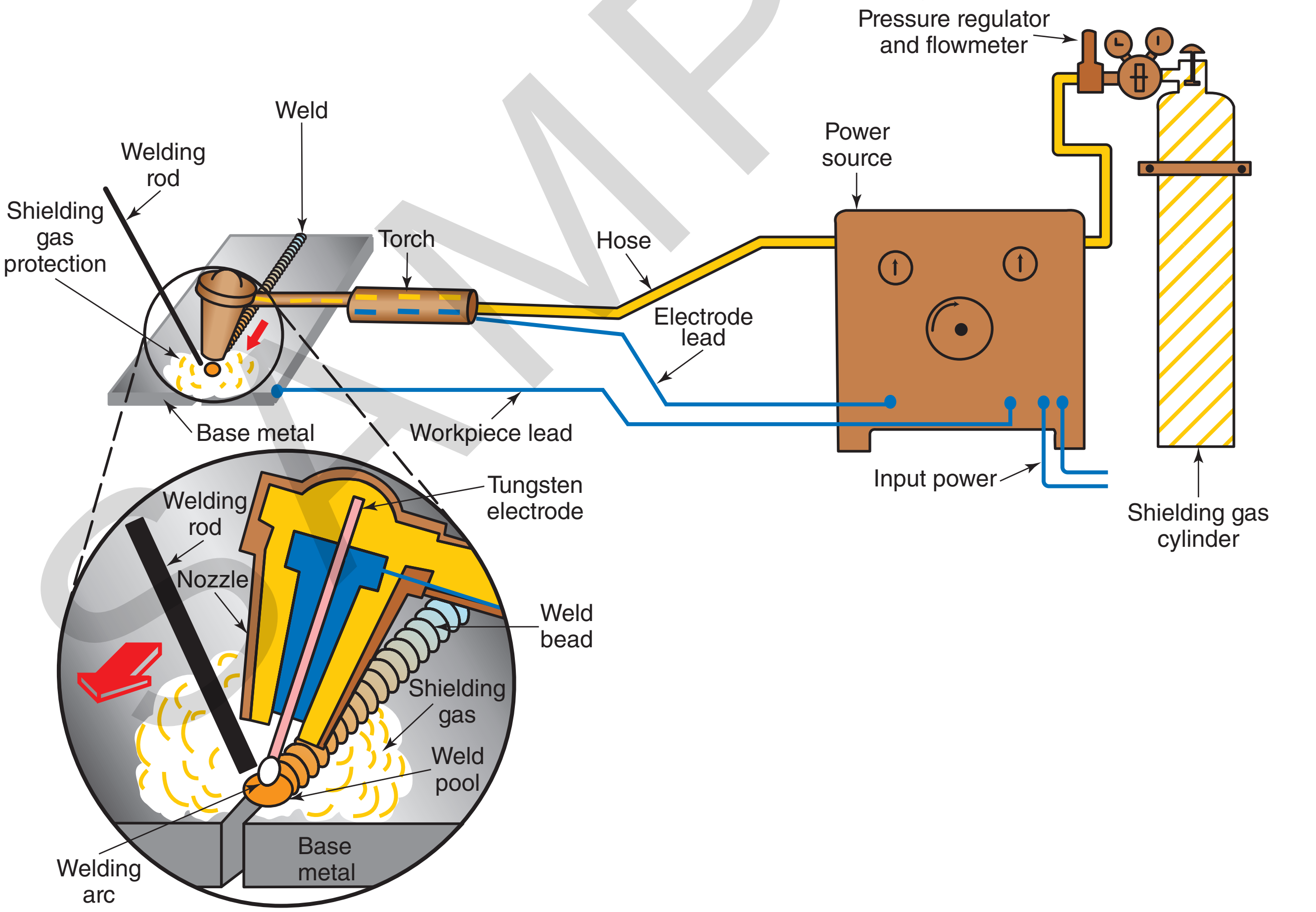


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**Figure 4-5.** Gas tungsten arc welding (GTAW). An electric arc is created between the end of the tungsten electrode and a spot on the base metal. Only the base metal melts. If filler metal is needed in the joint, a separate welding rod is fed into the weld pool. The welding rod melts to add filler metal to the molten weld pool as needed. Shielding gas flows out of a gas nozzle around the tungsten electrode to keep air away from the weld.

## 4.2 Oxyfuel Joining Processes

Oxyfuel joining processes covered in this section include oxyfuel gas welding, torch soldering, and torch brazing. These processes combine oxygen with a fuel gas to produce the source of heat required to weld, solder, and braze. The basic differences between these processes will be explained in the following subsections.

Commonly used fuel gases include acetylene, hydrogen, natural gas, butane, propane, and LP gas mixes. Acetylene and oxygen are most often used because, when burned together, they produce a hotter flame than any other fuel gas/oxygen combination. A neutral oxyacetylene flame can reach a temperature of 5589°F (3087°C).

### 4.2.1 Oxyacetylene Welding (OAW)

The ***oxyacetylene welding*** process combines oxygen and acetylene gases to provide a high-temperature flame for welding. This flame provides enough heat to melt most metals. An oxyacetylene outfit, as shown in **Figure 4-6**, is used in this process. Oxyacetylene welding is a manual process. The welder must manually control the movements of the torch and welding rod. Acetylene is supplied to the torch from one cylinder and oxygen is supplied from another cylinder. Both cylinders must be equipped with pressure-reducing regulators. Each regulator is fitted with two gauges.

One pressure gauge (high) indicates the pressure in the cylinder. This is referred to as *cylinder pressure*. The other pressure gauge (low) indicates the pressure of the gas being fed to the torch. This is referred to as *working pressure*.

Separate flexible hoses carry the gases to the torch. The torch has two needle valves, which are referred to as ***torch valves***. One torch valve controls the rate of flow of the oxygen, and the other controls the rate of flow of the acetylene to the torch tip. The mixed gases burn at the torch tip orifice (opening).

Other fuel gases can be used in place of acetylene. These include LP (liquefied petroleum), natural gas, and hydrogen. Be sure to use only fuel gases approved for the equipment being used.

**Welding goggles should be worn for eye protection. Gloves, nonflammable clothing, and all other required safety clothing should be worn to protect against burns. Fire safety and prevention techniques should be employed. Proper ventilation must be provided.**

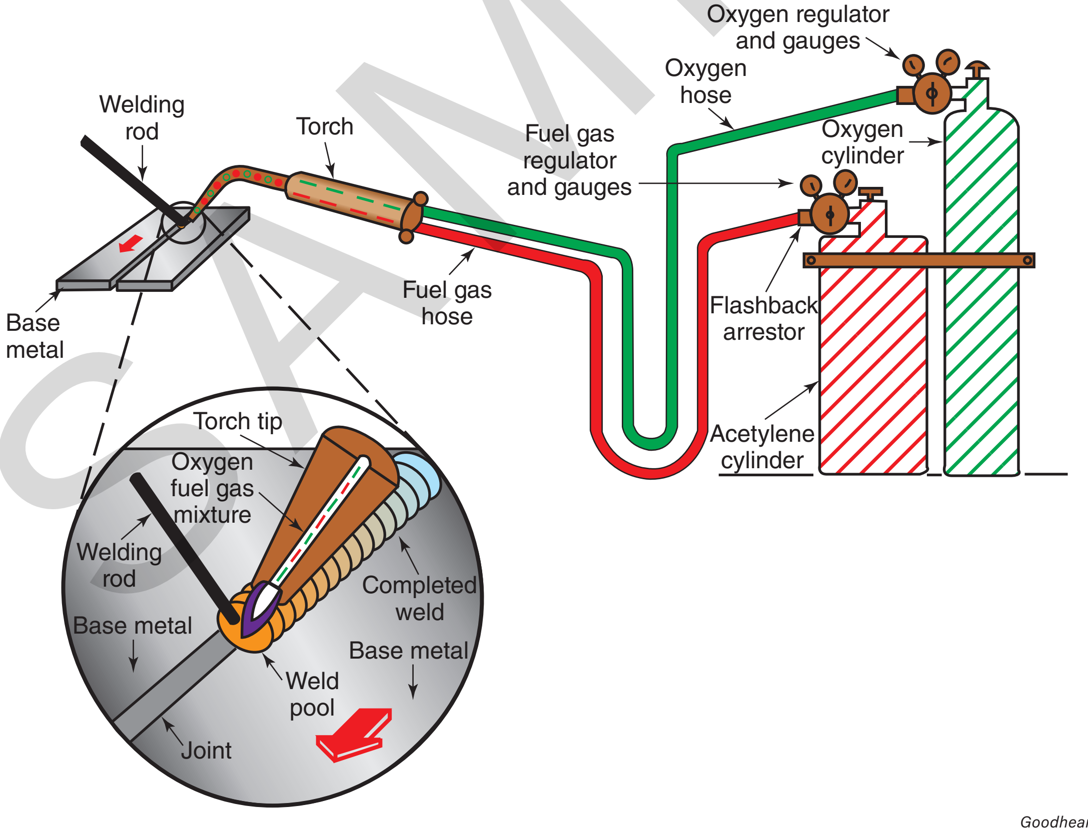


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**Figure 4-6.** Oxyacetylene welding (OAW). The oxygen and acetylene gas are mixed in a torch. The mixture burns at the torch tip. The heat from this flame is used to melt the base metal and welding rod. When this molten metal solidifies it forms a completed weld bead.

### 4.2.2 Torch Soldering (TS)

Torch soldering, as shown in **Figure 4-7**, uses an air-fuel gas flame. The flame heats the base metal. When the solder filler metal is touched to the heated base metal, the solder melts. The solder, a filler metal with a lower melting point than the base metal, will flow and bond to the base metal. Soldering occurs at temperatures below 840°F (450°C). The base metal does not melt. Liquid solder is drawn into a joint between two tightly fitting surfaces, typically a lap joint. Soldering is a popular method of joining metals in manufacturing and service operations. Torch soldering is used to fill a seam or to make an airtight and watertight joint.

In the soldering process, the amount of heat is controlled by the amounts of the gases flowing through the torch. When more heat is needed, larger torch tip orifices are used. The rate of gas flow is usually controlled by a needle valve on the torch. In air-fuel soldering, atmospheric air is drawn into the air-fuel torch through holes at the base of the torch tip, as shown in **Figure 4-7**. A regulator is mounted on the cylinder to control the fuel gas pressure to the torch. The final flame adjustment is made with the torch valve.

Acetylene, propane, or LP gas mixes can be used as the fuel gas. An oxyfuel station, like the one shown in **Figure 4-6**, can also be used for soldering.

Metal parts to be soldered are first cleaned. A flux material is applied to the base metal. The flux helps clean the base metal. The flux must be removed after the soldering process.

**Safety goggles or flash goggles are recommended to protect the eyes. Use pliers to handle hot metal.**

**Warning**

Keep moisture away from molten solder! Moisture in contact with molten solder instantly changes to steam. This may cause molten solder to fly in all directions.

Chapter 16, *Soldering*, has more detailed information about soldering.

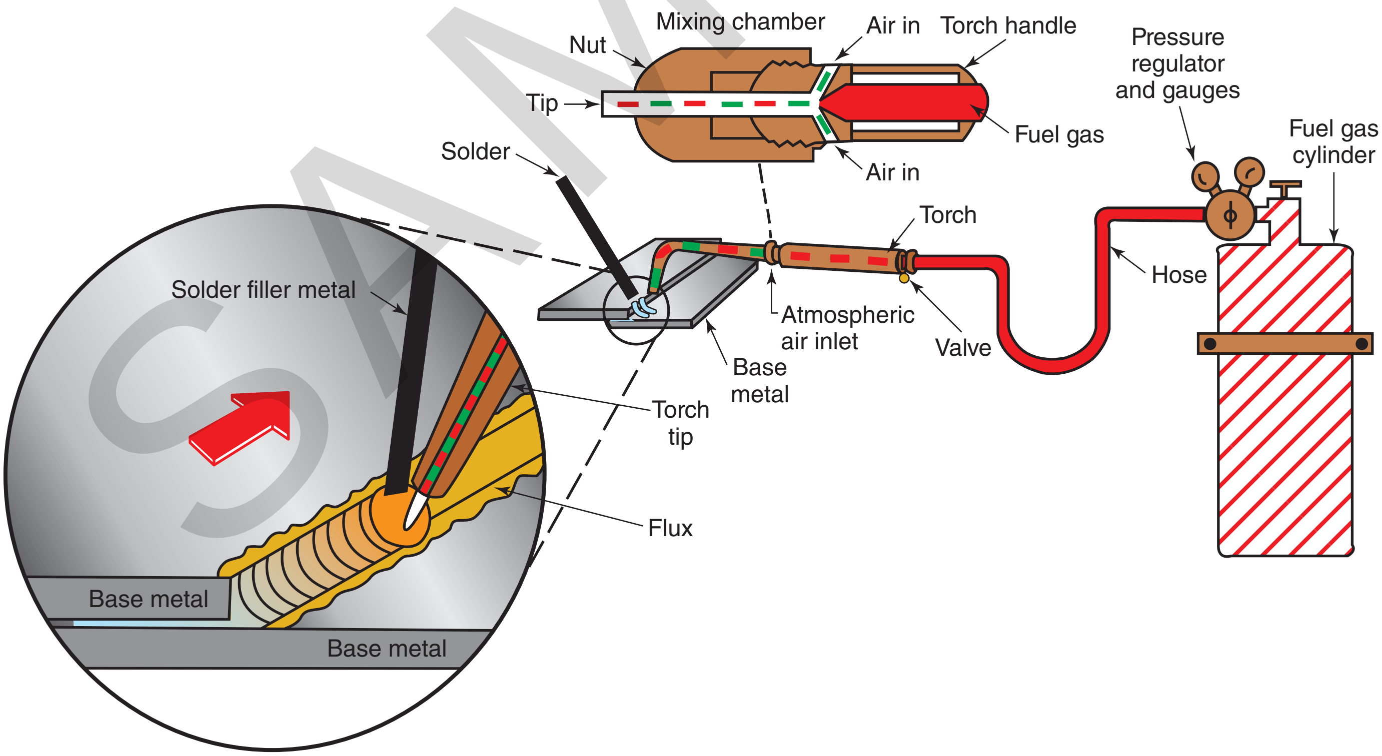


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**Figure 4-7.** Torch soldering (TS) with the air-fuel gas flame. A mixture of air and fuel gas is burned at the end of the tip. The flame provides the heat to the base metal, which in turn melts the solder. A flux is needed to keep the base metal and solder clean enough to allow the solder to adhere (stick).

### 4.2.3 Torch Brazing (TB)

In torch brazing, an oxyfuel gas flame heats the base metal, and the heated base metal melts the brazing rod. Brazing is done at temperatures above 840°F (450°C), but below the melting point of the base metal being joined. Brass and bronze, which have melting temperatures much lower than that of steel, are often used as brazing rods.

Torch brazing joins pieces of the base metal together with a thin layer of brass, bronze, or other brazing filler metals. The process of brazing is similar to soldering in the respect that the workpieces are joined together by a thin layer of metal and are not melted in the process. The melting point of brazing filler metal is higher than the melting point of solder, but still below the melting point of the base metal. Less warping of the base metal usually results from brazing and braze welding than from welding. This is due to the lower temperature involved in brazing or braze welding. **Figure 4-8** shows a typical torch brazing station.

The metal parts to be brazed are first carefully cleaned. A flux material is applied to the surfaces to be brazed. This flux helps clean the metal surfaces. Flux is available in powder or paste form or as a coating on the brazing filler metal.

An oxyfuel gas flame is used to heat the base metal. The brazing filler metal is touched to the base metal, where it melts and flows into the joint. If the mating surfaces were properly cleaned, a good brazed joint should result.

Torch brazing can also be used to produce thick, beveled joints similar to those made with oxyfuel gas welding. The process used on these thicker joints is called *braze welding*. In braze welding, as in brazing, the base metal is *not* melted.

**The welder should wear goggles, gloves, and fire-resistant clothing. There may be a severe health hazard if brazing filler metal contains zinc, cadmium, phosphorous, or beryllium alloys. For this reason, overheating of the brazing alloy should be avoided. The brazing operation must be well-ventilated to remove the fumes from the brazing alloys and flux.**

Chapter 17, *Brazing and Braze Welding*, provides more detailed information about brazing and braze welding.

