Welding and Cutting

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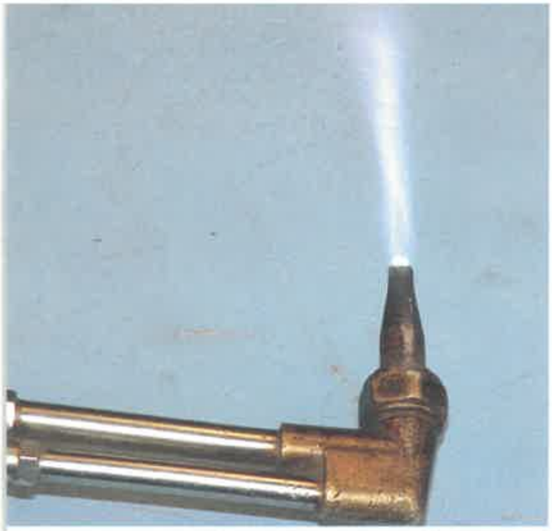

WORKSHOP INTRODUCTION

This workshop will provide a basic introduction to welding and cutting. The history and development of welding is presented, from the early working of copper through many of the modern industrial advances of the 20th century. The hazards of welding—from electricity, fumes, radiation (heat and light), and so on—and their appropriate safety precautions are discussed in detail. A general and very basic introduction to the science of metallurgy (how metals act on the atomic level, and the technology of metal shaping) is also included in the opening chapters.

The major kinds of cutting—oxyfuel cutting, plasma arc cutting, and carbon arc gouging—and of welding—shielded metal arc welding, gas metal arc welding, flux cored arc welding, and gas tungsten arc welding—are discussed in detail, each in its own chapter. The power sources, equipment, electrodes, filler metals, and so on, used in each kind of cutting or welding are introduced and explained. Welder safety is emphasized throughout each chapter.

Participants learn how to recognize weld symbols and how to "read" the directions given for welding.

WORKSHOP OBJECTIVES

Upon successful completion of this workshop, the participant will be able to:

1. Show a very basic understanding of the history and development of welding.
2. Demonstrate an understanding of welding hazards and the safety measures required to guard against them.
3. Discuss various power sources used with the different kinds of welding and cutting and explain why, where, and how the different power sources are used.
4. Demonstrate an understanding of the electrode classification system.
5. Properly use the various electrode holders, guns, and torches appropriate to the different kinds of welding and cutting.
6. Recognize required and optional weld symbols and understand the instructions they give.

CHAPTER 1

Introduction to Welding and Cutting

CONTENTS

INTRODUCTION

Welding has an ancient history. Welding technologies were developed during several key periods throughout history. Key times include the Industrial Revolution in the late 1800s and World Wars I and II. The important milestones in welding history and how welding technologies were developed will be presented along with which groups developed welding standards and safety practices that are followed today.

There are several common types of welding used today. They include shielded metal arc welding, gas metal arc welding, flux cored arc welding, and gas tungsten arc welding; some of these date back to the 1800s. Welding is used in just about every form of manufacturing there is. From cars to bridges and everything in between, welding plays a vital role in everyday society.

KEY TERMS

Key Terms are in order of appearance.

forge welding process of heating two or more pieces of wrought iron or steel until their surfaces are malleable and then hammering them together

ductile or **malleable** easily molded or shaped

blacksmithing forging and shaping iron with heat, an anvil, and a hammer

arc welding or **fusion welding** welding that uses an electric arc from a metal rod to the workpiece that provides heat for the joining of two or more metals

electrode metal rod or wire that conducts electricity

resistance welding or **spot welding** fusing parent metal with force and electrical current resistance

oxyacetylene welding fusing parent metal with heat from an oxyacetylene torch, with or without filler material

carbon arc welding arc welding process that uses a carbon electrode to create the electric arc to the workpiece; no shielding is used

shielded metal arc welding (SMAW) welding process using an electric current (either AC or DC) from a power supply to form an arc between an electrode coated in flux and the metals to be joined

gas tungsten arc welding (GTAW) or **TIG welding** welding process that creates heat using an arc created with a nonconsumable tungsten electrode

OBJECTIVES

Upon successful completion of this chapter, the participant should be able to:

1. List milestones in welding history.
2. Demonstrate an understanding of how types of welding technology were applied.
3. List names of those who developed welding standards.

KEY TERMS *(continued)*

gas metal arc welding (**GMAW**) or **wirefeed welding** or **MIG** or **MAG** welding process that transfers electric current to the parent metal through a wire that is melted and deposited into the puddle

flux cored arc welding (**FCAW**) uses a continuous-feed consumable wire electrode whose core is filled with flux and alloying agents; no pressure is applied

ASTM International (**ASTM**) standards-development organization formed in 1898; formerly known as the American Society for Testing and Materials (ASTM)

American Welding Society (**AWS**) organization that is completely devoted to welding standards, founded in 1919

American Society of Mechanical Engineers (**ASME**) organization that sets internationally recognized industrial and manufacturing codes and standards that enhance safety, founded in 1880

1 History of Welding

Archeologists have found evidence that welding took place as long as 6,000 years ago, when ancient people first worked copper, a soft metal that was commonly available. Copper was later mixed with tin to make bronze. Much later, as metalworkers discovered ways of achieving the necessary higher temperatures needed to make iron, it became the metal of choice because it is harder than bronze, which is harder than copper.

Forge Welding

To work copper and other metals, people used **forge welding** which is the simplest welding method. It uses heat high enough to make a metal **ductile**, or **malleable**, soft enough that it can be easily shaped and joined by another force, such as by blows from a hammer. Silver and gold were also forge welded. In 589 A.D. the Chinese learned to make steel from wrought iron. Steel is an alloy of iron and carbon. Steel soon became the choice metal from which to make swords and other weapons. The Japanese learned to control the amount of carbon in steel by using *fluxes*. The results were the renowned and revered Samurai swords, known for their quality and strength.

Blacksmithing Process All of the ancient welders used the **blacksmithing** process. That is, blacksmiths heated metal with fire until it reached a ductile, or malleable, temperature. Blacksmiths would then use a hammer and anvil to work the metal to the desired shape and join different metal pieces together. Frequent reheating was required to complete a project.

This welding method was used throughout the world until the Industrial Revolution in the mid-1800s. It was then that welding helped fuel the economic transformation that occurred throughout the world.

The Industrial Revolution and Forge Welding

Eli Whitney (1765–1825) is credited with helping start the Industrial Revolution in the United States. He invented the cotton gin as well as the industrial assembly line. When he got a contract from the federal government to produce 10,000 muskets in two years, he invented the assembly line and the interchangeable part.

The genius of Whitney's process was to make dies and molds to help standardize musket production. In other words, Whitney standardized the tools and the parts used to make the muskets so he could standardize the muskets themselves. Before Whitney, each musket was manufactured by hand, and each was unique. The muskets that Whitney produced all had the same parts and were all designed the same way. All the metal parts were welded in the same manner over and over again.

The muskets could also be produced much faster because different people worked on different parts. So all the pieces were created at the same time by the workers and then assembled. Henry Ford, one of the greatest manufacturers of the 20th century, used these same techniques to produce thousands of his Model T automobiles.

Three Welding Processes Developed in the 1880s

Welding as we know it began to develop in the early 19th century with the discovery of acetylene gas and electricity. During the 1880s, new welding techniques were developed: arc welding, resistance welding and oxyacetylene welding. These processes are still widely in use today.

FIGURE 1
Arc welding

Arc Welding The process of **arc welding**, or **fusion welding**, occurs when metal is melted by heat generated by an arc from the end of an **electrode** and carried across the electric arc to deposit filler metal in a joint. See Figure 1. This welding method had its beginnings in England when Sir Humphrey Davy discovered the electric arc in 1801. The first use of what we would recognize as arc welding occurred in 1881 when Auguste de Meritens welded two lead battery plates together using a carbon electrode and an electric arc.