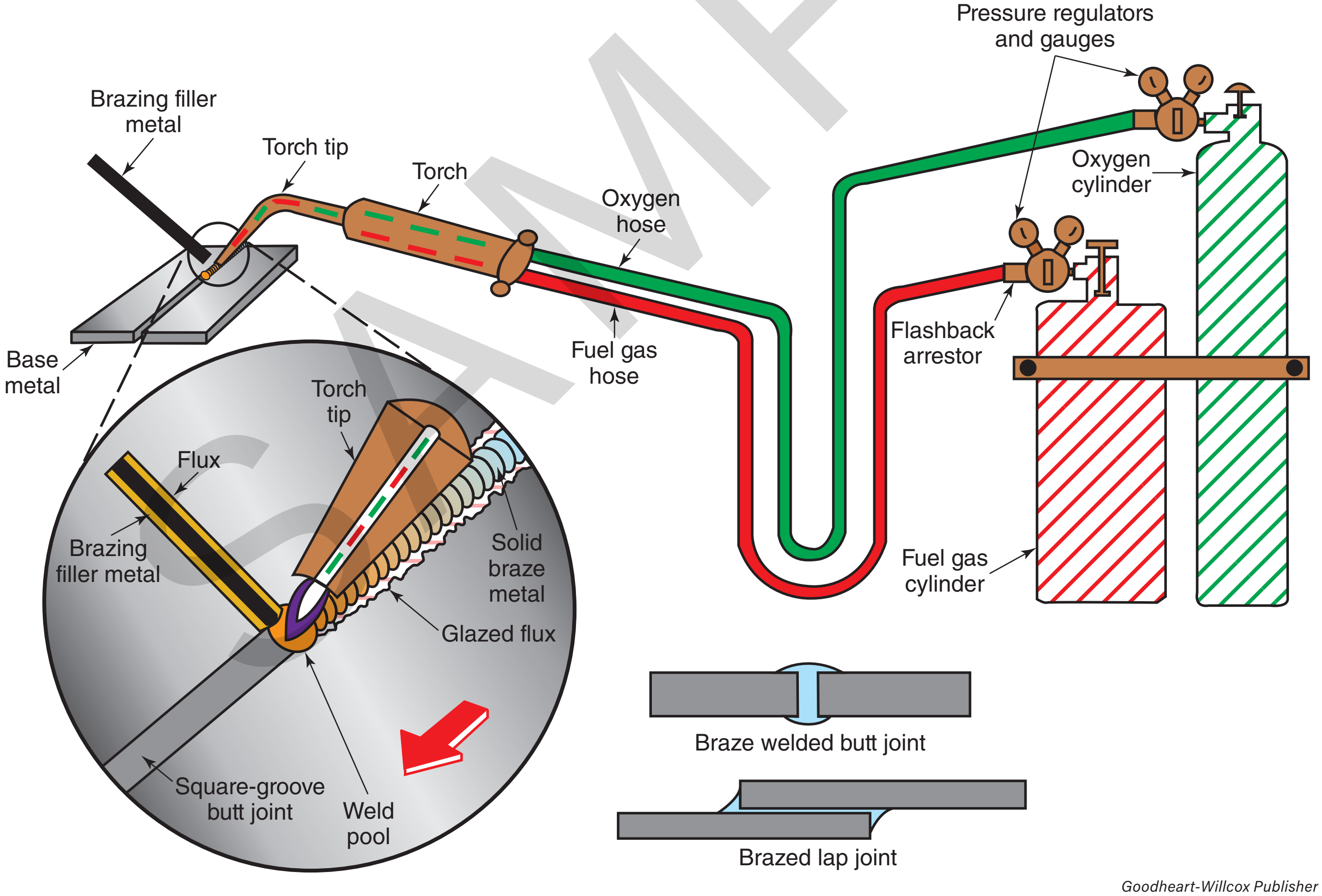


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**Figure 4-8.** Torch brazing (TB). Oxygen and a fuel gas are mixed in a torch. The mixture is burned at the torch tip. The heat raises the temperature of the base metal until the brass or bronze filler metal melts and adheres to it. A flux is used to keep the base metal and filler metal clean during the operation. In this drawing, a butt joint is being braze welded.

## 4.3 Oxygen Cutting Processes

Oxygen cutting processes covered in this section include oxyfuel gas cutting, oxygen lance cutting, and exothermic cutting. These cutting processes use heat to melt the material being cut. A high flow of oxygen is used to oxidize or burn the base metal and blow the molten metal from the cut.

During oxygen cutting operations, oxidation is the process used to cut (burn) the base metal using the application of intense heat and a high flow of oxygen. As a reminder, during welding operations, oxidation is undesirable. Oxidation is necessary during oxygen cutting processes.

### 4.3.1 Oxyfuel Gas Cutting (OFC)

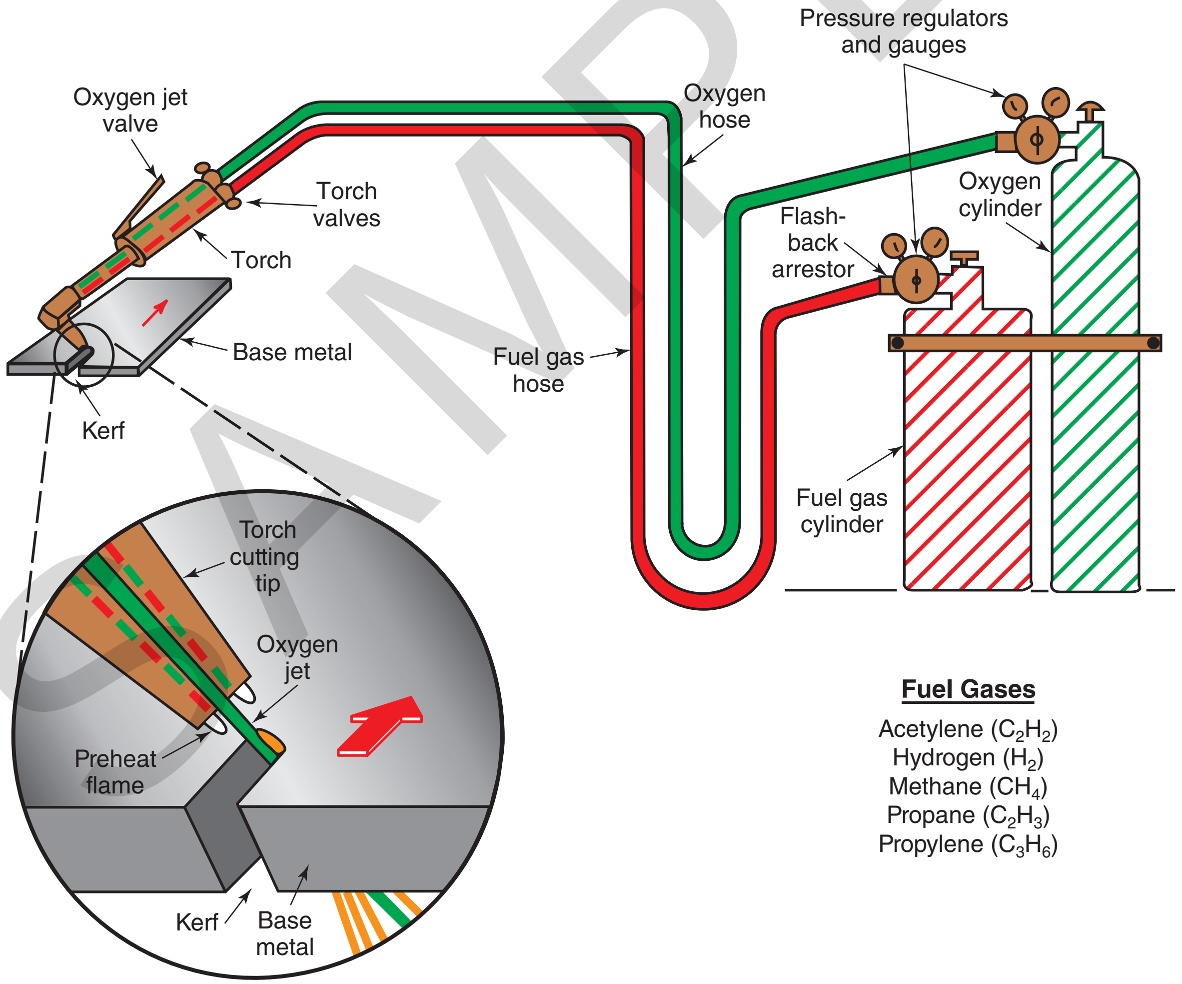
It is possible to ***burn*** (rapidly oxidize) iron or steel. The oxyfuel gas flame raises the temperature of the metal to a cherry-red color at 1470°F to 1830°F (800°C to 1000°C). Then, a high-pressure jet of oxygen from the cutting torch is directed at the metal. This causes the metal to burn and blow away very rapidly

**Nonstandard Terminology**

**Oxyfuel gas cutting** is sometimes referred to by the nonstandard term *burning*.

The OFC process requires cylinders of oxygen and a fuel gas, **Figure 4-9**. Each cylinder has a regulator and two pressure gauges. One pressure gauge indicates the pressure in the cylinder. The other gauge indicates the pressure of the gas being fed to the torch. Flexible hoses carry the gases to the torch.

Several different fuel gases may be used in this process.




**Fuel Gases**

Acetylene ($C_2H_2$)
Hydrogen ($H_2$)
Methane ($CH_4$)
Propane ($C_2H_3$)
Propylene ($C_3H_6$)

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**Figure 4-9.** Oxyfuel gas cutting (OFC). Oxygen and a fuel gas are mixed in the torch. The mixture burns at several orifices (openings) in the torch tip. When the flame has heated the base metal to a dull cherry red, the welder presses a lever on the torch. This allows a jet of oxygen to rush out of a central orifice in the torch tip. The oxygen jet quickly oxidizes the heated base metal and blows it away. This removal of material leaves a kerf (cut) in the base metal.

**Welding goggles should be worn for eye protection. Approved gloves and proper clothing must be worn to prevent burns. It is important that the area of work be cleared of combustible material. Good fire prevention practices should be followed. Proper ventilation should be provided.**

Chapter 14, *Oxyfuel Gas Cutting Equipment and Supplies*, and Chapter 15, *Oxyfuel Gas Cutting*, provide more detailed information about oxyfuel gas cutting.

## 4.3.2 Oxygen Lance Cutting (OLC)

The ***oxygen lance cutting*** process uses an oxyfuel gas torch to heat the base metal while a jet of oxygen from a separate oxygen lance is directed at the heated metal to cut (burn) it. This method has been used for many years to cut heavy steel sections. **Figure 4-10** shows a typical oxygen lance cutting station. The oxygen lance is a straight piece of iron pipe with a hand valve. It is attached by a hose to one or more large oxygen cylinders equipped with regulators and gauges. The oxygen lance is used along with an oxyfuel gas cutting torch. After the base metal is preheated to a cherry-red color with the torch, the oxygen lance is placed over the area to be cut and the oxygen valve is opened. A stream of oxygen cuts or burns through the base metal. OLC can cut sections of great thickness. The lance gradually melts away during the cutting and must be replaced.

**As with all cutting operations, the welder must wear proper eye protection, gloves, and clothing to prevent personal injury. It is also important to cover or clear the work area of combustible materials. Follow all fire prevention practices. Good ventilation is required.**

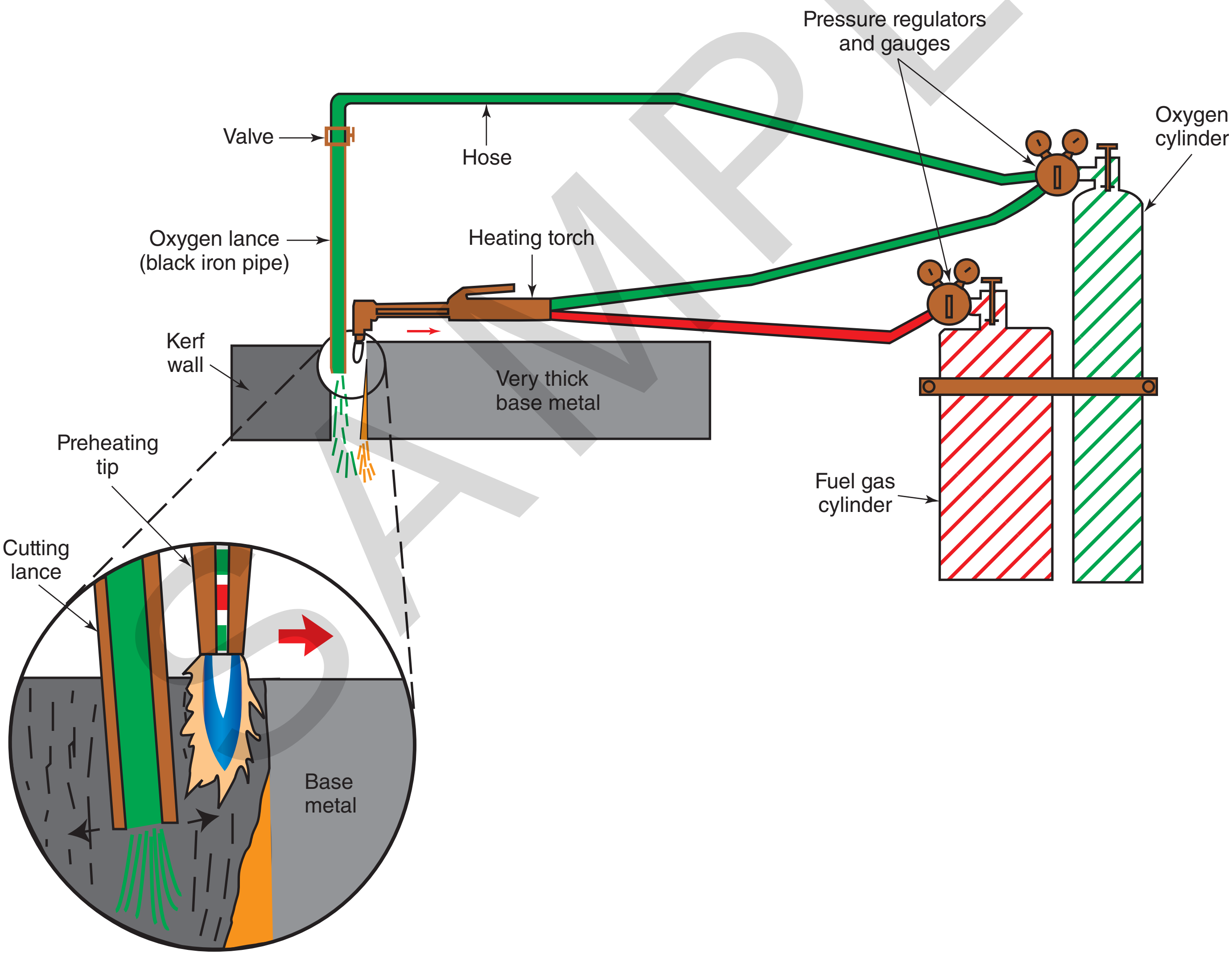


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**Figure 4-10.** Oxygen lance cutting (OLC). An oxyfuel gas torch is used to heat the base metal. A valve on the metal pipe lance is then opened and a jet of oxygen rapidly oxidizes the heated base metal and blows it away. The lance is gradually consumed as cutting progresses.

### 4.3.3 Exothermic Cutting

Exothermic cutting was developed in 1978 for underwater cutting on offshore oil platforms. Exothermic cutting is also used to make cuts on land. This process uses a special cutting torch, a special rod, an oxygen cylinder, a regulator, a hose, a 12-volt battery, a copper striker plate, and two electrical leads. See **Figure 4-11**.

Oxygen is delivered from a tank, through the regulator and oxygen hose to the cutting torch and special burning rod. The special rod is a copper-coated steel tube, which is filled with fuel wires, that burns and creates a great deal of heat. These fuel wires, once ignited, continue to burn, with oxygen to support the burning. The fuel wires burn hot enough to burn the outer tube as well. This self-consuming process is called an ***exothermic process***. The temperature of the burning exothermic tube and wires in oxygen reaches over 10,000°F (5500°C).

The torch holds the rod in a collet that is tightened when the collet nut is turned. One lead of the battery is connected to the torch collet. The other lead of the battery is connected to the copper striker plate.

To make a cut, the rod is scratched across the copper plate. When it begins to spark, the oxygen valve on the torch is opened. The burning rod is brought close to the base metal and the cut or gouge begins. The torch is then moved along the metal surface to complete the cut. To extinguish the rod, the operator turns off the oxygen.

Chapter 24, *Special Cutting Processes*, provides more details about exothermic cutting.