Resistance Welding Elihu Thompson, one of the inventors of alternating current, originated **resistance welding,** also known as **spot welding**, and his patents for this process date from 1885 to 1900. In the resistance or spot welding process, welding occurs when the working material "resists" the

FIGURE 2
Oxyacetylene welding

flow of welding current, producing its own heat. When combined with pressure from the welding tip, a weld is made. The electrodes in this process conduct the welding current, apply the needed force, and dissipate the heat from the weld area. Resistance welding is especially effective on thin metals such as sheet metal. It is widely used in the manufacture of automobiles. This process includes resistant spot welding, resistant seam welding, resistant projection welding, and resistant stud welding.

Oxyacetylene Welding Englishman Edmund Davy discovered the combustible gas acetylene in 1836. The process of **oxyacetylene welding** uses this gas, acetylene, combined with oxygen to create a flame hot enough to weld metal. A torch suitable for regulating low-pressure acetylene was developed around 1900. Today, the oxyacetylene flame is controlled by valves on the welding torch. By changing the proportion of oxygen and acetylene flowing through the torch, the chemical characteristics of the flame change and a neutral, oxidizing, or carburizing flame can be produced. See Figure 2.

SELF CHECK

1. How many years ago did people start welding?
2. How many welding processes were developed in the 1880s?

Carbon Arc Welding When an electric arc is made between a nonconsumable carbon *electrode* and metal, **carbon arc welding** occurs. The first instance of carbon arc welding was the first instance of any arc welding. As mentioned above, the first arc welding occurred in France in 1881 when Auguste de Meriten, of Cabot Laboratories, welded lead battery plates together using a carbon electrode. Two of his pupils, Russians Nikolai N. Benardos and Stanislaus Olszewski, continued working on the process and were granted a British patent for welding in 1885 and an American patent in 1887. Their patents show an early version of an electrode holder.

Electrode Improvements In 1890, C. L. Coffin of Detroit was awarded the first U.S. patent for an arc welding process using a metal electrode. Called "bare electrode welding," it replaced the carbon arc welding method as the most popular type of arc welding until the early 1920s.

Bare metal electrodes had a few problems in practical use. The welds produced by the metal electrodes were not as strong as the metal being welded. In addition, the welding arc was unstable. People all over the world worked on a solution. In 1900, A. P. Strohmenger introduced a coated metal electrode in Great Britain. The coating he used was clay or lime. In 1907, Oscar Kjellberg of Sweden invented an electrode coated in carbonates and silicates. Kjellberg received another patent for an improved electrode with a heavier coating of asbestos and sodium silicate in 1912.

Welding During and After World War I

Until 1914, developments in welding were few and far between. All that changed when World War I began. Until then, welding had been used chiefly to repair and maintain existing equipment. When war broke out, a way was needed to manufacture armaments faster and cheaper. A prime example of where welding proved superior to old methods of manufacturing was shipbuilding. Until World War I, metal ships were fabricated by riveting large plates of metal together. This was a slow and expensive method. Welding proved to be not only a cheaper and faster method of building ships, it also built a lighter, faster, and safer ship. Riveted ships were very leaky but welded ships let in far less water.

After welding proved its manufacturing worth during World War I, many developments in welding electrodes occurred over the next 15 years. Two welding techniques that came into widespread use during that time were shielded metal arc welding (SMAW) and gas tungsten arc welding (GTAW).

Shielded Metal Arc Welding (SMAW) Commonly known as "stick welding" and also "arc welding," the **shielded metal arc welding (SMAW)** process is an improvement over the earlier arc welding techniques. The weld occurs when the heat from the electric arc brings the metal to be welded and the electrode to a molten state. The molten metal from the electrode gathers in a molten pool in the parent metal to create the weld.

SMAW is used on *ferrous*, meaning containing iron, and some *nonferrous*, containing no iron, metals. It is especially effective on the following metals and alloys.

- carbon steel
- low-alloy steel
- stainless steel
- cast iron
- nickels and their alloys
- aluminum and its alloys

Gas Tungsten Arc Welding (GTAW) The idea to weld in a nonoxidizing atmosphere was patented by C. L. Coffin in 1890. However, it took many years before the technology caught up with the idea.

During the 1920s, experiments continued on coated electrodes. In the mid-1920s, Alexander and Langmuir first experimented with tungsten in what became known as **gas tungsten arc welding** (**GTAW**), commonly referred to as **TIG welding**, which stands for tungsten *inert* gas. In 1930, a patent was granted to Henry Hobart and Phillip Devers of General Electric for their work covering the principle of gas-shielded arc welding. Finally in 1944, Russell Meredith of the Northrop Aircraft Company won a patent for developing a method to weld magnesium and magnesium alloys. It was Meredith's process that is now known as the GTAW or TIG welding.

GTAW uses a nonconsumable tungsten electrode instead of a carbon electrode to sustain the arc. The tungsten electrode is shielded from the atmosphere by an inert gas. GTAW is versatile in that a weld can be made with or without a filler metal. In addition, metal as thin as less than one millimeter can be welded using this technique.

GTAW is used on ferrous and nonferrous metals or with difficult to weld metals such as the following metals and alloys.

- aluminum
- stainless steel
- magnesium
- titanium

After World War II, many of the welding processes developed between the world wars were further refined to meet changing needs. One process that came about during this time was gas metal arc welding (GMAW).

Gas Metal Arc Welding (GMAW) The initial introduction of **gas metal arc welding** (**GMAW**) was to weld nonferrous metals, specifically magnesium and aluminum, for the aircraft industry. Gas metal arc welding is also known as **MIG** or **MAG** welding. MIG stands for metal inert gas and MAG stands for metal active gas. The gas being used determines which term is used.

The GMAW process pushes wire from a spool through a torch where a gas is introduced to shield the weld. Because it uses wire from a spool, GMAW is often called **wirefeed welding**. Wirefeed welding has become one of the fastest ways to weld. It has all but replaced gas tungsten arc welding (GTAW) in some applications, as well as replacing shielded metal arc welding (SMAW) in other applications. See Figure 3.

GMAW is also useful on other metals and their alloys such as the following.

- nickel
- magnesium
- titanium
- copper
- steel

FIGURE 3
Gas metal arc welding

Flux Cored Arc Welding Another popular kind of arc welding, **flux cored arc welding** (**FCAW**) is a process that involves an electric arc and a consumable electrode that contains a flux. The FCAW process obtains the shielding gas that it requires from the flux and uses no external gas. This process is good for a wide range of both ferrous and nonferrous metals.

SELF CHECK

1. Why are welded ships better than riveted ships?
2. Which type of welding is commonly known as "stick welding"?

2 Developing Welding Standards

With the onset of World War I, welding became a vital part of the manufacturing industry. Today, there are over ninety different welding processes in use. As technology began to develop, so did the need for standards. Several important organizations were formed over the last century to improve safety and work standards. The welding industry adheres to many of the standards established by these groups.

ASTM International (ASTM)

ASTM International, known until 2001 as the American Society for Testing and Materials (ASTM) formed in 1898, and was created because the rapidly growing railroad network was experiencing frequent rail breaks. A group of engineers and scientists got together to address the problem and formulate a solution. As a result of their work, steel for rail construction became standardized and railroad transportation became safer and more reliable. ASTM is known for its best-in-class practices for standards development and delivery across a wide range of manufacturing and service industries.

American Welding Society (AWS)

Founded in 1919, the **American Welding Society** (**AWS**) was founded as a multifaceted, nonprofit organization with the goal of advancing the science, technology, and application of welding and related joining disciplines. AWS supports the education and technological advances for the welding industry.