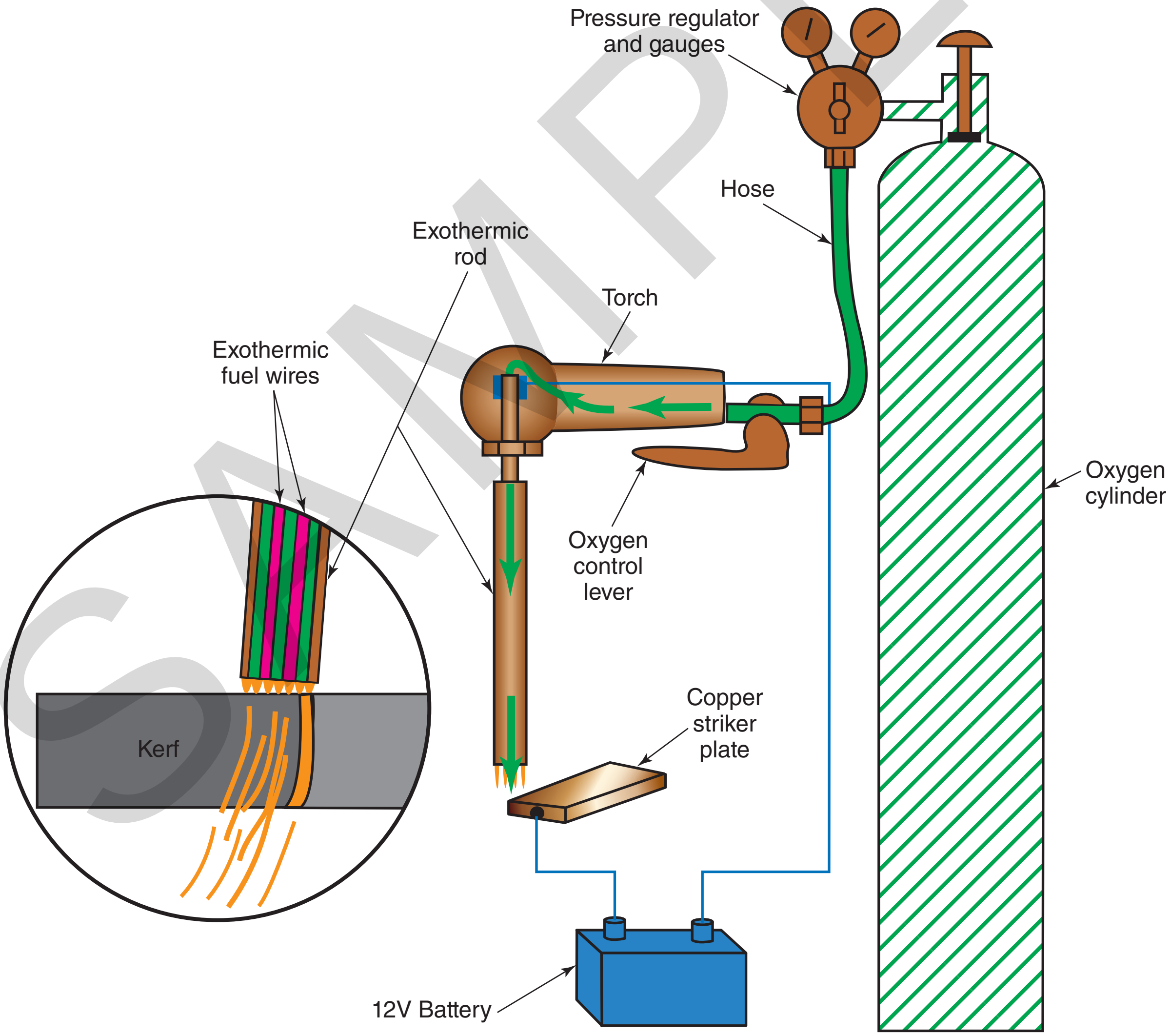


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**Figure 4-11.** Exothermic cutting. Oxygen is fed to the cutting area through the torch and burning rod. Fuel wires inside the larger exothermic rod are self-consuming. They are ignited by striking them on a copper striker plate. The fuel wires provide the heat to melt the base metal, while the oxygen blows the metal out of the kerf (cut).

## 4.4 Resistance Welding Processes

Resistance welding processes covered in this section include resistance spot welding, projection welding, resistance seam welding, and flash welding. These processes pass very high electrical current, often thousands of amps, through the parts to be welded. The parts are forced together during welding. The high current passing through the parts creates heat. The majority of the heat is developed where the parts contact each other. This heat melts the parts where they touch. After a controlled time, the current is stopped and the liquid metal cools and forms a weld.

### 4.4.1 Resistance Spot Welding (RSW)

Resistance spot welding, also called ***spot welding***, passes an electric current through the metal being welded. Resistance to the electrical flow heats the metal to welding temperature. The process is used to weld together two or more overlapping pieces. It is well-suited to automatic welding. Spot welding is commonly used to join auto body sections, cabinets, and other sheet metal assemblies.

As shown in **Figure 4-12**, a step-down transformer converts fairly high-voltage/low-amperage current to a low-voltage/high-amperage current. The weld is made between two electrodes that press the metals together. A large electrical current flows from one electrode to the second electrode through the metals being welded.

These electrodes are made of special copper alloys that can carry the high current and still have physical strength to operate under high pressures. They are typically water-cooled.

Resistance spot welding quality is controlled by the amperage, the electrode pressure, and the length of time the current flows. In an automatic spot welder, the welder sets the electrode current, electrode pressure, and the timing. The electronic controller repeats the desired weld cycle each time the start switch is pushed.

**When performing resistance welding, the welder must wear flash goggles, approved clothing, and safety shoes. Gloves are needed to prevent cuts and burns to the hands.**



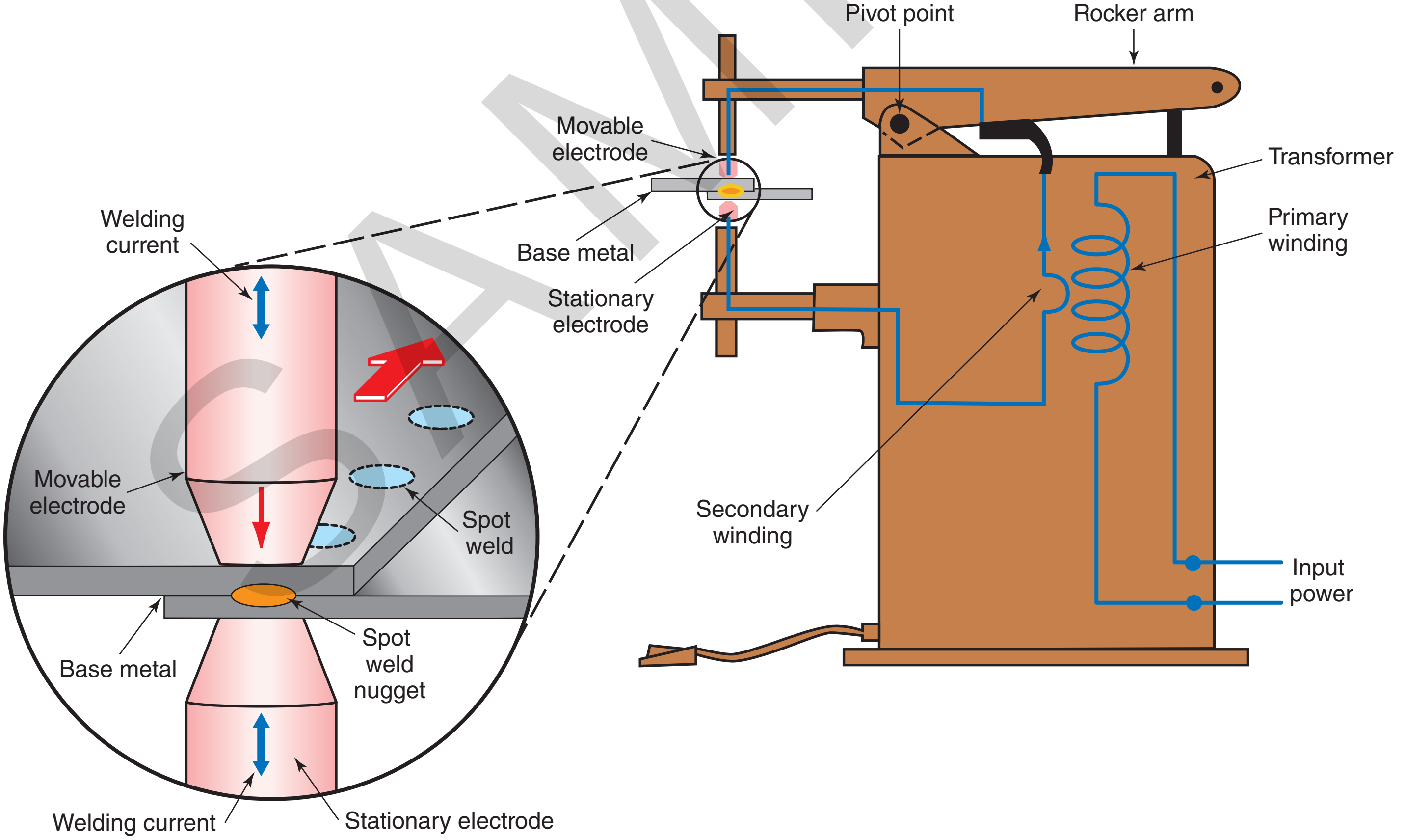


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**Figure 4-12.** Resistance spot welding (RSW). High electrical current heats a small area on two or more sheets of metal as the sheets are pressed together between the spot-welding electrodes. The metals become hot enough to fuse together.

Chapter 18, *Resistance Welding Equipment and Supplies*, and Chapter 19, *Resistance Welding*, provide detailed information about resistance spot welding.

### 4.4.2 Projection Welding (PW)

The projection welding process, **Figure 4-13**, uses resistance to the flow of electricity to create heat for welding. It is similar to spot welding and is commonly used in production welding. One of the two pieces of metal is produced with bumps or projections of a specific shape and size in the metal.

The welding machine electrodes are often flat plates called ***platens***. The two pieces of base metal are placed together between the platens. They touch only at the projections (bumps) on the one piece. Welding current is supplied by a resistance welder transformer. The welding current flows through the pieces to be welded while they are clamped between the platen plates. Due to the projections, the current is concentrated at the points of contact. These points heat up and melt.

The welding current flows for a short time as pressure is applied between the two platens. The weld current is stopped and the weld is complete. Timing of the current flow and application of welding pressure are important parts of this welding process.

**Some flash and sparking may take place during projection welding. The welder should wear flash goggles, approved clothing, safety shoes, and approved gloves.**

Additional information about projection welding is provided in Chapter 19, *Resistance Welding*.

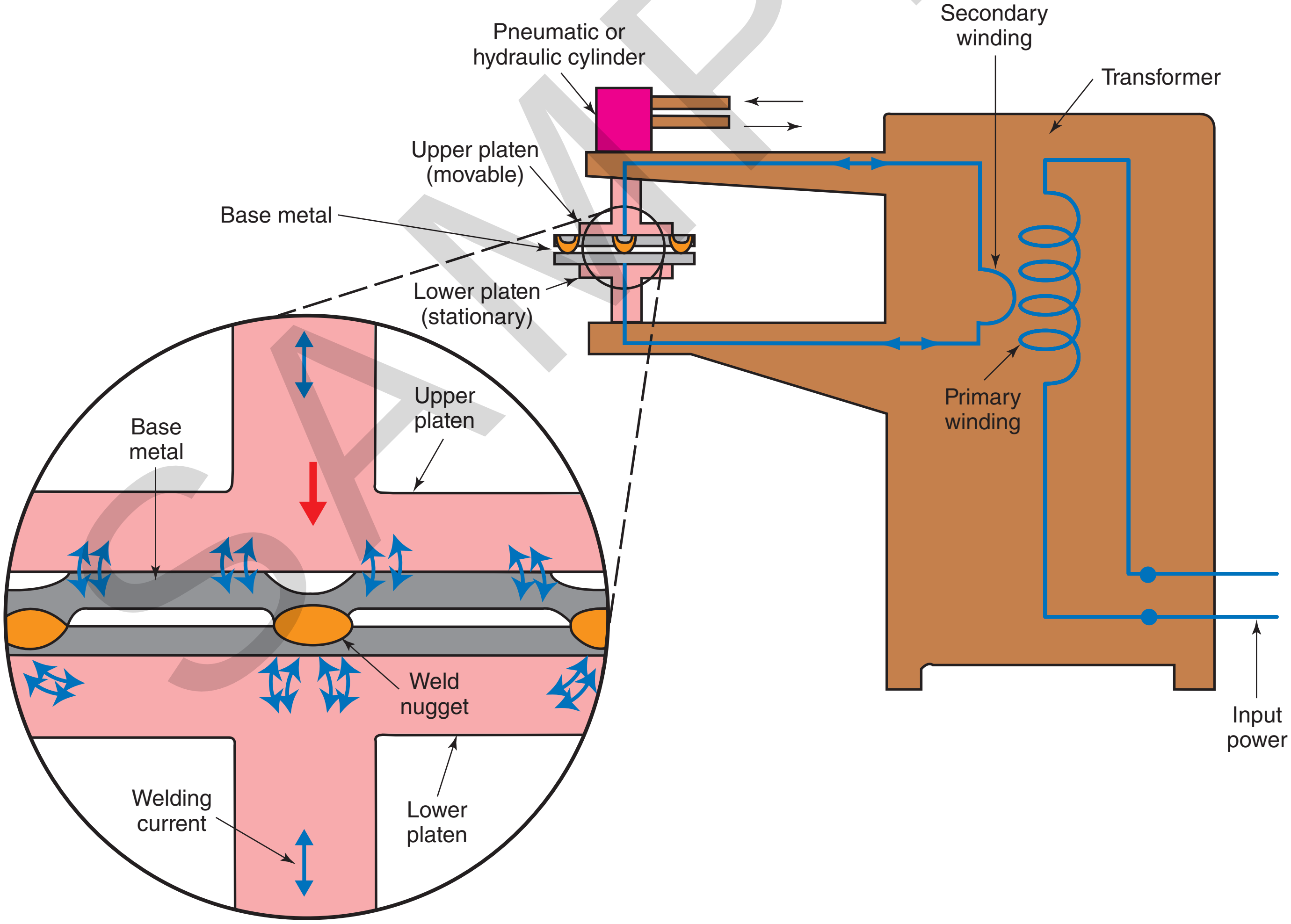


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**Figure 4-13.** Projection welding (PW). Electrical resistance heats the projections in one sheet of base metal as they touch another sheet of base metal. Both pieces become hot enough at the contact spots to fuse together as pressure is applied.

### 4.4.3 Resistance Seam Welding (RSEW)

Resistance seam welding, **Figure 4-14**, is a special application of resistance welding. It is often used to weld joints in containers and other products that require an airtight or vapor-tight seam.

The electrodes are in the form of wheels, with the work to be welded passed between them as they rotate. A timing device turns on the welding current at controlled, rapidly repeated intervals. The rapidly repeating current flow makes a series of overlapping spot welds that appear to be a continuous line of welding. These machines are usually automatic. The current, pressure on the electrodes, and sequence times are set by the welding operator. The timing of the process is regulated by an electronic controller.

**The operator must wear flash goggles and all other required safety clothing. The operator must also wear approved gloves.**

Chapter 18, *Resistance Welding Equipment and Supplies*, and Chapter 19, *Resistance Welding*, provide additional information about resistance seam welding.

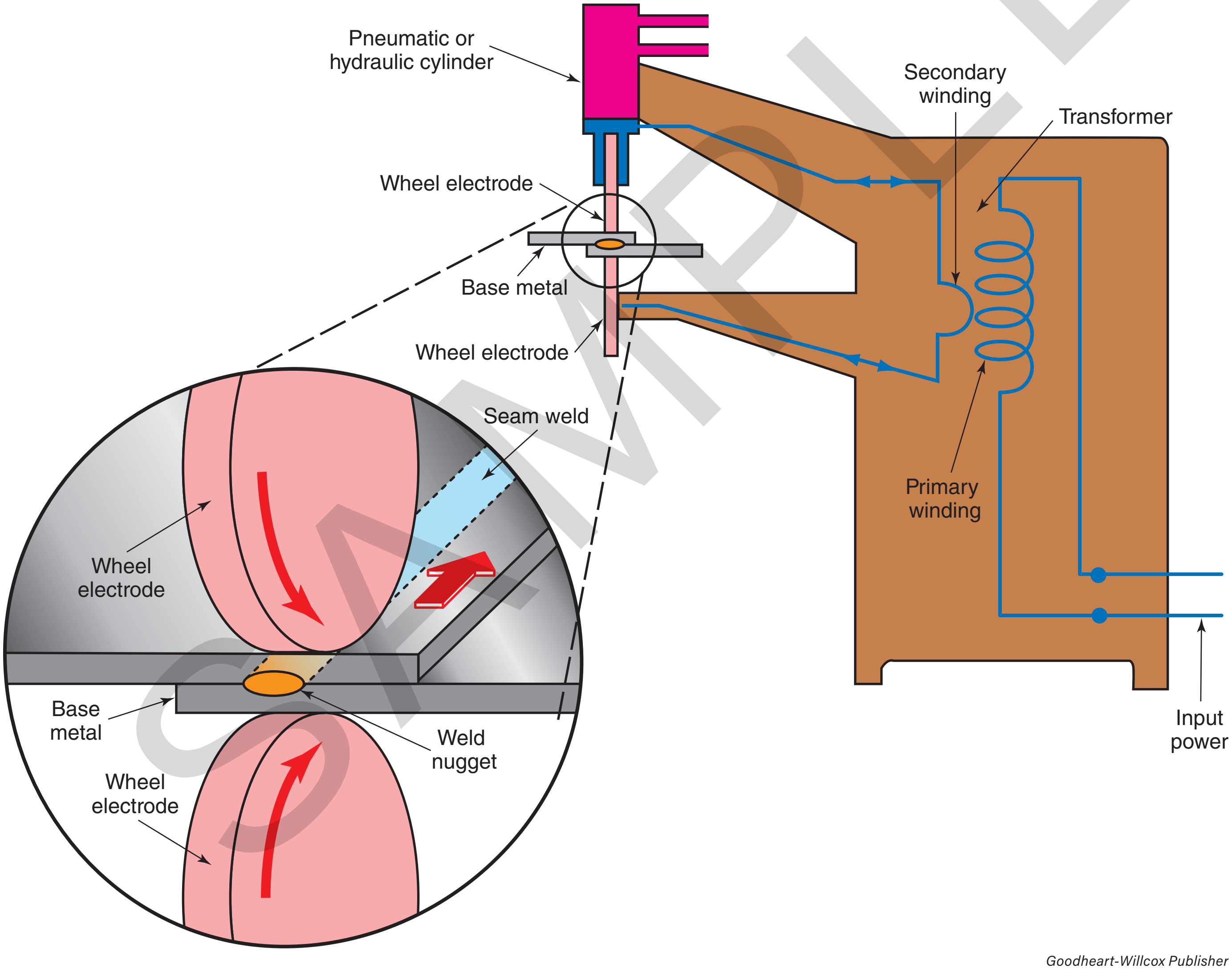


**Figure 4-14.** Resistance seam welding (RSEW). Electrical energy travels between two electrode wheels. As two sheets of metal are fed into the machine, the wheels rotate and clamp the two sheets of base metal together. Electricity travels through the base metal, making it hot enough to fuse the two sheets together and form a seam weld.