American Society of Mechanical Engineers (ASME)

Founded in 1880, the **American Society of Mechanical Engineers** (**ASME**) now has over 120,000 members worldwide. It is focused on technical, educational, and research issues of the engineering and technology community. ASME sets internationally recognized industrial and manufacturing codes and standards that enhance safety.

Summary

Welding began some 6,000 years ago and continues today. During the 1880s, rapid developments in welding technology led to new types of welding: arc welding, resistance welding, and oxyacetylene welding. Since then, many improvements have been made to these three basic types of welding. These include shielded metal arc welding (SMAW), gas tungsten arc welding (GTAW), and gas metal arc welding (GMAW). Organizations have been created to improve welding standards and safety. These organizations are the ASTM, AWS, and ASME.

Introduction to Welding and Cutting QUESTIONS

Show your understanding of the information in this chapter by answering the questions and filling in the blanks below.

1. The first welders worked with _____ 6,000 years ago.
   - **a.** copper
   - **b.** iron
   - **c.** steel
   - **d.** aluminum

2. Eli Whitney helped start the ______________ ______________ in America.

3. Welding became a vital part of American manufacturing during _____.
   - **a.** the American Revolution
   - **b.** the Civil War
   - **c.** World War I
   - **d.** World War II

4. SMAW stands for ______________ ______________ ______________ ______________.

5. The ______________ ______________ ______________ (______________) is the name of the organization completely devoted to welding standards.

CHAPTER 2

Welding and Cutting Safety

CONTENTS

INTRODUCTION

Welding metals together is not a gentle process. The act of welding causes intense light, noise, smoke, and fumes. Welders work in the presence of gases and high heat. Protective clothing such as jackets, chaps, helmets, shields, and so on, is very important to protect the welder. Knowing how to work safely where welding is occurring will protect not only the welder but also coworkers and property.

KEY WORDS

Key Terms are in order of appearance.

hot work any work involving burning, welding, or similar operations capable of initiating fires or explosions

flammable catches fire when exposed to flame or sparks or when heated above its flash point

non-ionizing radiation visible, ultraviolet, or infrared radiation; heat or light transfer from welding work

fumes vapor, gas, or smoke by-products of welding

noise unpleasant and/or loud sounds; can damage hearing

personal protective equipment (PPE) equipment, such as goggles, helmets, gloves, and so on, specifically designed to protect exposed or vulnerable body parts when welding

gloves protect the welder's hands from heat, slag, and sparks

jacket worn over existing clothing to protect the torso

apron protective covering for the upper body and torso; worn when welding, sitting, or kneeling to deflect hot particles and protect against heat

coverall extensive protective covering worn when welding, sitting, or kneeling to deflect hot particles and protect against heat

sleeves can be worn over existing clothing to protect the arms

spats designed to protect the ankle area from exposure to welding particles

bib part of a leather ensemble to protect the upper torso

chaps protective covering to provide extra leg protection against heat and sparks or hot particles

welding helmet specially made plastic or leather shield to protect the face and eyes from welding by-products

visor shaded or clear viewing window in a welding helmet

shade rating assessment of how dark a lens is; measured on a numeric scale—the smaller the number the lighter the shade

OBJECTIVES

Upon successful completion of this chapter, the participant should be able to:

1. Identify the hazards associated with welding.
2. List the proper clothing to wear when welding.
3. Demonstrate an understanding of welding safety precautions.
4. Describe personal protective equipment and its use.
5. Identify the types of leather accessories available for use.
6. State the importance of personal protective equipment.
7. List the materials and parts that helmets are made of.
8. Describe the different styles of helmets.
9. Conduct a test to determine if the right shade of lens is being used.

1 Welding Hazards

Joining metal together takes a great deal of persuasion: heat, pressure, gases, electricity are all involved in the process. Any one of these processes can be hazardous. A great deal of care needs to be taken so that people and property are not harmed.

The following hazards and ways to handle them will be discussed: hot work, hot sparks, radiation, metal fumes and smoke, and noise. Each one of these hazards should be taken seriously by the welder. The American Welding Society (AWS) has put together a series of Safety and Health Fact Sheets that address welding hazards and how to prevent accidents. These Fact Sheets were used to provide the material below.

Hot Work

Any work involving burning, welding, or similar operations capable of initiating fires or explosions is considered **hot work**. Welding by its very nature involves chemical reactions brought on by heat. This heat can cause nearby items to catch fire or burn someone working on or near welding activity. A welder must always be aware of potential fire hazards.

To prevent fires, welders should be mindful of the following.

- combustibles within 35′-0″ of where welding is occurring
- wall or floor openings that expose combustible materials within 35′-0″
- metal walls, ceilings, roofs, or pipes connected to the welding work; care must be taken that transferred heat does not affect nearby combustible items

To prevent burns, welders should do the following.

- Wear dry, leather gloves that have no tears or holes.
- Wear protective garments such as a heavy shirt, leather welding jacket, cuffless pants, leggings, high shoes or boots, and a cap.
- Wear approved safety glasses with side shields.
- Use approved helmets or handheld shields that protect the face, neck, and ears.
- Wear leggings, aprons, cape, sleeves, shoulder covers, and bibs.
- Wear flame-resistant earplugs or protective earmuffs to keep sparks out.
- Remove all **flammable** objects, such as butane lighters and matches, from pockets.

Hot Sparks

Hot sparks result from welding and cutting activities. These sparks can fly in all directions and can be a hazard to the welder, those standing near the work, and to objects nearby. In fact, flying sparks are the main causes of fires during welding and cutting activities. Sparks and molten metal can travel up to 35′-0″ horizontally from the work area. In addition, sparks can pass through or become lodged in ceilings, floors, walls, and other small openings where they can cause fire

To prevent contact with sparks and flying particles, welders should do the following:

- Wear dry, leather gloves that have no tears or holes.
- Wear protective garments such as a heavy shirt, leather welding jacket, cuffless pants, leggings, high shoes or boots, and a cap.
- Wear approved safety glasses with side shields.
- Use approved helmets or handheld shields that protect the face, neck, and ears.
- Wear leggings, aprons, cap sleeves, shoulder covers, and bibs.
- Wear flame-resistant earplugs or protective earmuffs.

FIGURE 1
Welder wearing proper clothing

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Figure 1 shows a properly dressed welder.

To prevent fires from flying sparks, welders should be mindful of the following things.

- combustibles within 35′-0″ of where welding is occurring
- wall or floor openings that expose combustible materials within 35′-0″

Radiation

Intense bright flashes of light at a construction site are a sure sign that welding is taking place. That bright light is one of the radiation hazards of welding. There are two types of radiation.

- ionizing radiation
- non-ionizing radiation

Ionizing radiation is present in the dust created during the grinding of thoriated tungsten electrodes for gas tungsten arc welding (GTAW). Ionizing radiation is capable of displacing electrons from atoms, creating charged atoms or ions. Ionizing radiation is *extremely* harmful to all living beings. Excessive exposure to it poses a health risk.

The other kind of radiation, **non-ionizing radiation**, occurs in just about every other kind of welding except resistance, or spot, welding and cold-pressure welding. There are three types of non-ionizing radiation: visible, infrared and ultraviolet.

FIGURE 2
Face shields

The welder can see the visible radiation in the form of light but infrared and ultraviolet cannot be seen. Infrared and ultraviolet light, along with visible light, are present when most welding processes are conducted. Non-ionizing radiation can cause eye damage and skin burns. When arc welding or observing arc welding, it is necessary to observe the following safeguards.

- Wear proper eye and skin protection, even if the work is of very short duration.
- Wear an appropriately shaded helmet or shield and glasses with side shields. See Figure 2.
- Avoid wearing contact lenses.
- Wear appropriate gloves to protect hands and upper arms and to keep hands dry.
- Wear clothing to protect the neck area, such as cap sleeves, shoulder covers, and bibs.