### 4.4.4 Flash Welding (FW)

The flash welding process uses an electric arc to heat the base metals. It combines resistance welding, arc welding, and pressure welding. Flash welding provides a strong, clean weld joint and is chiefly used in production welding.

A step-down transformer provides the welding current for flash welding. The two pieces to be welded are held in current-conducting clamps, one of which is stationary and another that is movable. See **Figure 4-15**. To make a flash weld, the workpieces are brought together under light pressure. A low-voltage/high-amperage current travels between the base metals.

As soon as the current is established, the two pieces of metal are drawn apart very slightly. This causes an electric arc to form between them. The arc heats the surfaces of the two metals. When sufficiently heated, they are forced together under very high pressure. This pressure causes an outward flow of heated and somewhat dirty metal from the joining surfaces. The clean, heated subsurface metal brought into contact produces a good weld. The finished weld has ***flash***, or enlargement, at the joint.

Welding heat is controlled by the current adjustment setting. The quality of the weld is controlled by the current, the length of time of the arc, and finally, the pressure at the time the two surfaces are brought together.

**It is necessary to wear protective clothing, a face shield, and gloves. Flying sparks (metal expelled at the joint) are produced during this process.**

Chapter 18, *Resistance Welding Equipment and Supplies*, and Chapter 19, *Resistance Welding*, provide more detailed information about flash welding.

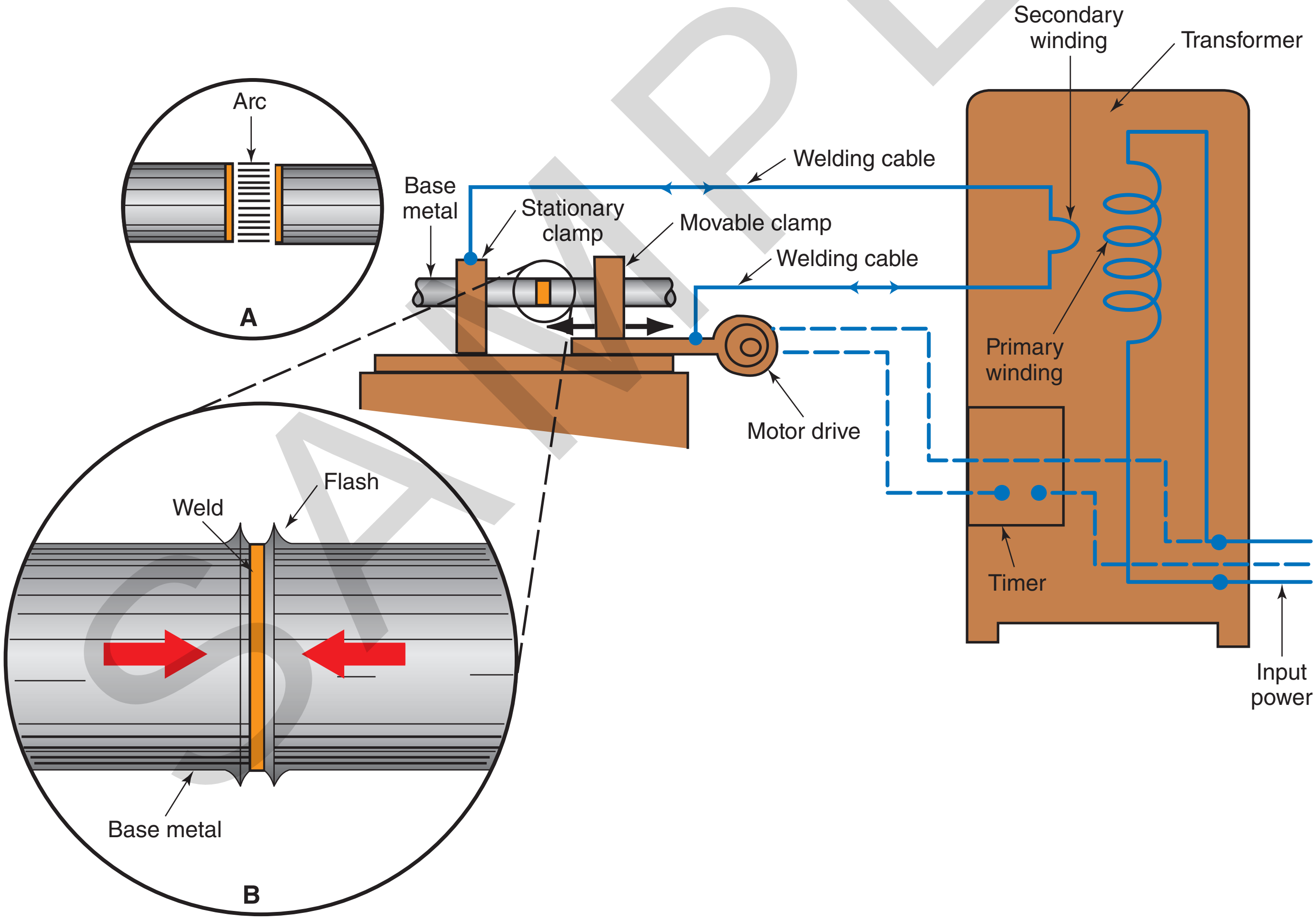


**Figure 4-15.** Flash welding (FW). A—Electrical energy creates an arc that melts the ends of two pieces of base metal. B—When the ends are molten, they are pushed together to fuse into one piece.

## 4.5 Arc Cutting Processes

Arc cutting processes covered in this section include plasma arc cutting, shielded metal arc cutting, and air carbon arc cutting. These processes use an arc to melt and blow the molten metal from the cut. In air carbon arc cutting, air is used in addition to the arc to help blow molten metal out of the cut.

### 4.5.1 Plasma Arc Cutting (PAC)

Plasma arc cutting uses an electric arc and fast-flowing super-heated ionized gases to melt and cut metals. This process cuts steel, stainless steel, aluminum, and all other metals rapidly. Nonmetals, such as concrete, can also be cut with plasma arc cutting.

**Figure 4-16** shows a plasma arc cutting station. The metal is melted by the heat of the plasma arc. The molten metal is blown away by the high-velocity jet of ionized gas.

A plasma arc cutting torch is equipped with a special cutting nozzle and a hafnium, tungsten, or zirconium electrode. The torch is connected to a source of DC power, compressed gas, and suitable controls.

Plasma arc cutting can be done manually, or the torches can be mounted on mechanized cutting machines so specific patterns can be cut repeatedly with high precision. The current is set and controlled by the power source. Water can be used to cool the torch.

**Plasma arc cutting is a very noisy process. The operator or welder must wear earplugs and/or industrial "earmuffs." The welder must also be protected**

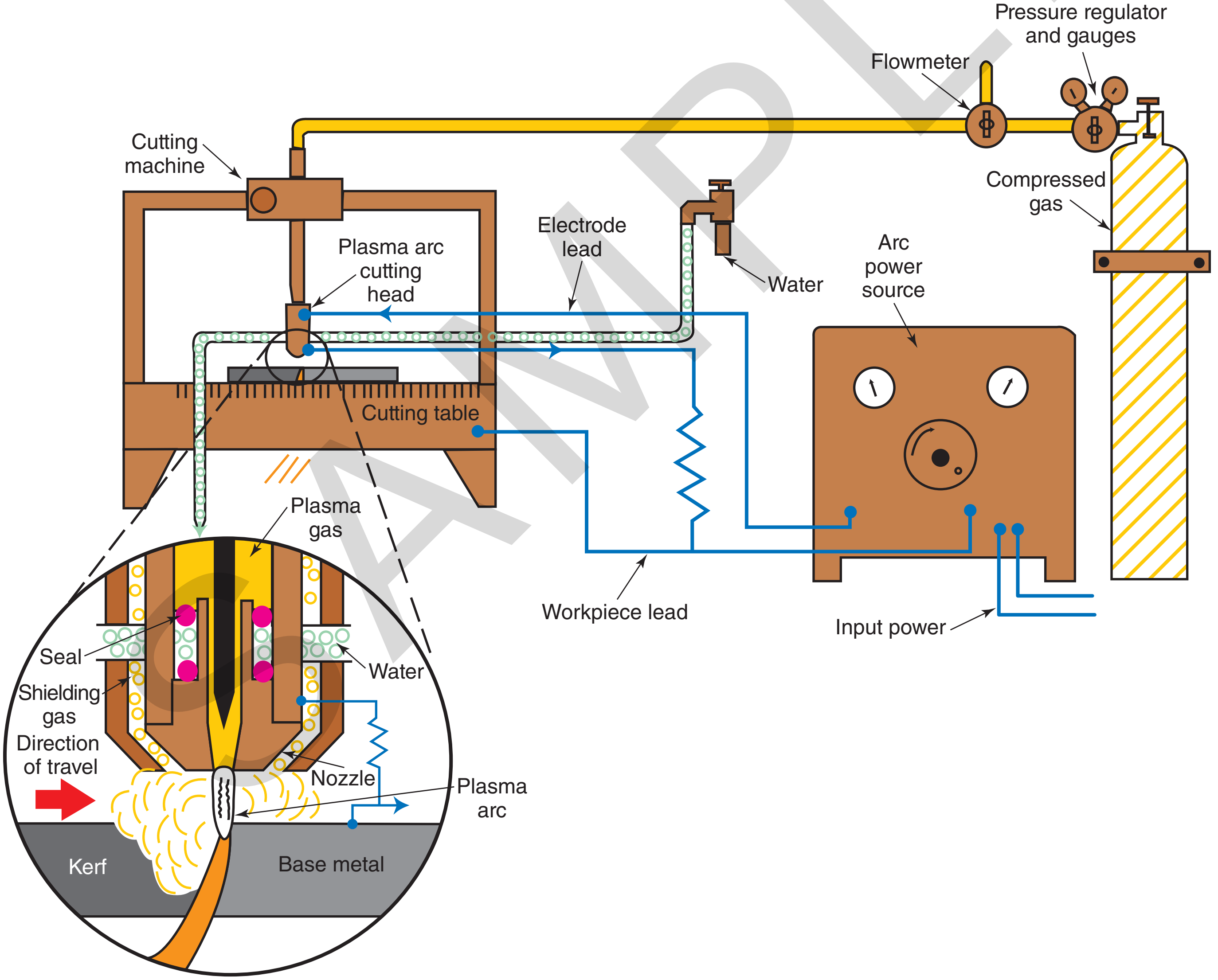




**Figure 4-16.** Plasma arc cutting (PAC). An electric arc between a tungsten alloy electrode and the base metal ionizes the cutting gas. This ionized gas (plasma) is at a very high temperature, which melts the base metal. Molten base metal is blown away by the high-velocity jet of ionized gas, which creates a kerf (cut) in the base metal.

**with an approved helmet, gloves, protective clothing, and other required safety equipment.**

Chapter 11, *Plasma Arc Cutting*, covers plasma arc cutting in greater detail.

## 4.5.2 Air Carbon Arc Cutting (CAC-A)

The air carbon arc cutting process uses an electric arc to melt the base metal. A jet of air then blows the molten metal away. Air carbon arc cutting can be used on many metals.

**Figure 4-17** shows a typical station for air carbon arc cutting and gouging. The electrical supply may be either a direct current (DC) or an alternating current (AC). An electrode lead (flexible cable) connects the electrode holder to the welding machine, and a ***workpiece lead*** connects the base metal to the machine.

The air jet is supplied from either a compressed air cylinder or an air compressor. The air line is attached to the electrode holder. A lever-operated valve in the electrode holder controls the airflow. The welder operates the electrode holder manually. This process can be used for either cutting or gouging metal.

Current is set by adjustments on the welding machine. The arc length is controlled by the welder. The length of the carbon electrode between the air jet nozzle and the arc must be maintained at such a distance that the air jet will be effective in blowing away the molten metal.

**This cutting process produces considerable sparking. The welder must be protected by gloves, helmet, and clothing. Excellent ventilation is needed. Good fire prevention practices must be followed.**

Chapter 24, *Special Cutting Processes*, provides additional information about air carbon arc cutting.

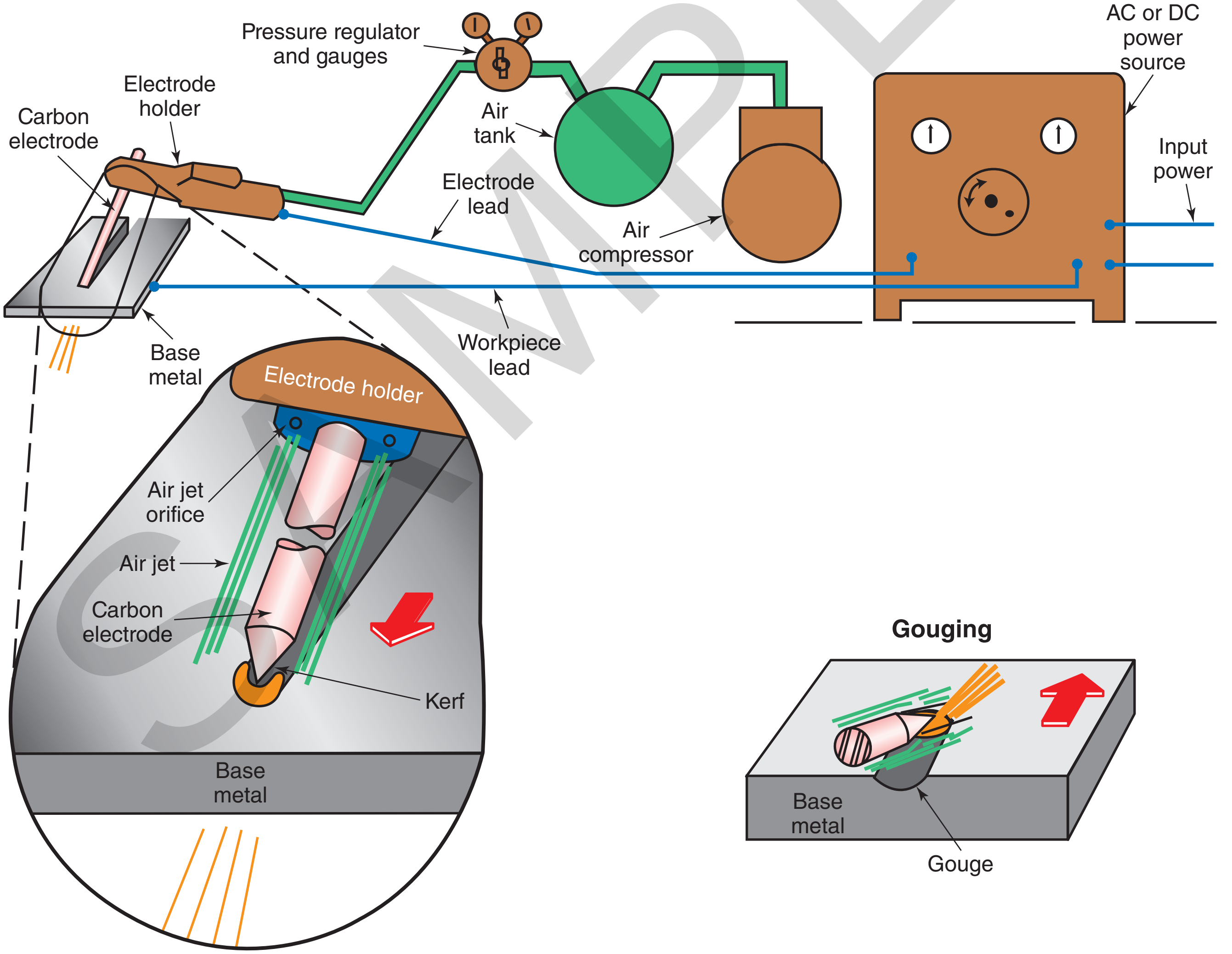


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**Figure 4-17.** Air carbon arc cutting (CAC-A). An electric arc between the carbon electrode and the base metal melts the base metal. Manually operated air jets attached to the electrode holder blow the molten metal away. This process is used for gouging base metal as well as for cutting.

### 4.5.3 Shielded Metal Arc Cutting (SMAC)

The shielded metal arc cutting process uses an arc between a metal electrode and the base metal. This arc melts the base metal. The electrode is coated with a thick layer of flux. The electrode melts up inside the thick coating, creating a high-velocity gas jet. The high-velocity gas jet blows the molten metal away from the base metal to form a kerf (cut).

SMAC uses the same type of welding machine used for SMAW, but with a special cutting electrode. If a special cutting electrode is unavailable, a standard SMAW electrode can be used. However, this requires a special technique to get the electrode to cut the metal instead of adding metal to it.

The shielded metal arc cutting process requires a power source, either AC or DC. A manually operated electrode holder provides a grip for controlling the electrode. Electric current from the arc welding machine flows through the electrode holder lead and forms an arc between the electrode and the workpiece. A workpiece lead between the workpiece and the power source completes the circuit in this process.

**Figure 4-18** shows a shielded metal arc cutting station. Heat from the arc is controlled by the current, arc length, and electrode material. The welder strikes the arc between the electrode and the base metal, and the cutting is started. The welder moves the electrode as the cut progresses through the base metal.

**To protect the welder from intense heat, the light of the arc, and sparks, an approved helmet, gloves, and welder's clothing must be worn. The equipment used must include the necessary shielding and safety devices. Excellent ventilation is needed. Good fire prevention practices must be followed.**

Chapter 24, *Special Cutting Processes*, provides additional information about shielded metal arc cutting.



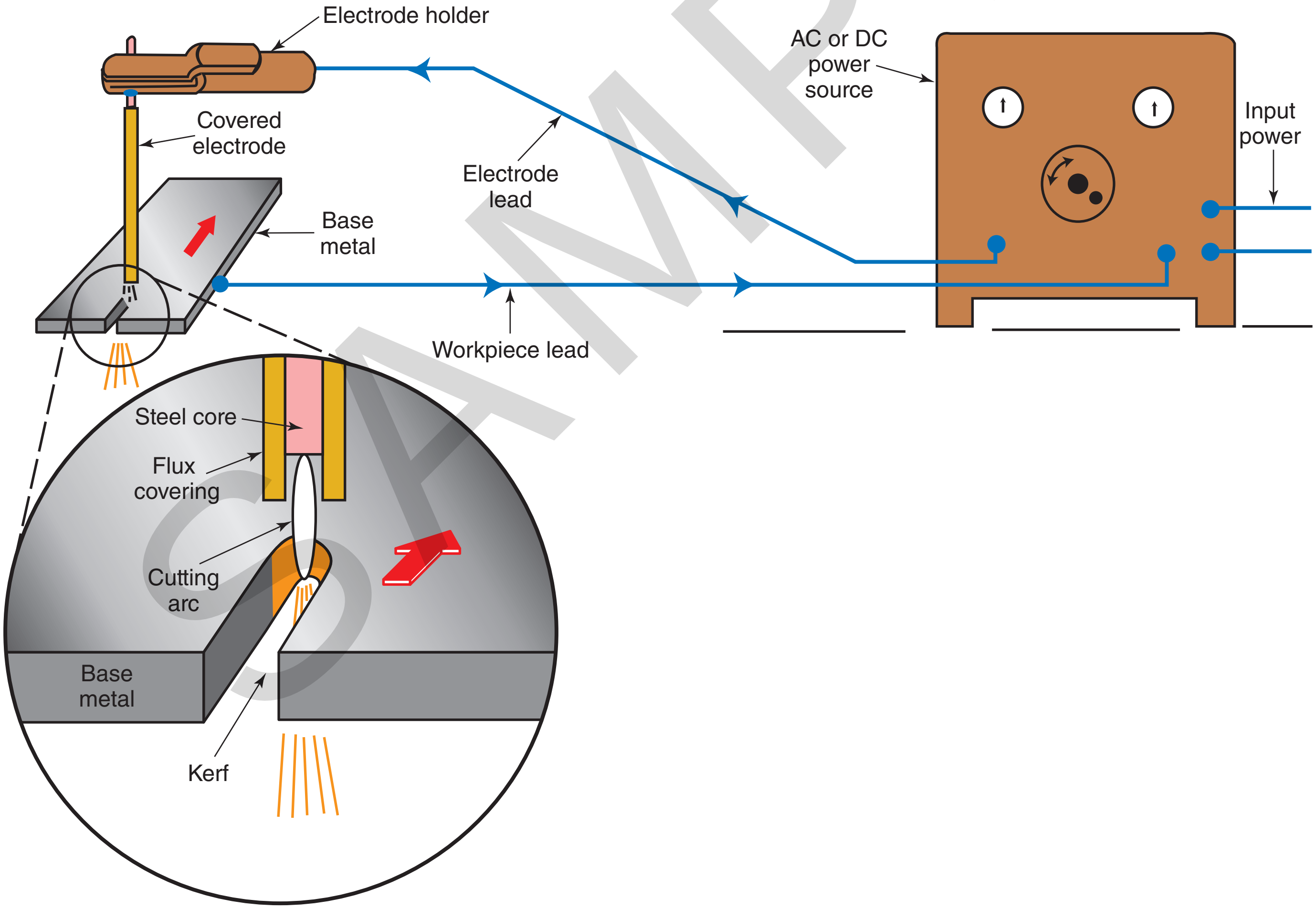


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**Figure 4-18.** Shielded metal arc cutting (SMAC). An arc between a very heavily covered metal electrode and the base metal melts the end of the electrode and the base metal. The metal electrode melts far back into the covering, producing a jet of gases that blows the molten base metal away.

## 4.6 Specialized Arc Welding Processes

Specialized arc welding processes covered in this section include submerged arc welding, electroslag welding, and arc stud welding. While each of these welding processes uses a powerful electric current, they differ greatly from each other. Each has its place in the field of welding.

### 4.6.1 Submerged Arc Welding (SAW)

In submerged arc welding, an electric arc between an electrode and the base metal produces welding heat. The arc is submerged in a granular flux. SAW is often used for welding thick plate joints. The equipment is operated automatically or semiautomatically. As with GMAW and FCAW, the electrode feeds automatically into the arc. See **Figure 4-19**.

A hopper and feeding mechanism deposit flux over the joint being welded. The arc, generated by AC or DC current, is submerged in the flux. The chemical composition of the flux affects the composition of the completed weld. Alloying elements are added to the flux. These alloying elements combine with the molten base metal to improve the properties of the weld. As the weld progresses, some of the flux melts and forms a slag covering over the weld. The slag protects the base metal from oxidation while it cools. A vacuum machine can be used to pick up any unaffected flux for reuse.

Welding heat is regulated by changing the voltage and wire feed speed on the welding machine. The electrode, which is power-fed and made of carbon steel, extends through the flux to a point just above the base metal. The correct arc length is automatically maintained beneath the flux.

**Since the arc is submerged in the flux, it cannot be seen during welding. This reduces, to some extent, the hazards of burns and flying sparks. Still, the welder should wear approved safety goggles, gloves, and clothing. Good ventilation should be provided.**

Chapter 20, *Special Welding Processes*, presents more information about submerged arc welding.



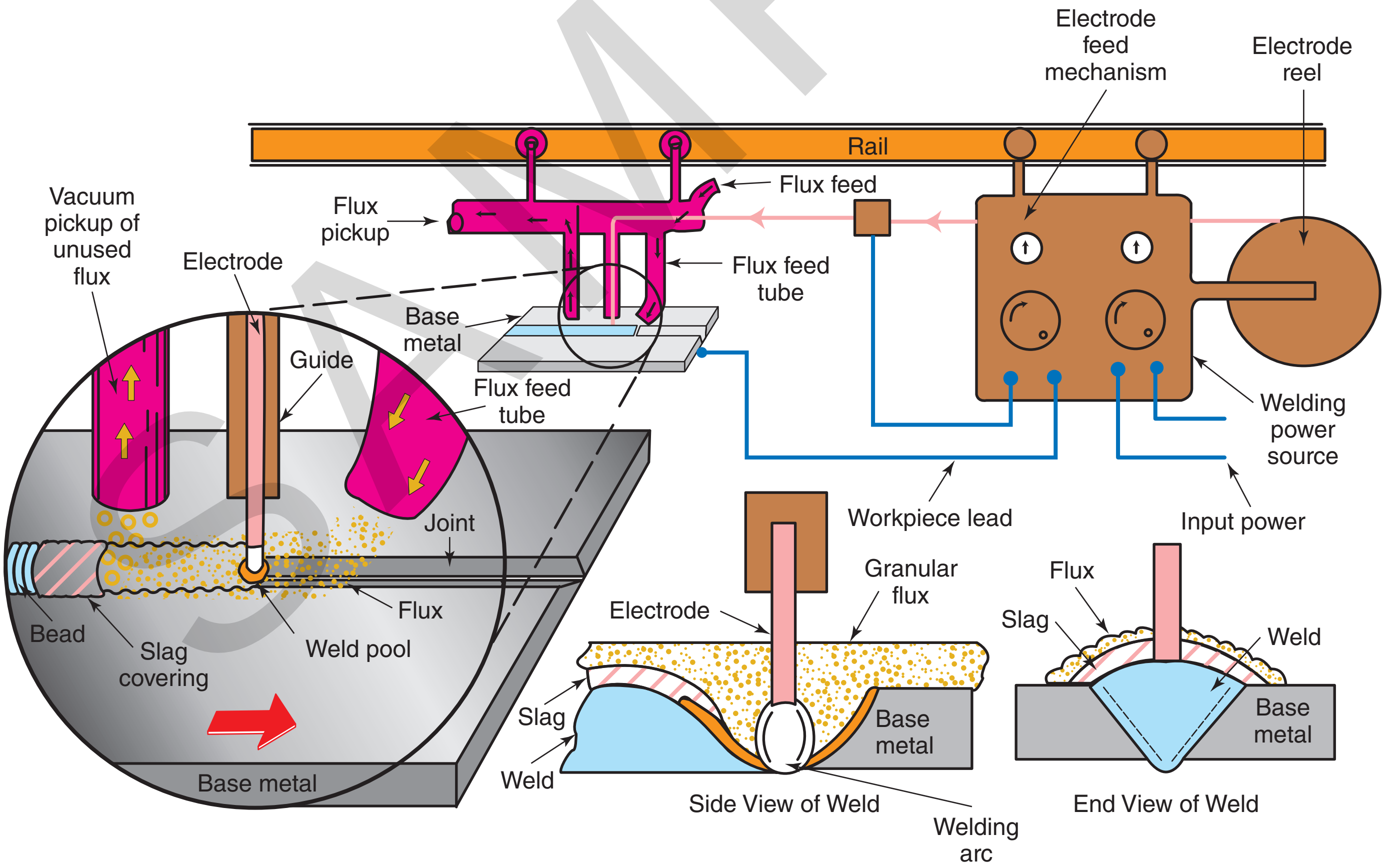


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**Figure 4-19.** Submerged arc welding (SAW). The arc is covered, or submerged, in a layer of flux. Electric current creates an arc to heat and melt the end of the electrode wire, the base metal, and some of the flux. Flux adds alloys to the weld pool. When the flux solidifies, it forms a slag covering over the weld.

## 4.6.2 Electroslag Welding (ESW)

Electroslag welding is used to weld various joints on thick metal. The weld is performed vertically, moving upward.

**Figure 4-20** shows a typical setup for electroslag welding of a butt joint. Prior to the start of the welding process, a flux material several inches deep is placed between the two base metals. To start the weld, an electric arc is struck between one or more electrodes and the base metal. The electrodes are continuously fed by a drive mechanism. The electrodes are often automatically ***oscillated*** (moved back and forth) when extremely thick plates are welded. The flux is melted by the heat of the arc. After the flux becomes molten, it conducts electricity. The arc stops, but electricity continues to flow. The flux (slag) is kept molten by its resistance to the flow of the electricity through the electrode and flux to the base metal.

The molten flux melts the base metal and the continuously fed filler metal to form a weld. Movable, water-cooled molds (shoes) are used on each side of the joint. The shoes are water-cooled to prevent them from melting into the weld. These shoes keep the molten flux, filler metal, and base metal in place as the weld moves upward. The molten flux shields the weld from the atmosphere.

The heat source is controlled by the amount of current and the physical characteristics of the flux. **Operators must wear typical work clothes and PPE, which include long pants, shirt, steel-toed shoes, gloves, and safety glasses. The heat developed in this process is very intense, but the welding operator is not exposed to the high heat.**

Chapter 20, *Special Welding Processes*, provides more instruction on electroslag welding.

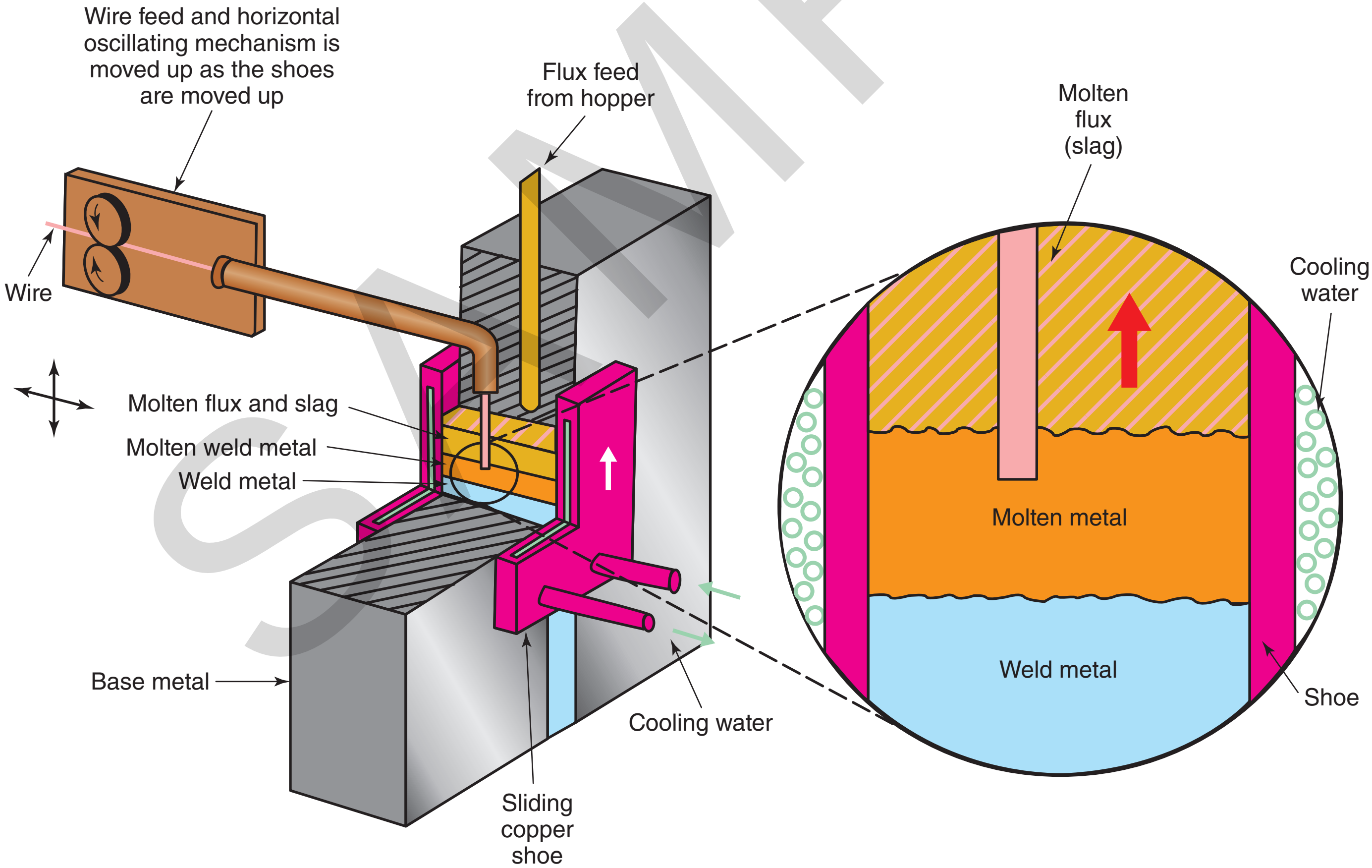


**Figure 4-20.** Electroslag welding (ESW). The energy for welding is an electric current. This current melts the flux and also keeps the flux molten. The molten flux melts the base metal; the melting electrode wire provides the filler metal. The weld is formed vertically. Water-cooled shoes prevent the molten metal from flowing out of joint as the metal cools and solidifies.