SAFETY TIP

If safety questions arise about a material being worked with, consult its Safety Data Sheet (SDS).

Metal Fumes and Gases

Metal **fumes** and gases are by-products of most welding processes. Metal fumes are solid particles originating from welding consumables such as coated electrodes, the base metal, or any coatings on the base metal. The amount and makeup of these fumes depends on several factors such as composition of filler and base material and the type of welding process being used. Coated metals present a greater health hazard than non-coated materials. Always ask the supervisor for specific safety-related issues or consult a Safety Data Sheet (SDS), if applicable, before starting.

Care must be taken to avoid contact with these by-products as they pose a health risk. Several things can be done to avoid exposure to fumes and gases.

- Position the head to avoid the fume plume.
- Do not breath fumes or gases.
- Make sure the working area is well-ventilated.
- If the area cannot be adequately ventilated, wear a respirator.

SAFETY TIP

Earplugs and protective earmuffs not only offer hearing protection, they also protect welders from sparks, spatter, and hot slag.

Noise

Welding and cutting and the equipment used can produce high **noise** levels. Noise is sound that changes frequency, high or low pitch, and intensity, degree of loudness, and is generally unpleasant, uncomfortable, and sometimes painful. Noise levels are measured in *decibels*. Regulations require safety precautions if noise levels reach 85 decibels on an 8-hour time weighted average (TWA) basis.

When exposed to high decibel levels for a long duration, hearing loss and other health hazards can occur. Not only is noise a health concern, it can also be a safety concern: it can drown out sounds the welder needs to hear.

There are several ways to protect hearing and health from noise.

- Use room acoustics to reduce or control noise.
- Wear protective earplugs, which offer some protection.
- Wear earmuffs, which offer more protection.
- Wear both together, which offers the most protection.

Figure 3 shows a common type of earplug.

FIGURE 3
Earplugs provide good noise protection

SELF CHECK

1. What is hot work?
2. What three kinds of non-ionizing radiation do most welding processes produce?
3. How can noise harm a person?

2 Safety Clothing

In welding, clothing and footwear are an important part of **personal protective equipment** (**PPE**). Personal protective equipment also includes safety goggles, helmets, and other items specifically designed to help protect the welder and any observers from hazards associated with welding.

Clothing

Clothing should be made of appropriate material, as some materials, such as polyester, can actually be dangerous when exposed to heat and sparks. Clothing in general should be made of wool or cotton or a commercial fire-resistant material. Clothing made of polyester is completely unacceptable, as it will melt when exposed to heat; never wear clothing made of polyester when welding or in an area where welding is taking place.

SAFETY TIP

Never wear polyester when welding or in an area where welding is taking place.

Clothes should be in good repair and should not have any frayed edges. These edges could catch fire if a spark comes into contact with the fraying.

SAFETY TIP

Ensure all combustibles are removed from clothing before welding, cutting, or grinding.

Pants Pants should be made of wool or cotton. Pants should not have cuffs as they are potential collection places for sparks and splatter. Pants should be clean and free of frayed edges. Pants should be worn outside of boots to help prevent sparks and spatter from entering boot tops.

Shirts Shirts should be made of wool or cotton. If a lot of welding is to be done, it is better to wear shirts with snaps instead of buttons, as the radiation from arc welding can degrade the button's thread. Shirts should also be buttoned to the top so no skin is exposed to radiation. Shirt pockets should have flaps to prevent sparks from entering the pocket.

Gloves Welding **gloves** should be made of leather. Gloves should be *gauntlet*-style, meaning they have an extended cuff, to help protect the

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skin below the shirtsleeve. Gloves should be kept dry to help maintain electrical safety.

SAFETY TIP

Position the hands so the glove gauntlet opening is facing down whenever possible. This will keep hot sparks from entering the glove.

Jackets Protective **jackets** are normally made of leather or cotton treated with a flame-retardant. Leather jackets are suitable for cooler climates while cotton is better for warmer climates.

Aprons and Coveralls Sometimes **aprons** or **coveralls** are used for protection during welding. Both should be made from flame-resistant materials, either leather or a treated, flame-retardant material.

Footwear

SAFETY TIP

When buying work footwear, be certain it meets the minimum safety standards established by the American National Standards Institute (ANSI).

The safety-conscious welder always wears boots or high-top shoes.

Boots Welders wear smooth leather pull-on boots with steel toes. If lace-up boots are worn, they should be fitted with bellow tongues to prevent sparks and slag from entering the boot and should have leather laces. If low-cut boots are worn, be sure to wear spats, discussed in Leather Accessories, to keep flying metal out of the boot.

3 Leather Accessories

Many accessories for the welder are made of leather, which is extremely durable and relatively fire-resistant. See Figure 4.

Leather Jackets, Sleeves, and Gloves

Jackets Leather jackets help protect a welder's upper body from slag, sparks, and other welding debris. Care should be taken to keep the jacket clean and free of oil and grease. Pockets should be covered to avoid catching spatter or sparks. It is important that fasteners be snaps rather than buttons, because continual exposure to radiation can degrade button thread.

Sleeves Leather **sleeves** protect a welder's arms from flying spatter and sparks. These "shirtless" sleeves can be worn over existing clothing and in combination with other protective gear. When welding overhead, leather sleeves offer very important protection against falling welding debris.

Gloves Leather welding gloves come in a variety of styles to suit different types of welding. Leather gloves should come with a gauntlet to help protect the welder's wrist area. Leather gloves are made in the usual five-fingered style, but also come in mitt style. The mitt style allows movement of the index finger and the thumb, but the other three fingers remain together. Depending on the type of welding being performed, the five-fingered style usually works well.

Leather gloves should be kept dry. Damp or wet leather gloves do not protect the wearer from electrical shock. If the gloves are torn or otherwise sustain damage where skin can show through, the gloves should be replaced.

Other Leather PPE

Spats Leather **spats** are shields that slip around a welder's ankle, lower shin, and foot area. Leather spats prevent spatter and sparks from burning the skin or clothing in these sensitive areas.

Aprons Leather aprons protect the area from the chest to the thighs from heat, spatter, and sparks. Aprons, like other leather garments worn while welding, should be kept clean of oil and grease. If a tear or other damage develops, the apron should be replaced. Aprons are effective protection when welding in a kneeling or sitting position. See Figure 5.

Bibs Leather **bibs** protect a welder's throat and upper shoulders. This is especially critical when welding overhead. In this position, it is much more likely that sparks and splatter will land on the welder.

FIGURE 4
Welder wearing protective gloves, bib, apron, helmet, and boots

FIGURE 5
Welder wearing an apron

2 SAFETY

PRODUCTIVITY TIP

Select welding clothing that allows free range of motion. If clothing restricts motion, the welder's productivity is lower.

Chaps Leather **chaps** protect a welder's legs. Chaps are joined leggings worn over trousers that can be useful when welding is performed while standing. If welding is done while sitting or kneeling, an apron offers more protection from flying debris.

SELF CHECK

1. What type of material is never suitable to weld in?
2. Why are welders' accessories made of leather?
3. What kind of gloves should be worn when welding, and why?

4 Helmets

Since ultraviolet and infrared rays from welding can harm the eyes even when standing 50′-0″ away and damage the skin within 20′-0″ away, it is very important to wear the proper safety gear when working on or near welding. The piece of PPE that protects the welder's head and eyes is the **welding helmet**. Sunglasses are never an acceptable welding shade. Anything not specifically designated as a welding shade is not appropriate for welding and should not be used.