### 4.6.3 Arc Stud Welding (SW)

Arc stud welding is a semiautomatic welding process. It is used to attach metal fastening devices to metal plates, beams, or sheet metal without drilling and tapping. Bolts, screws, rivets, and spikes can be attached in this way.

**Figure 4-21** shows an arc stud welding station. The heat source is an electric arc. The energy source is an electric welding transformer. The control on the welding machine determines the current in the electric arc. Current settings vary with the size of the stud and the kind of metal. The control unit has a timer that controls the duration of the arc.

The welder installs the stud in the gun. The gun is then positioned on the base metal. A trigger on the gun starts the stud welding operation cycle. The stud is drawn away from the base metal and an arc is created. The arc melts the end of the stud and some of the base metal. Once both are slightly molten, the stud is forced onto the base metal. The molten metal solidifies and the weld is complete.

**The welder must wear gloves, a face shield with flash goggles, and fire-resistant clothing.**

A more complete explanation of arc stud welding is presented in Chapter 20, *Special Welding Processes*.



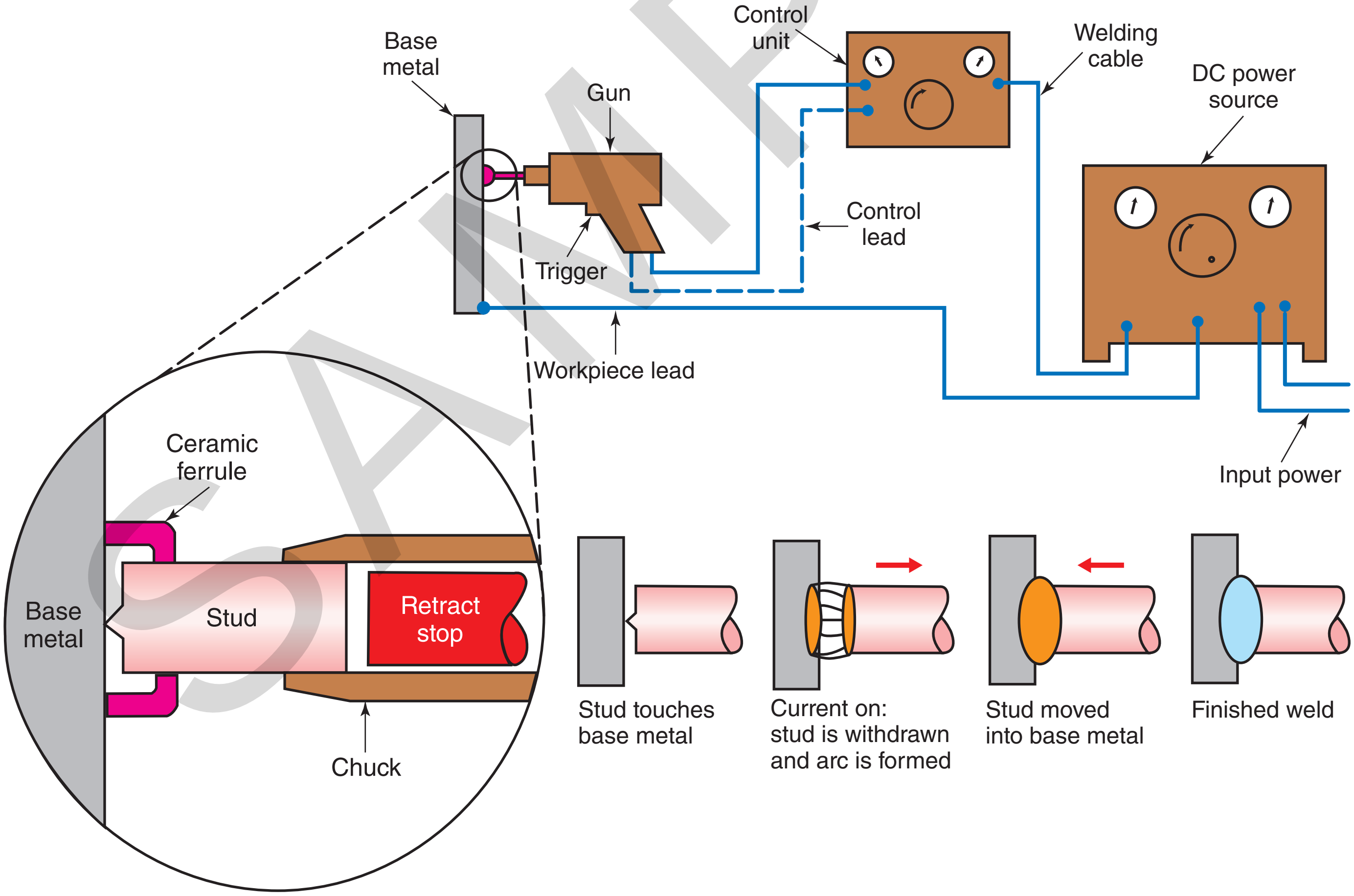


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**Figure 4-21.** Arc stud welding (SW). Electrical energy creates an arc that melts the end of the stud and the base metal. Once the stud and base metal are slightly molten, the stud is forced into the base metal weld pool. The assembly is held briefly until the weld metal cools. The enlarged view shows the stud, stud chuck, and ceramic ferrule. The sequence of four drawings shows the steps in the stud welding process.

## 4.7 Solid-State Welding Processes

Solid-state welding processes covered in this section include cold welding, explosion welding, forge welding, friction welding, friction stir welding, and ultrasonic welding. These processes do not use an arc, a flame, a beam of energy, or any form of resistance to heat the metals being joined.

The American Welding Society defines solid-state welding in the following way: "A group of welding processes that produce coalescence by the application of pressure without melting any of the joint components." Solid-state welding is done when the material is cold, warm, or hot. However, the temperature is always below the melting points of the materials being joined. Also, no filler metal is ever used.

### 4.7.1 Cold Welding (CW)

No outside heat source is used in this process. Cold welding uses very high pressure to force metals together. Only the surface molecules are heated and fused to form a weld. The method is used mainly to join softer metals, such as aluminum to aluminum, copper to copper, and aluminum to copper. Good fusion occurs, resulting in a strong weld. Butt joints and lap joints can be welded with this process. Metal surfaces being joined must be exceptionally clean.

The source of energy to make the weld is tremendous pressure, usually produced by hydraulic cylinders. See **Figure 4-22**. The weld is controlled by the size of the die surfaces in contact with the metal and the amount of hydraulic pressure.

**The operator should wear gloves, a face shield or safety goggles, and approved clothing.**

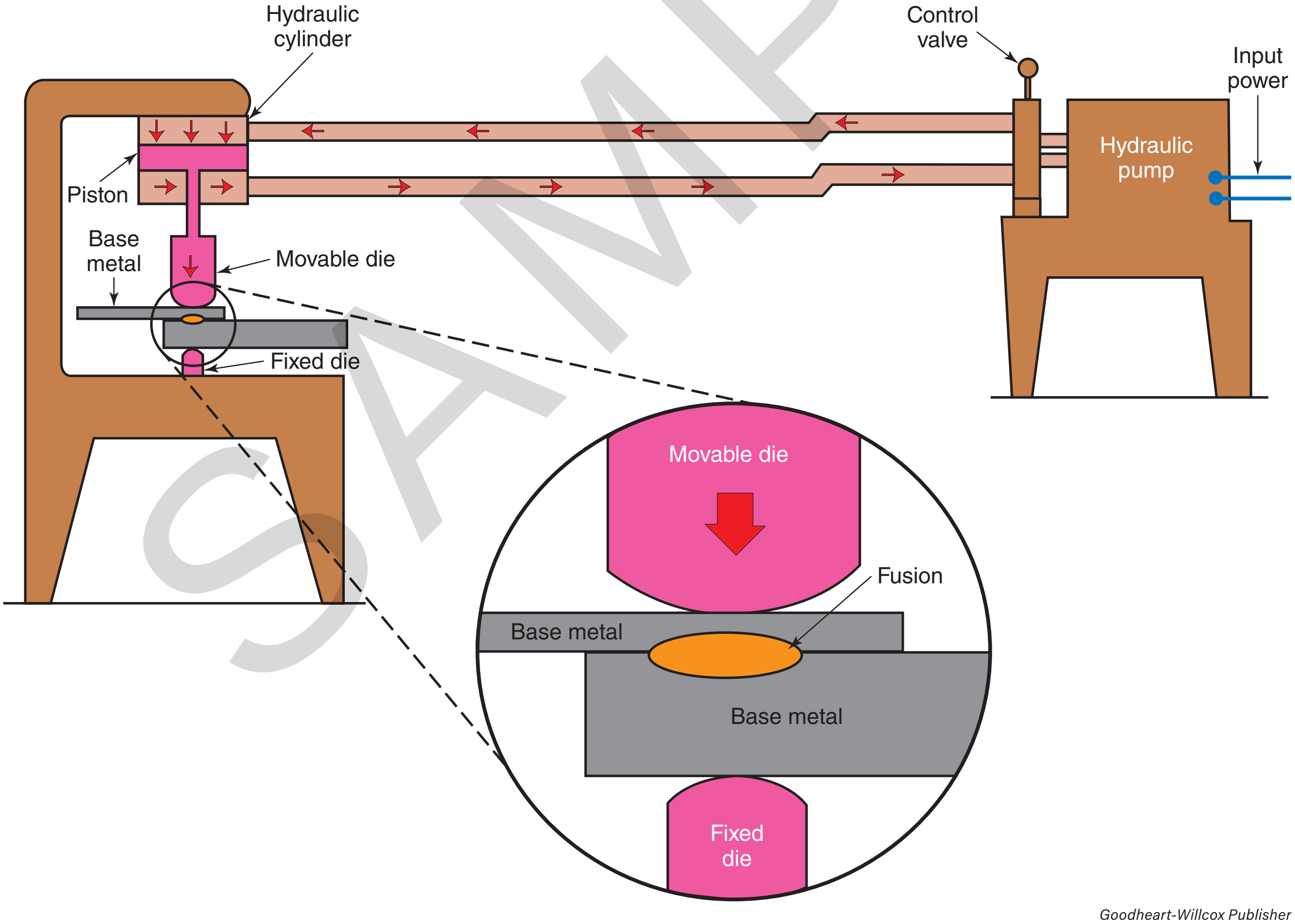


**Figure 4-22.** Cold welding (CW). Pressure creates the welding energy. No heat is needed. High pressure is required to force very clean base metals together. A hydraulic piston is used to create and apply the high pressure.

## 4.7.2 Explosion Welding (EXW)

Explosion welding, **Figure 4-23**, joins metals together using a powerful shock wave. This creates enough pressure between two metals to cause surface flow and cohesion. EXW is often used to weld large sheets together. It is used to weld stainless steel plate to carbon steel, titanium to carbon steel, aluminum to stainless steel, and aluminum to molybdenum, among other applications.

The energy source is the tremendous shock wave caused by detonating an explosive material. The operation requires precise setup. Bonding takes place in an instant. **Safety glasses, ear protection, and approved clothing must be worn when handling the explosives before and after welding.**

### Warning

Extreme caution is required when handling explosives! Explosives should be handled only by experts. Many state and federal permits are required for explosion welding. No one is allowed to be near the welding process when the explosives are detonated. People must be behind a protective barrier or a great distance from the process.

Chapter 20, *Special Welding Processes*, explains this special type of welding in more detail.



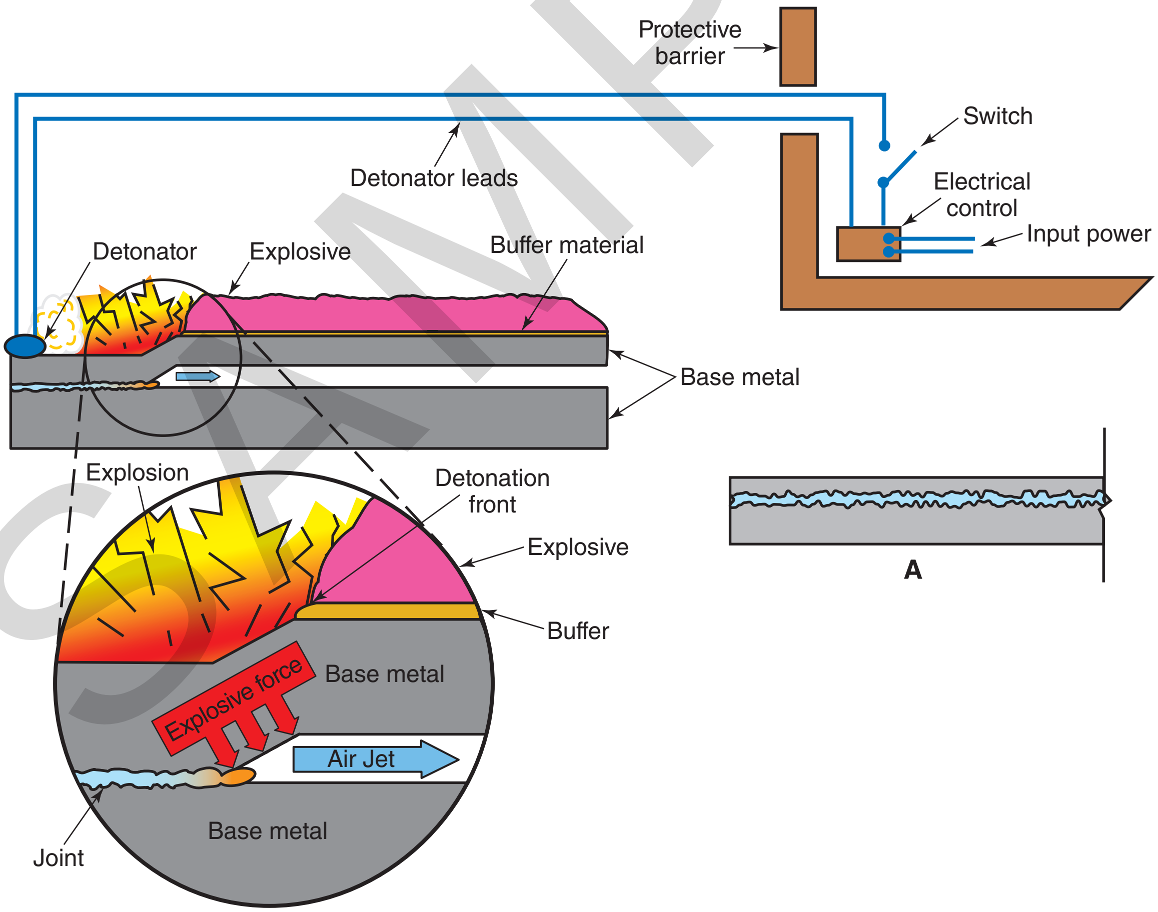


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**Figure 4-23.** Explosion welding (EXW). A buffer material is applied to the top surface of one of the metal sheets. Welding energy comes from explosive material placed on top of buffer material. An ignitor (detonator) is operated from behind a barrier. The explosion proceeds from left to right and welds the top plate to the bottom plate almost at once, without deforming either piece of metal. The completed weld is shown at "A".

### 4.7.3 Forge Welding (FOW)

In ***forge welding***, two pieces of metal are heated in a furnace to a plastic temperature, the temperature at which the metal becomes easily malleable. ***Forging*** (hammer blows) is used to fuse the two pieces together. This process is used to join wrought iron, low-carbon steel, and medium-carbon steel workpieces. Forge welding can be performed in places where there is no electricity or fuel gas available. It can be performed using a fuel gas furnace or a blacksmith's forge welding station. See **Figure 4-24**.

Metal parts to be welded are heated in the forge or furnace. When the parts reach forging temperature (indicated by the bright red color of the metal), they are withdrawn. The heated parts are placed together on an anvil and hammered to make a weld.

**The blacksmith/welder should wear eye protection, safety shoes, and flame-resistant clothing and gloves. This process produces a great deal of heat. Sparks are often created when the hot metal is struck with the hammer.**

Chapter 20, *Special Welding Processes*, provides additional information about forge welding.



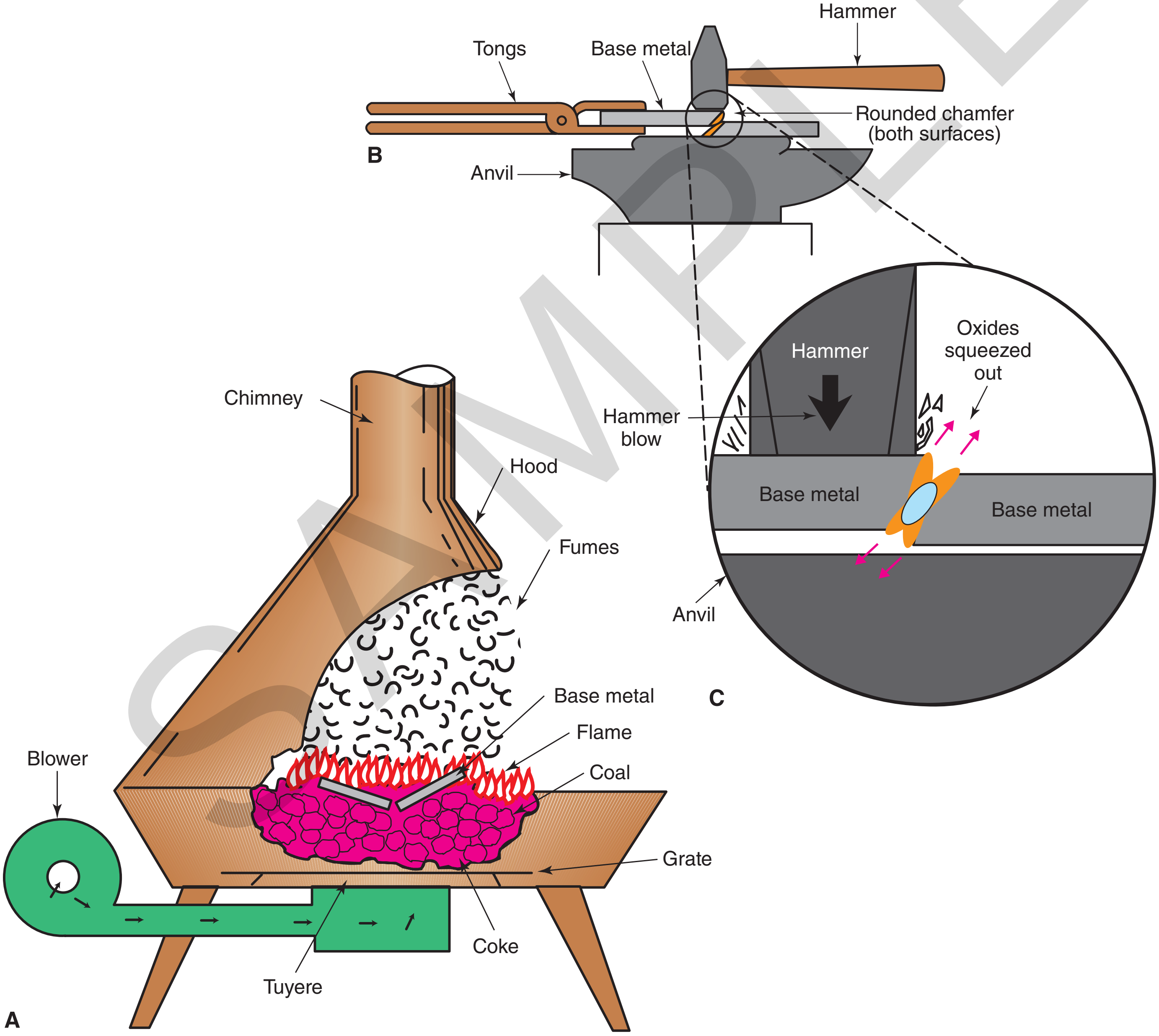


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**Figure 4-24.** A forge welding (FOW) station. A—Cross section through blacksmith's coal-fired forge. B—Hammer and anvil being used to make a forged weld. C—Enlarged view of the welding action.

## 4.7.4 Friction Welding (FRW)

Friction welding uses heat generated by friction (rubbing of surfaces) to fuse two pieces of metal together. This process is used chiefly for welding a butt joint on fairly large, round rods or cylinders. **Figure 4-25** shows a friction welding station.

No outside heat is supplied. One of the pieces is made to rotate. The ends of the pieces to be joined are then brought together under a light pressure. The resulting friction between the stationary and rotating parts develops the heat needed to form the weld. As the metal surfaces reach the plastic state, they are forced together under a much greater pressure. The process creates a clean metal-to-metal welded surface.

Equipment includes the necessary clamping devices, a mechanism for rotating one part, and a method for applying high pressure to the friction surfaces. The control of this type of welding is based on the speed at which the surfaces rotate against one another and the pressure that is applied.

**Friction welding produces considerable sparking. The operator needs to wear approved clothing and goggles or a face shield to avoid injury.**

Chapter 20, *Special Welding Processes*, provides additional information about friction welding.

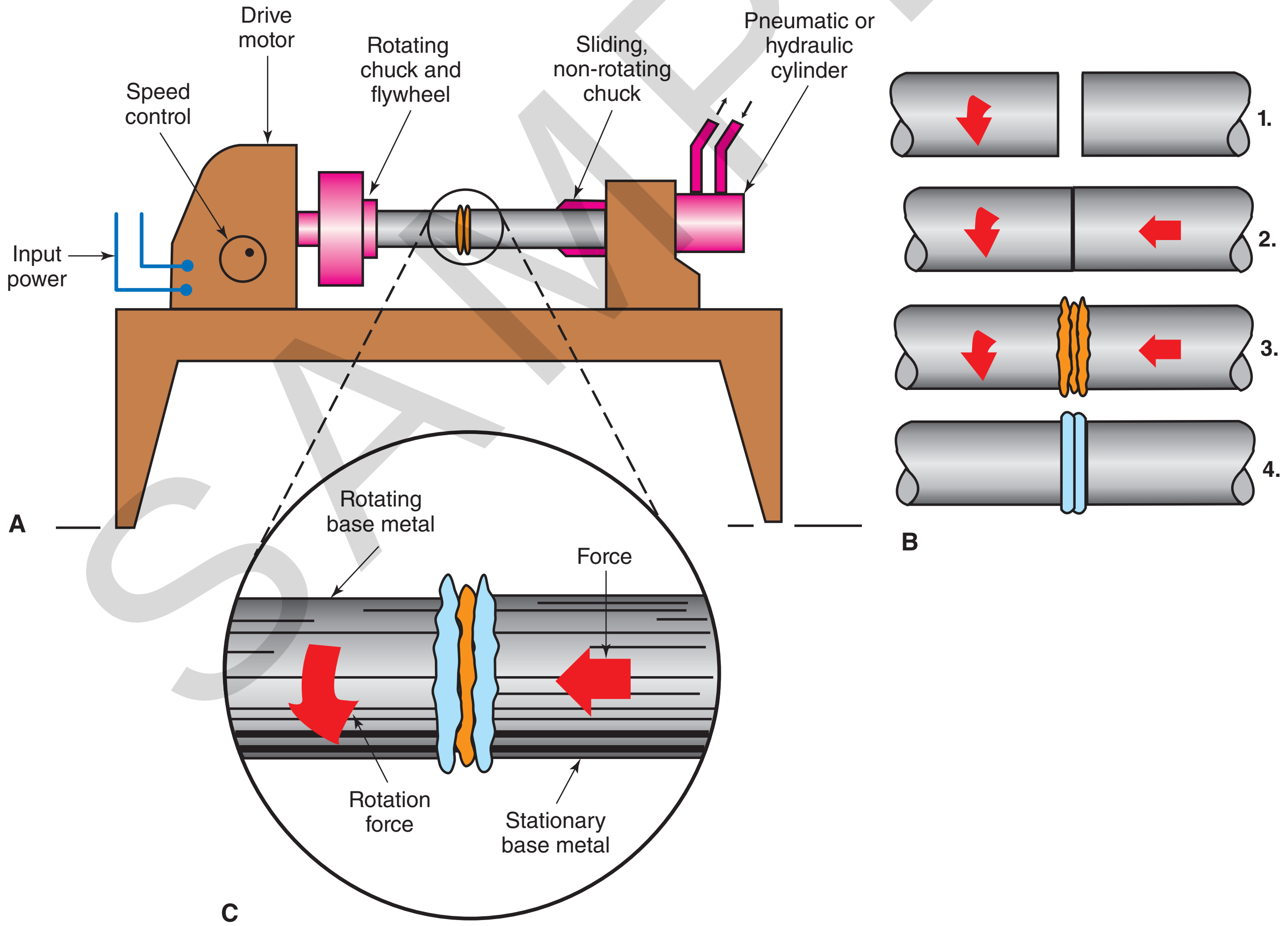


**Figure 4-25.** Friction welding (FRW). A—Schematic of a friction welding station. B—Four steps in producing a friction weld. C—Closeup of a friction weld being made.

### 4.7.5 Friction Stir Welding (FSW)

***Friction stir welding*** is a solid-state welding process similar to friction welding. A variety of joints can be welded using the friction stir welding process. It is most often used to weld butt joints.

Equipment required to perform a friction stir weld is rather simple but is expensive. Friction stir welding requires a special welding tool that has two main features. The first feature is a relatively small, tapered cylinder or probe. The second feature is a larger tool shoulder. The length of the small, tapered probe on the welding tool is determined by the thickness of the metal being welded. The diameter of the larger tool shoulder is determined by the required width of the weld bead.

To create a weld, the friction stir welding tool is rotated at a high speed. The heat of friction heats the joint to a plastic temperature as the small, tapered section of the welding tool is pressed into the weld joint. The depth of the weld is determined by the length of the probe part of the tool. The larger shoulder part of the welding tool spins along the surface of the joint. It creates a smooth bead and keeps the probe at a constant depth. The welding tool is moved along the center of the joint to form a clean-looking and very strong welded joint. See **Figure 4-26**.

Chapter 20, *Special Welding Processes*, presents more information about friction stir welding.

### 4.7.6 Ultrasonic Welding (USW)

In ultrasonic welding, very-high-frequency vibrations excite molecules on the surface of metal. This movement among the molecules produces fusion of overlapping surfaces. This process is most often used to join very light materials. For example, ultrasonic welding is used for attaching fine wires to foil or wires to wires.

**Figure 4-27** shows an ultrasonic welding station. Since no outside heat is applied, this process is particularly well-suited for applications in which control of the heat-affected zone is important.

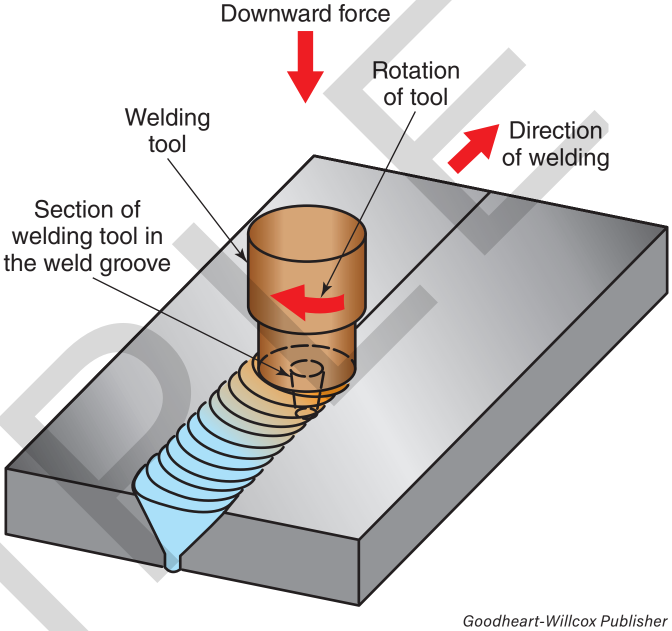


**Figure 4-26.** Friction stir welding (FSW). The friction stir welding tool is rotated at high speed, creating the heat to bring the joint to a plastic state. FSW welds are very clean and strong.

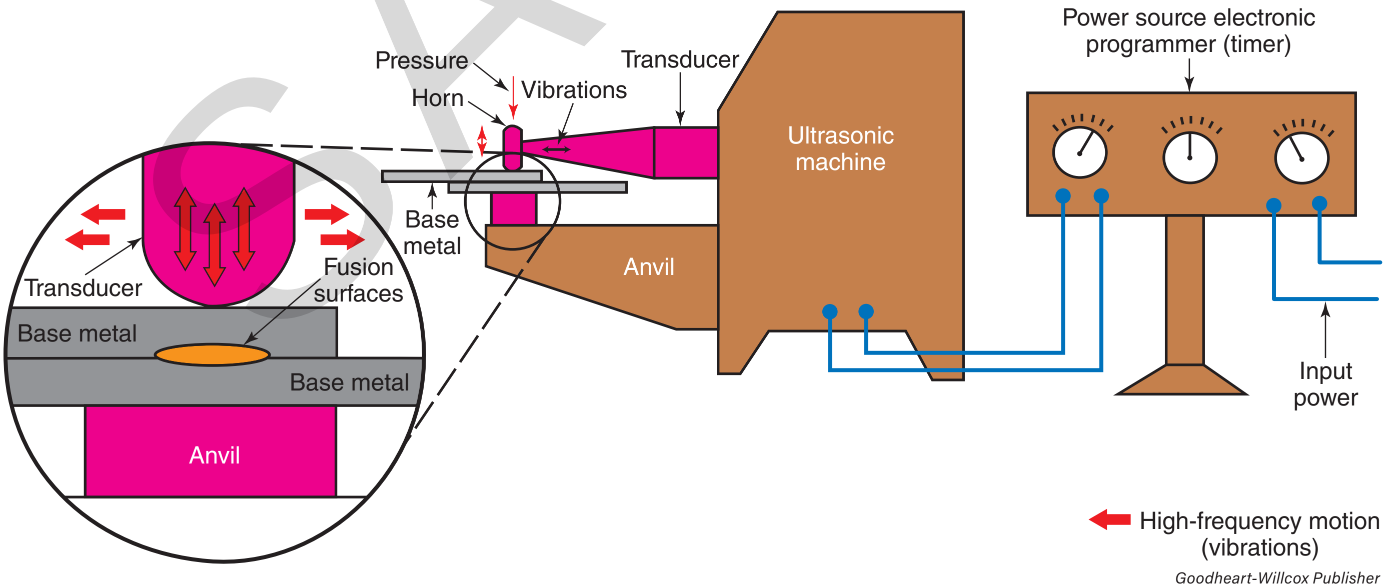


**Figure 4-27.** Ultrasonic welding (USW). Welding energy is created by extremely high-frequency vibration of the machine horn. The molecules at the surfaces of the two pieces of base metal are made to move so rapidly that the surfaces fuse.

The horn and anvil contact the two materials to be welded. The horn vibrates at an ***ultrasonic*** frequency (frequency above the audible sound range). This causes the materials the horn is in contact with to vibrate at a corresponding rate. During the vibrations, some molecules of the two surfaces become intermixed and form a strong joint.

This type of welding is controlled by the rate of vibration and the pressure exerted by the vibrating element on the parts being welded. Surfaces to be joined by ultrasonic welding must be very clean and free of oxidation. **Operators should wear gloves and goggles since fine particles could be thrown off.**

Chapter 20, *Special Welding Processes*, provides more details about ultrasonic welding.

## 4.8 Other Welding Processes

Other types of welding processes include laser beam welding, electron beam welding, and torch plastic welding. These welding processes do not meet the definition for any of the major welding process classifications including arc welding, oxyfuel gas welding, resistance welding, or solid-state welding. Therefore, the American Welding Society has created a distinct category for these other welding processes. Refer to **Figure 4-1**.

### 4.8.1 Laser Beam Welding (LBW)

In laser beam welding, a single-frequency light beam puts energy into the metal, causing it to melt. The laser beam is useful in welding small, light materials, particularly in locations difficult to weld with any other process. Larger parts, including automobile transmission clutch housings, are welded with laser beam welding. Two types of lasers are used for welding—$CO_2$ (carbon dioxide) and Nd-YAG (neodymium-yttrium aluminum garnet). See **Figure 4-28**.

The beam is created by exciting the Nd-YAG crystal or the $CO_2$ gas. A single-frequency energy is generated. The energy increases in intensity by traveling between two mirrors. During welding, some of the laser energy passes through the partially reflecting mirror and is reflected and focused onto the weld joint. The release of the laser beam is controlled by laser controls. This is an automatic welding process.

The laser beam is directed to the weld joint using mirrors. The energy of the laser beam is focused by lenses onto a tiny spot. The size of the spot determines the penetration. The base metal is instantly melted by the laser. **Operators must wear special goggles designed for laser operations.**

**Warning**

Laser beams must not be directed toward any part of the human body or anything of a heat-sensitive nature.

Chapter 20, *Special Welding Processes*, provides more information about laser beam welding.