FIGURE 6
Free-floating headband with adjustable crown

Helmet Construction

Helmets are made out of heat-resistant materials such as various types of plastic or even leather. Helmets feature an adjustable headband and crown, shown in see Figure 6, a foam or other absorbent material insert, ratchet controls to control the visor lift rate, and on some models, a lens-darkening adjustor and solar cell. Some helmets also feature a place to attach a hard hat. See Figure 7. These are called hard hat lugs.

FIGURE 7
Welding helmet fitted to a hard hat

SAFETY TIP

Welders with long hair must tie it behind their necks.

Helmet Styles

There are several helmet styles available, each suitable for the type of welding being performed or the welder's personal preferences. All helmets have **visors**, the usually shaded window through which the welder can see. Whatever the preference, it is very important to wear a helmet while welding.

Fixed Visor The fixed visor is a one-piece helmet. It has an adjustable free-floating headband with an adjustable crown. See Figure 8. As the name indicates, the shaded lens cannot be moved independently of the hood. The entire helmet can be pivoted at the head gear to inspect work. These hinges can be adjusted tighter or looser, depending on the operator's preference.

Flip-Up Visor The flip-up visor is equipped with a hinge that will allow the operator to quickly and easily flip the shaded lens up. Then the hood can be used as a face shield for other things such as chipping or grinding. The shaded lens can be flipped back down to continue welding. See Figure 9.

Slide Visor When a helmet is equipped with a slide visor, the shaded lens slides out of the welder's view. This is accomplished with an internal slide mechanism that is controlled from outside of the hood. With the shaded lens up, this hood can be used as a face shield for other things such as chipping or grinding. See Figure 10.

Leather Sock Hood When welding must take place in a hard-to-reach area, the leather sock hood offers the best protection while allowing the welder the most maneuverability. The leather sock hood is actually a leather sock with a shaded lens in it. The small size allows the welder to see in small spaces where a standard hood would not fit.

Not suitable for welding are *handheld shields*. Handheld shields have a handle and are used by a foreman or welding inspector to protect his or her face

SAFETY TIP

Safety glasses with side shields must be worn at all times underneath a helmet.

FIGURE 8
Helmet with fixed visor

FIGURE 9
Helmet with flip-up visor

FIGURE 10
Helmet with slide visor

2 SAFETY

when inspecting work. Since the shield must be held with one hand, it is not suitable for welding. See Figure 11.

FIGURE 11
Handheld shield

Whatever the individual visor preference, the helmet must be fully adjustable, not only as to where it sits on the welder's head, but also as to how far the helmet is away from the face and as to the angle it fits on the welder's head in relation to the eyes. This is very important, as safety glasses with side shields must always be worn under the welding helmet.

Types of Lenses

Helmets come with a variety of lenses. These lenses vary in size, material and degree of shading. They are made of polycarbonate plastic or glass. Lenses are 2″ × 4.25″ or 4.5″ × 5.25″ in traditional helmets.

There are several parts to every lens. On most helmets, there is a shaded filter lens, the protective outer lens, and a secondary protective inside lens. The outer and inner lenses are made of optical plastic or glass and help protect the more expensive filter from welding sparks, slag, and heat.

Polycarbonate Plastic Polycarbonate plastic lenses come clear and shaded. These lenses protect both sides of the more expensive glass filter lenses from damage. A variety of shade levels are available. The welder should use the recommended shade based on the work being performed. See Table 1 in Degrees of Shading. When these lenses become scratched and damaged from extensive use, they should be replaced.

Glass Glass lenses provide good protection and come in both clear and shaded styles. Most helmets come with two or three layers of glass. The outer glass lens protects the shaded lens from damage. The welder should use the recommended shade for the inner lens, based on the work being performed. See Table 1, Recommended shading rating for various welding processes. When these lenses become scratched and damaged from extensive use, they should be replaced.

Gold Gold lenses are available in glass or polycarbonate plastic. The gold shade allows the welder to see the arc in natural color while reflecting 90 percent of the welding heat.

Magnifiers Also known as cheaters, these lenses can be attached to the regular lens to magnify work. Magnifiers are used to correct for poor eyesight. Like shade ratings, the higher the number the higher the magnification.

PRODUCTIVITY TIP

Automatic lenses allow the welder to quickly position the welding arc and reduce the need to raise and lower the welding hood or lens. This leaves more time for welding.

Automatic Lenses One of the latest developments in lens technology is the auto-darkening lens. These lenses darken within 1⁄10,000 of a second when an arc is detected. The lens has either a predetermined shade limit or can be manually adjusted to suit the type of welding being performed. These lenses are battery-powered and often have a solar battery booster.

SELF CHECK

1. Why is it important to wear a helmet?
2. In what circumstance might a magnifier lens be used?
3. Can the eye see the arc striking when using an auto-darkening lens?

Degree of Shading

It is important to use a welding lens that is appropriately shaded for the work. A lens that is too dark can impede work and cause eye strain. A lens that is too light can cause eye damage.

Lens shading is measured by **shade rating**, with number ratings ranging from 2 to 14, with 2 being the weakest and 14 the strongest. Shaded lenses provide excellent protection for vision: an eclipse of the sun can be safely viewed with a 10 or higher welding lens.

The Occupational Safety and Health Administration (OSHA) publishes a recommended shade rating table. Please refer to this information when choosing shade strength.

TABLE 1

Recommended shade rating for various welding processes

Shade	Recommended uses	Percent of rays transmitted		
		Noninjurious visible rays	Injurious infrared	Injurious ultraviolet
2	Reflected glare and low temperature furnace work	28.0	0.87	1.075
3	Light brazing and lead burning	16.0	0.43	1.035
4	Acetylene burning and brazing	6.5	None	0.097
5	Light acetylene welding and cutting	2.0	None	0.046
6	Standard shade for acetylene gas welding	0.8	None	None
8	Heavy acetylene welding, electric arc cutting and welding up to 75 A	0.25	None	None
10	Electric arc cutting and welding between 75 and 250 A	0.014	None	None
12	Electric arc cutting and welding above 250 A	0.002	None	None
14	Carbon arc cutting and welding	0.0003	None	None

Choosing a Shade Number for Comfort Welders can determine if the right shade is being used that best suits their eye. The welder should find something to read at a distance, but not so far that it causes eye strain. Then they should weld for about 15 minutes and return to the same location. If the welder then strains to read, the lens may be too dark. If the welder sees a light dot while trying to read, then the lens may be too light.

Lens Installation Sequence

Since the welding helmet lenses need to be periodically replaced, it is important to know how to replace them without damaging the helmet or decreasing its effectiveness. The correct sequence in which the lenses should be replaced, working from the outside in, is listed here.

- clear outside lens
- outermost lens gasket
- shaded lens
- innermost lens gasket
- clear inside lens

Summary

Welding safety involves protecting people and the environment from the by-products of welding: heat, sparks, radiation, fumes, smoke, and noise. Using personal protective equipment is an important part of staying safe while welding. It is also important to be aware of the environment: know what is flammable in the work area, understand the ventilation situation, and be aware of others working nearby. Clothing should be carefully chosen and appropriately worn to provide the most protection possible. Careful consideration should be paid to protecting eyes from radiation and ears from noise.

Welding and Cutting Safety QUESTIONS

Show your understanding of the information in this chapter by answering the questions and filling in the blanks below.

1. Hot sparks can fly up to ______________ feet away.
2. ____ is not considered radiation.
   a. Ultraviolet light
   b. Infrared light
   c. Visible light
   d. Gold lens
3. The combination of ______________ and ______________ provide the best hearing protection.
4. The least safe material to wear while welding is ______________.
5. ____ are the safest shoes to weld in.
   a. Tennis shoes
   b. Sandals
   c. Leather pull-on boots with steel toes
   d. Hiking boots
6. ______________ and ______________ ______________ are two properties that make leather a good protective clothing choice for welders.
7. Spats help protect the ____.
   a. head
   b. arms
   c. fingers
   d. feet
8. It is acceptable to have exposed pockets on a leather welding jacket. (True; False)
9. ____ help protect the wrists.
   a. Gloves
   b. Spats
   c. Chaps
   d. Aprons
10. The bib is important to wear when welding in a(n) ______________ position.
11. Welding helmets are made of ______________ or ______________.