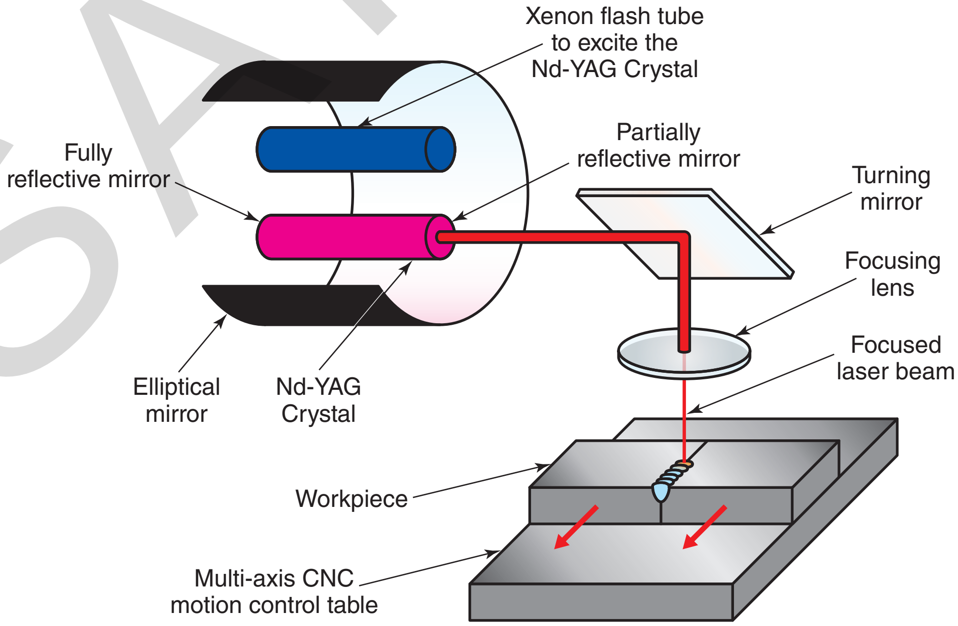


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**Figure 4-28.** Laser beam welding (LBW). A single-wavelength light beam creates the welding energy as it strikes the base metal. The laser beam can also be used for cutting and piercing base metals.

## 4.8.2 Electron Beam Welding (EBW)

Electron beam welding uses energy from a focused stream of electrons to heat and fuse metals. It is a good process for welding thick parts when the distance between them is small. Welds can be made in deep, narrow spaces with an extremely narrow weld zone. **Figure 4-29** shows an electron beam welding setup. This process is used to join metals that are difficult to weld by other processes. It can also be used to weld metals at very high speeds. Because the equipment is large and expensive, it is used only where other processes cannot do the job.

The machine uses a filament that emits (gives off) electrons. These streams of electrons are controlled (focused and concentrated) by electromagnets called a ***magnetic lens***. The electron beam is generated in much the same way as in old CRT-type television sets. The beam can be bent or directed by a magnetic field as in the television set. Weld energy is regulated by the current in the electron gun filament.

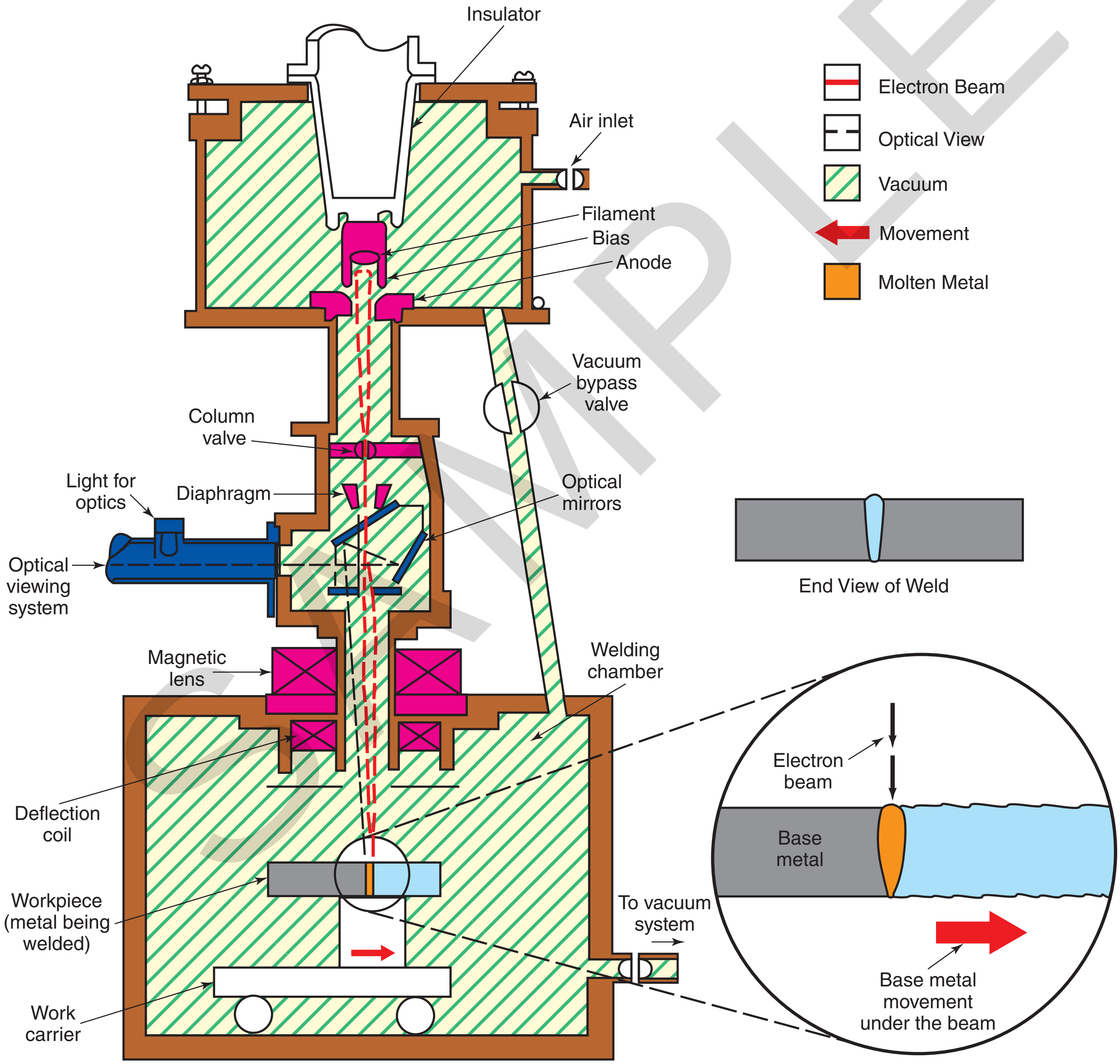


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**Figure 4-29.** Electron beam welding (EBW). Welding energy is created by striking the base metal with a beam of electrons. The heat energy is very intense. Very narrow welds are formed.

An electron beam weld is made in a vacuum or partial vacuum since air molecules interfere with the beam. The walls of the vacuum chambers also act as a shield against radiation.

The welder views the electron beam path through a safe optical system and programs the beam with remote controls. When programming is complete, the process welds automatically and welds at a very high speed. The surfaces to be joined should be cleaned prior to welding. The parts being joined must fit together very tightly.

**The welder and other persons near the machine must be protected from the radiation given off by the beam. Most machines use lead as a shielding material.**

Chapter 20, *Special Welding Processes*, provides more information about electron beam welding processes.

### 4.8.3 Torch Plastic Welding

In torch plastic welding, heated air or heated shielding gas melts and fuses together plastic base materials and plastic filler materials. **Figure 4-30** shows a typical torch plastic welding setup.

The gas or air is heated by an electric heating coil. The heated gas flows through the nozzles and heats the parts to be welded. The welding tip is designed to press the heated plastic filler material into the weld area. Plastics are joined at between 400°F and 800°F (200°C and 425°C). The heat source is controlled by adjusting the resistance unit and gas flow rate. The welder manipulates both the torch and the filler material.

**The temperature of the filler material during welding is hot enough to cause severe burns. It is advisable to wear gloves and safety goggles. Good ventilation is recommended.**

Chapter 22, *Special Nonferrous Welding Applications*, provides more information on welding plastics.

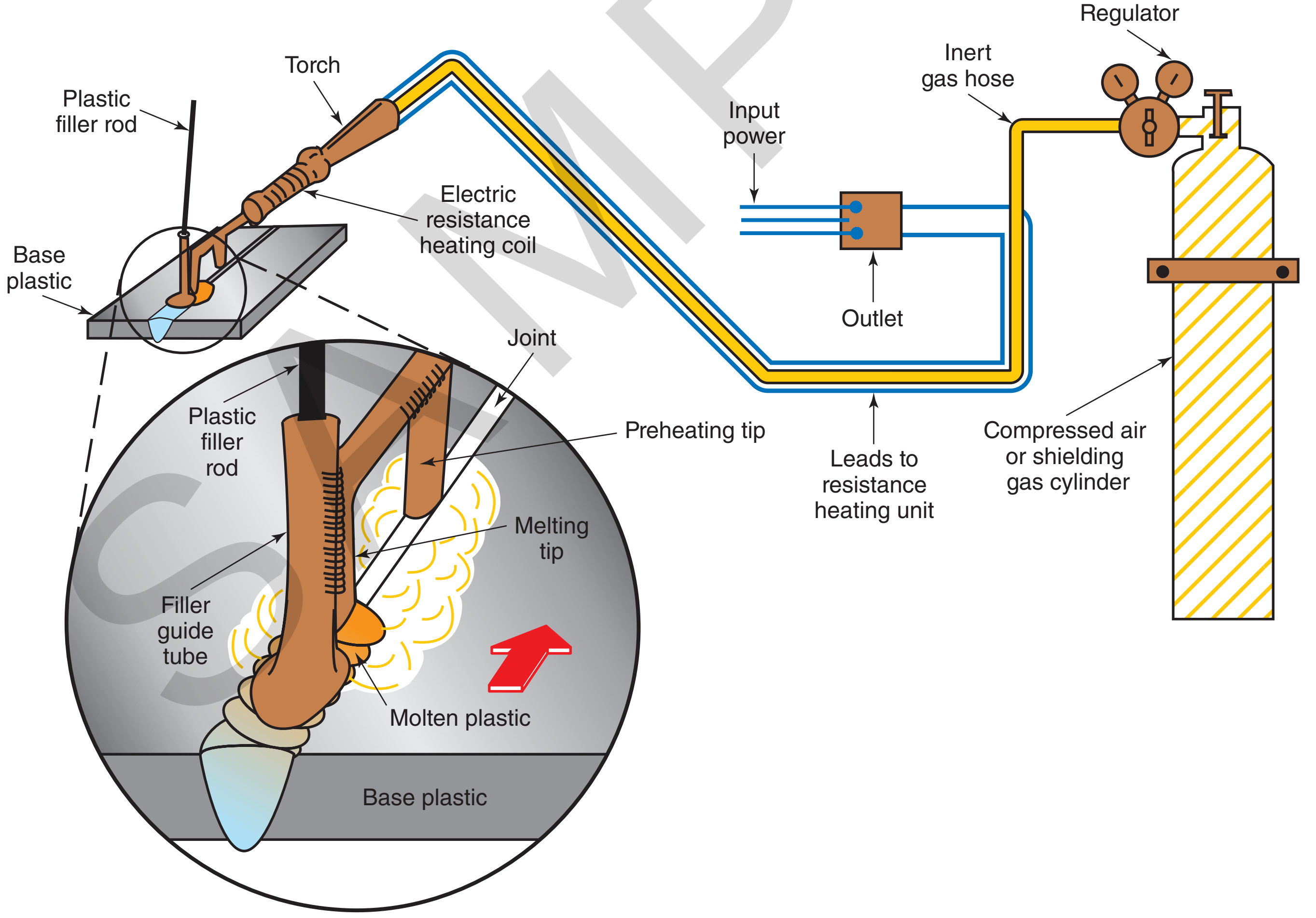


**Figure 4-30.** Torch plastic welding. The heat source is heated air or a heated inert gas. The stream of heated gas first preheats the joint, then heated gas from a second orifice further heats the base material as a plastic filler rod is fed through a tube to the joint.

## Summary

- Arc welding processes include shielded metal arc welding, gas metal arc welding, flux cored arc welding, and gas tungsten arc welding.
- In arc welding processes, the heat from the arc melts the base metal and the welding electrode or welding rod. The molten base metal plus additional filler metal flow together. Once the molten material solidifies, the metals are welded together.
- Oxyfuel joining processes include oxyfuel gas welding, torch soldering, and torch brazing. These processes combine oxygen with a fuel gas to produce the source of heat required to weld, solder, and braze.
- Oxygen cutting processes include oxyfuel gas cutting, oxygen lance cutting, exothermic cutting, and flux cutting. These processes use heat to melt the material being cut. A high flow of oxygen oxidizes (burns) the base metal and blows the molten metal from the cut.
- Resistance welding processes include resistance spot welding, projection welding, resistance seam welding, and flash welding. These processes pass very high electrical current through the parts, which are forced together during welding. The high current passing through the parts creates heat that melts the parts where they touch. When the current is stopped, the molten metal cools and forms a weld.
- Arc cutting processes include plasma arc cutting, air carbon arc cutting, and shielded metal arc cutting. These processes use an arc to melt and blow the molten metal from the cut.
- Specialized arc welding processes include submerged arc welding, electroslag welding, and arc stud welding.
- Solid-state welding processes include cold welding, explosion welding, forge welding, friction welding, friction stir welding, and ultrasonic welding. In solid-state processes, pressure is applied without melting any of the joint components.
- The AWS has created a distinct category called "Other Welding" processes, which includes laser beam welding, electron beam welding, and torch plastic welding.

## Technical Terms

base metal
burn
exothermic process
filler material
flash
flux cored arc welding
forge welding
forging
friction stir welding
gas metal arc welding
gas tungsten arc welding
magnetic lens
oscillated
oxidation
oxyacetylene welding
oxygen lance cutting
platens
processes
shielded metal arc welding
shielding gas
spot welding
torch valve
ultrasonic welding
welding temperature
workpiece
workpiece lead

## Review Questions

*Answer the following questions using the information provided in this chapter.*

### Know and Understand

1. *True or False?* In SMAW, the electrode diameter and flux material determine the amount of welding current and the type (AC or DC) required.
2. Which statement about GMAW is *false*?
   A. The arc is shielded by a gas that is supplied through the welding gun.
   B. A constant current DC welder is used.
   C. A wire feeder continuously supplies metal electrode.
   D. This process is popular in robotic welding.
3. *True or False?* In FCAW, adjusting the wire speed changes the current at the arc.
4. *True or False?* In gas tungsten arc welding, a consumable tungsten electrode is used.
5. *True or False?* The process of soldering melts the base metal.
6. *True or False?* In oxygen cutting operations, the base metal is cut by the application of intense heat and a high flow of oxygen.

7. In the _____ cutting process, fuel wires burn and create a great deal of heat in a self-consuming process.
   A. oxygen lance
   B. flux
   C. exothermic
   D. plasma arc
8. In _____ processes, a very high electrical current is passed through the parts to be welded, and the parts are forced together during welding.
   A. resistance welding
   B. torch brazing
   C. electroslag welding
   D. exothermic cutting
9. In electroslag welding, water-cooled _____ keep the molten flux, filler metal, and base metal in place as the weld moves upward.
   A. studs
   B. wheels
   C. arms
   D. shoes
10. Which of the following is *not* a solid-state welding process?
    A. Friction welding.
    B. Ultrasonic welding.
    C. Cold welding.
    D. Electron beam welding.

## Apply and Analyze

1. Why is it important to prevent oxygen from contacting the metal being welded?
2. In the OFC (oxyfuel gas cutting) process, what causes the rapid oxidation or burning of the steel after the metal is heated to a melting temperature?
3. What factors affect the heat of the arc in FCAW?
4. In the soldering process, how is the amount of heat controlled?
5. In which process are an electric arc and fast-flowing super-heated ionized gas used to melt and cut metals?
6. Why is submerged arc welding referred to as "submerged"?
7. In ESW (electroslag welding), what prevents the shoes from becoming welded to the base metal?
8. What welding process creates a smooth bead with a constant depth by using a spinning tool?
9. How does ultrasonic welding join two pieces of metal together?
10. Why is EBW (electron beam welding) done in a vacuum?

## Critical Thinking

1. What factors account for the fact that oxyfuel gas welding is a much slower welding process than the arc welding processes?
2. When planning a welding job, what criteria and factors are considered in selecting the best welding process to use for that job?

## Experiment

1. Pick one process from each of the following: arc welding, resistance welding, solid-state welding, and other welding processes. Based on what you know about each of these welding processes and information presented in this chapter, try to think of two or three specific applications where each process could be used. For example, for resistance spot welding you might write down manufacturing of automobile bodies and file cabinets. Next, research the applications you wrote down on the internet to determine if the welding process is actually used and matches your expectations. If the process used is different from the one you guessed, try to determine the reason for the difference.