12. Lenses are made of ______________ or ______________ ______________.

13. The higher the shade number, the lighter the shade. (True; False)

14. When a lens is damaged, it should be replaced. (True; False)

15. What is the benefit of using a gold-colored lens?

a. small things look larger
b. large things look smaller
c. color within the welding field remains true
d. they protect from arc flash

CHAPTER 3

Welding Equipment

CONTENTS

INTRODUCTION

There are several types of shielded metal arc welding (SMAW) machines. These machines use either alternating current (AC) or direct current (DC) power. It is important to understand how these machines work so that welding can be performed effectively. Two very important components of the welding machine are the electrode holder and the ground clamp. The electrode holder is what the welder grips to feed the weld. The ground clamps create a ground between the welding machine and the work. Clamps are connected to cables, or leads, which run from the welding machine to the work. They conduct current from the welding machine to the work and back. If a cable is damaged or not functioning properly, the result could be a bad weld or even electrocution.

KEY TERMS

Key Terms are in order of appearance.

resistance welding or **spot welding** process that fuses parent metal using force and resistance to electrical current

oxyfuel welding process that utilizes acetylene, MAPP®, or propane gas with oxygen, with or without filler material

arc welding various welding processes that use an electric arc from a metal rod to the workpiece to create a weld

shielded metal arc welding (SMAW) or **stick welding** process that uses an electric current (AC or DC) to form an arc between an electrode coated in flux and the metals to be joined

gas tungsten arc welding (GTAW) or **TIG welding** process that creates heat using an arc created with a nonconsumable tungsten electrode

gas metal arc welding (GMAW) or **wire feed welding** or **MIG** or **MAG** process that transfers electric current to the parent metal through a wire that is melted and deposited onto the work

flux cored arc welding (FCAW) process that uses a continuous-feed consumable wire electrode whose core is filled with flux and alloying agents

alternating current (AC) electric current that reverses direction at regular intervals

direct current (DC) electric current that flows in a constant direction

cables or **leads** insulated electrical conductor composed of thousands of flexible thin copper wires

rectifier converts AC to DC current

transformer device that converts power from one current to another

OBJECTIVES

Upon successful completion of this chapter, the participant should be able to:

1. Recognize and identify the different types of welding machines.
2. Demonstrate an understanding of what an AC/DC transformer is and how it works.
3. Demonstrate an understanding of what a rectifier and an inverter are.
4. Demonstrate an understanding of the types of generators used in welding.
5. Explain different types of electrode holders and their parts.
6. Discuss and know how to inspect the ground clamp, cables and leads.
7. Discuss the types of available welding tools and how these tools are used.

KEY TERMS *(continued)*

inverter changes frequency to convert high-voltage, low-amperage AC current to low-voltage, high-amperage DC current

output slope change in relationship between the output voltage and the output current, or amperage of the machine as the current or welding workload is changed

constant current when the current does not change based on workload

constant voltage when voltage does not change based on workload

duty cycle amount of time a welding machine can run without overheating

electrode holder clamping device used to hold the electrode for welding

ground clamp produces a ground between the welding machine and the work

chipping hammer double-ended tool to chip slag in corners, edges, and ripples and for general cleaning

wire brush removes rust, slag and other dry materials from workpiece

1 Types of Welding

Before discussing welding equipment, this section briefly outlines some different types of welding.

Resistance Welding

The technique of **resistance welding** includes resistant **spot welding**, resistant seam welding, resistant projection welding and resistant stud welding. In the resistance welding process, welding occurs when the working material resists the flow of welding current; this resistance converts electricity into heat. When the generated heat is combined with pressure from the welding tip, a weld is made. The electrodes in this process conduct the welding current, apply the needed force, and dissipate the heat from the weld area. Resistance welding is especially effective on thin metals such as sheet metal. It is widely used in the manufacture of automobiles.

Oxyfuel Welding

The process of **oxyfuel welding** uses acetylene, *MAPP*®, or propane gas combined with oxygen to create a flame hot enough to weld metal. The oxyfuel flame is controlled by valves on the welding torch. By changing the proportion of oxygen and fuel gas flowing through the torch, the chemical characteristics of the flame change and a neutral, oxidizing, or carburizing flame can be produced.

Arc Welding

In **arc welding**, welding takes place when metal is melted from an electrode and carried across the electric arc to deposit filler metal in a joint. There are several different types of arc welding performed today: shielded metal arc welding, called SMAW or stick welding, gas tungsten arc welding, often referred to as GTAW or TIG welding, and gas metal arc welding, otherwise known as GMAW or MIG or MAG welding.

Shielded Metal Arc Welding (SMAW) A popular technique, **shielded metal arc welding** (**SMAW**) is commonly known as **stick welding**. This technique does not use pressure. Rather, the weld occurs when the heat from the electric arc brings both the metal to be welded and the electrode to a molten state. The heat melts the electrode and the parent metal, that is the metal to be welded, near it. The droplets from the electrode gather in a molten pool in the parent metal to create the weld.

SMAW is used on ferrous and some nonferrous metals. It is especially effective on the following metals and alloys.

- carbon steel
- low-alloy steel
- stainless steel
- cast iron
- nickels and their alloys
- aluminum and its alloys

Gas Tungsten Arc Welding (GTAW) The techniques referred to as **gas tungsten arc welding** (**GTAW**), also referred to as **tungsten inert gas welding** (**TIG welding**), use a nonconsumable tungsten electrode to sustain the arc. The tungsten electrode is shielded from the atmosphere by an inert gas. GTAW is versatile in that a weld can be made with or without a filler metal. In addition, metal less than one millimeter thick can be welded using this technique.

GTAW is used on ferrous and nonferrous metals or with difficult to weld metals such as the following metals and alloys.

- aluminum
- stainless steel
- magnesium
- titanium

Gas Metal Arc Welding The initial purpose of **gas metal arc welding** (**GMAW**) was to weld nonferrous metals, specifically magnesium and aluminum, for the aircraft industry. GMAW is also known as metal inert gas welding (**MIG welding**) or metal active gas welding (**MAG welding**) depending on the gas used. In the field, it is frequently called **wire feed welding**.

GMAW is also useful on other metals and their alloys including the following.

- nickel
- magnesium
- titanium
- copper
- steel

Flux Cored Arc Welding (FCAW) Another type of wire feed welding is **flux cored arc welding** (**FCAW**). FCAW uses a continuous-feed consumable wire electrode whose core is filled with flux and alloying agents. There are two types of FCAW, gas-shielded (FCAW-G) and self-shielded (FCAW-S). In FCAW-G, argon and carbon dioxide are the two main gases used to provide the additional shielding needed for this process. The electrodes used in FCAW-S provide their own shielding gas and slag upon melting and do not require an external shielding gas. FCAW can be used on ferrous and nonferrous metals.

SELF CHECK

1. What does SMAW stand for?
2. What welding technique works on metal less than 1mm thick?

2 Power Sources

There are a number of power sources for welding equipment. These include AC-DC transformers, transformer-rectifiers, inverters, and generators.

AC Transformers, AC/DC Transformer-Rectifier Set

Certain metals and alloys require **alternating current** (**AC**) power to weld more efficiently while **direct current** (**DC**) power is required for other metals. An AC-DC welding machine has both power types available in one machine. AC-DC welder machines are used for SMAW and GTAW.

To select between these two power outputs, the welder simply flips a switch or changes where the **cables**, or **leads**, are plugged into the machine. Figure 1 shows what an AC-DC welding machine looks like. These machines have a built-in **rectifier** to convert AC current to DC. This feature allows welders to choose the current best suitable for welding the metal on which they are working.

FIGURE 1
300-amp AC-DC GTAW/SMAW machine

DC Transformer-Rectifier

The DC transformer-rectifier is a versatile machine. It can be used for GTAW and SMAW on multiple-operator systems. It supports direct current electrode negative (DCEN) welding, also called straight polarity welding, or direct current electrode positive (DCEP) welding, also called reverse polarity welding.

DC transformers have a simple design with two main components: a transformer and a rectifier. The **transformer** produces and regulates AC entering the machine and the rectifier converts the AC to DC current. Another important component of the DC transformer-rectifier is the cooling fan. Since a lot of heat is generated during power conversion, the fan helps prevent the machine from overheating.

Unlike transformers, which regulate AC, rectifiers convert AC to DC. Some welding machines offer both AC and DC power. When a switch is flipped, the alternating current is directed through the rectifier and direct current is produced for welding. See Figure 2.

Inverter

The **inverter** converts high-voltage, low-amperage AC current by changing the frequency to low-voltage, high-amperage DC. It does this by running the current through a series of rectifiers, gating transistors, and transformers. The inverter is a popular power source, for a number of reasons.

- It is lightweight and highly portable.
- It has a low purchase price.
- It is economical to run because it uses much less electricity to generate the necessary power.
- It has fewer maintenance issues and fewer breakdowns.
- It produces a stable current, which is better for welding.
- It has versatile power input 110, 220, 480, single or 3 phase.

Figure 3 shows an AC power inverter.

FIGURE 2
Rectifiers convert AC to DC

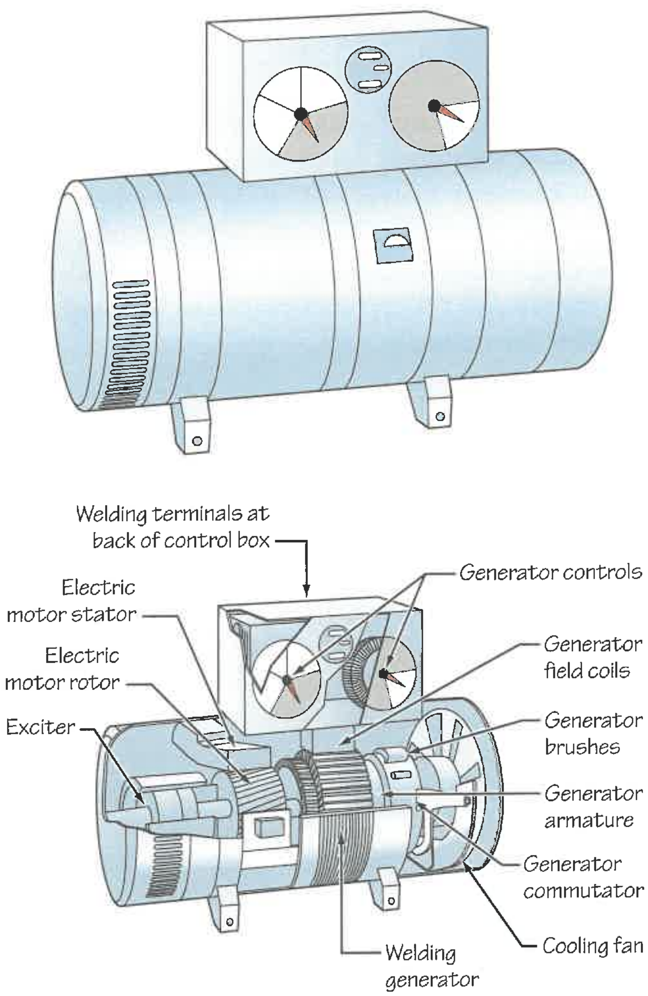


FIGURE 3
AC power inverter

3 EQUIPMENT

FIGURE 4
Engine-driven generator (alternator) for stick welding

Generators

There are two types of motor generators; they are classified according to the motor that provides the power.

1. The first type of generator has an AC motor, a DC generator, and an exciter built on a single shaft. This type of motor is powered by AC electricity found on the jobsite.
2. The second type of generator, the alternator-motor-driven generator, generates its own electricity by running a gasoline- or diesel-powered alternator motor. See Figure 4. These welders are used when power is unavailable at a jobsite.

Classifying Power Sources

Above, power sources have been identified by the pieces of equipment involved. But a power supply can also be classified as to whether it supplies AC or DC power and it can be classified by its *output slope.*

Output Slope The **output slope** is the change in relationship between the output voltage and the output current (or amperage) of the machine as either the current or the welding workload is changed. This change is controlled by whether the power is constant current or constant voltage; it cannot be both.

Constant Current Current is measured in amps. Amps measure the amount of current flow exiting a machine, which determines how hot the weld can become. When the number of amps exiting the machine does not change, it is considered **constant current**. It is also known as variable voltage, because while the current remains constant, the voltage will vary as the welding load changes. GMAW and GTAW welders are the primary constant current welding machines. Constant current machines are available in both DC and AC welding current.

Constant Voltage When a welding machine produces **constant voltage**, the current will change depending upon the welding workload. It can be understood as the amount of pressure being exerted by an electric current.

Duty Cycle Another important concept is **duty cycle**, which is the amount of time a piece of equipment can operate at a certain output. If a welder had a 100 percent duty cycle, the machine could run at its rated current continuously, for the duration of the welding job. However, most machines cannot run at 100 percent duty cycle. Duty cycles are measured in 10-minute increments. A welder with a 60 percent duty cycle can run continuously six minutes of every ten. After the six minutes are up, the machine must be stopped in order to cool. Some machines have only a 20 percent duty cycle and can only run two out of every ten minutes.

PRODUCTIVITY TIP

Select a welding machine with a duty cycle that will not require the welder to stop welding to let the machine cool.

SELF CHECK

1. What are the two main components of a DC transformer?
2. Which two welding machines use constant current?
3. What is a duty cycle?

3 Electrode Holders

The **electrode holder** is a device that holds the electrode used for welding. This device is sometimes referred to as a stinger. There are two types of electrode holders: insulated and noninsulated. Insulation prevents accidental short circuits if the holder comes into contact with the work.

Electrode Holder Components

The traditional electrode holder design is comprised of nine parts. See Figure 5.

One drawback of traditional electrode holders is that the electrode has to be rather long in order to be useful. New designs allow a much shorter electrode to be used. Figure 6 shows a new electrode holder design with a twist-lock device. This holder has a strong clamping force, thereby allowing the electrode to remain secure, even when used to break through slag to start an arc. Figure 7 shows an electrode holder with an angled head. This type of holder is also lighter and shorter than other holders of the same capacity.

Electrode holders come in different sizes and are rated for different amperages. Welding equipment manufacturers will recommend a specific rated electrode holder, based on the amperage of the welding machine and the welding job requirements. If a holder is used that is too small for the machine, overheating can occur.

Inspection

It is important to make certain each component of the electrode holder is functioning properly. For instance, if the lower body tong has a damaged

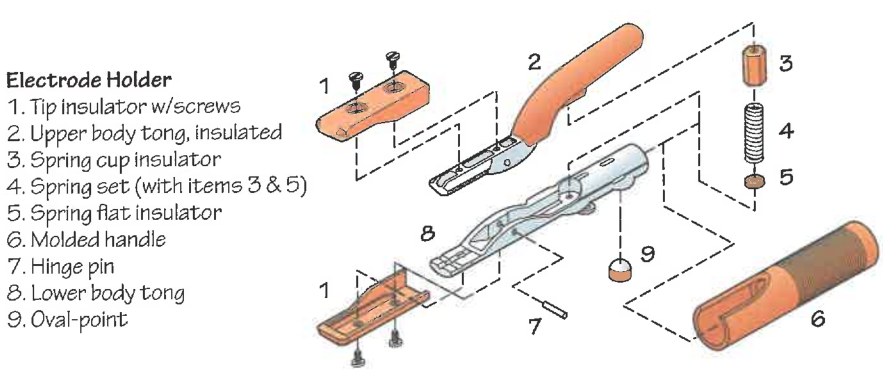


FIGURE 5
Components of an electrode holder

3 EQUIPMENT

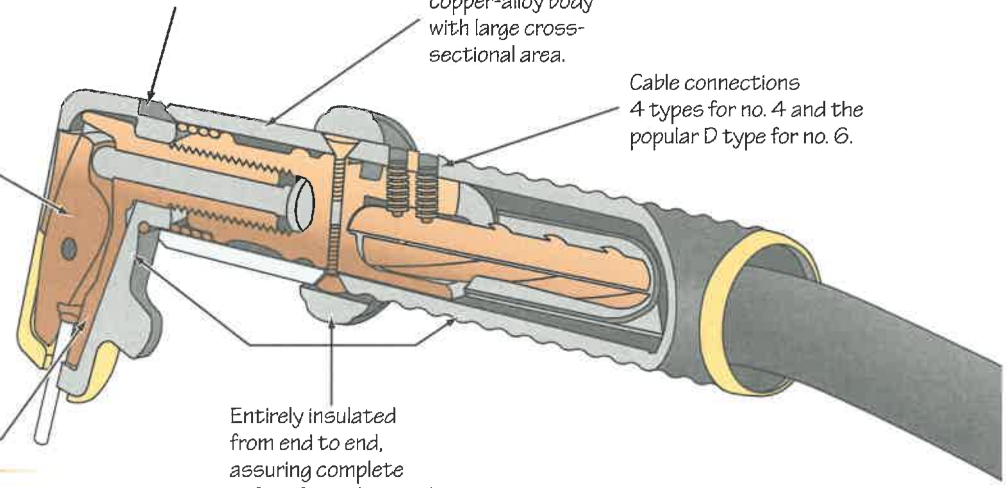
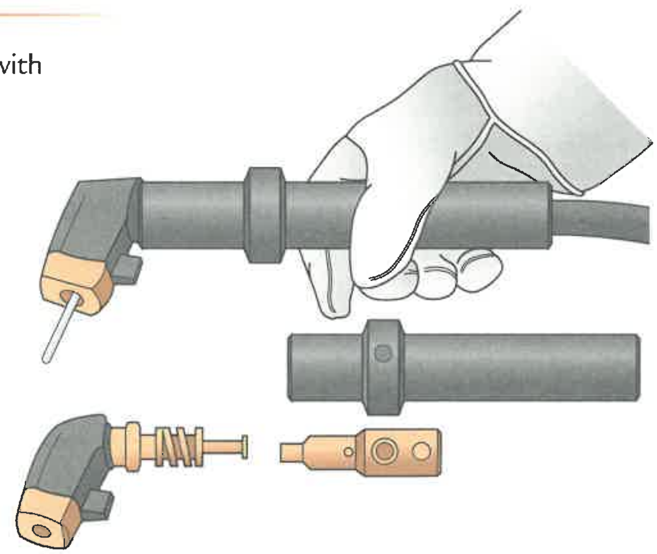


FIGURE 6
Electrode holder with a twist lock

FIGURE 7
Electrode holder with angled head



hinge, it might not hold the electrode firmly. Also, if any insulation is missing from the handle, the welder could be burned.

4 Ground Clamps

It is necessary to have a good **ground clamp** to make a good weld. Ground clamps are used to ground the work to the welding machine. If the ground is loose, the welder may not produce enough heat to make a good weld and the machine itself could be damaged.

Grounding the Welding Machine

There are three main ways to ground the welding machine.

- Fasten the ground cable to the work using a C-clamp. See Figure 8.
- Use a spring-loaded clamp. See Figure 9.
- Bolt or tack-weld the end of the ground cable to the work. See Figure 10.

Inspecting the Electrode Handle and Ground Clamp

Before welding begins, the electrode holder handle must be inspected for wear, tear and defects. The electrode must fit firmly within the grips and the grip must be fully insulated so that nothing is exposed that can conduct heat to the welder's hand.

Ground clamps should be held firmly in whichever clamp is being used. Make sure that the clamp cannot be twisted or easily knocked out of place. Bolting or tack-welding the end of the ground cable to the workpiece ensures a permanent common ground.

FIGURE 8
C-clamp ground clamp

FIGURE 9
Spring-loaded ground clamp

FIGURE 10
Bolted ground clamp

FIGURE 11
Properly connected cables

5 Cable Connections and Inspections

Cables are an important part of the welder's equipment. They must be properly connected and in good condition, to ensure a good weld and a safe welder.

Cables must also be the right length and gauge for a good weld to be made. Cables that are too small for the welding machine's amperage could result in overheating and a poor weld. Cables that are too long can cause a voltage drop and negatively affect welding activity.

Cable Connections

Making solid cable connections is a critical first step to making a good weld. Solid connections are also necessary to ensure the welding machine's safe operation. Figure 11 illustrates a good, solid connection.

Cable Inspection

Since cables are used to complete the electric circuit that allows welding to occur, it is very important that they be inspected before work begins. There are three main things to check on cables.

1. Check to see if the cable to be used is in good shape; make sure there are no insulation tears or exposed copper wires.
2. Make sure the cable is the right size and length for the work being performed.
3. Check the lugs, ground clamp, and electrode handle connections to ensure they are tight, there are no broken cable wires at the connection, and they make good contact with the copper wire in the cables.

Cables that are torn, frayed or that have damaged lugs can affect the quality of the weld and also present an electrocution hazard. If the cable itself is in good shape, make sure the ground connection is secure and not likely to be knocked out of place. See Figure 12.

FIGURE 12
Example of faulty cable

SELF CHECK

1. What are the three methods of securing a ground?
2. What size electrode holder should be used?
3. Why are good connections important in the welding process?

6 Chipping Hammers and Wire Brushes

The **chipping hammer**, sometimes referred to as the cleaning hammer, is a required tool for welding. The chipping hammer is used to remove slag, rust, and other materials from the welded surface. This becomes critical when multiple-pass welds are made.

FIGURE 13
Traditional chipping hammer

Types of Chipping Hammer

Chipping hammers are available as a hand tool or a power tool. See Figure 13. Given the type and size of work being performed, one may be more suitable than the other.

Hand Chipping Hammers Most chipping hammers have two heads. One head is to chip rust and slag away from easily accessible areas of work. The other end is shaped like a pick, so that hard-to-reach areas can be cleaned. The chipping heads come in various sizes and shapes. They also come in combination with a wire brush so one tool serves two functions.

The distinguishing feature of most hand chippers is the handle. Some handles are made of wood and resemble a traditional hammer handle. However, some hammers feature a steel spring handle. See Figure 14. These handles are designed to absorb the shock created when hitting a metal surface.

FIGURE 14
Spring-handled chipping hammer

Power Chipping Hammers Power chipping hammers come in electric, hydraulic, or pneumatic versions. See Figure 15. Depending on the power situation on a jobsite and the type of welding being performed, one of these may be more suitable than the other.

Power chippers are good when there is a lot of cleaning and preparation to do, and they are ruggedly built to withstand heavy use.

Hammer Marks When a hammer is used on welded work, marks are left behind. See Figure 16. Depending on how the finished product should look, sandblasting may be required to achieve a completely smooth finish that is suitable for painting.

3 EQUIPMENT

FIGURE 15

Schematic of an electric hammer

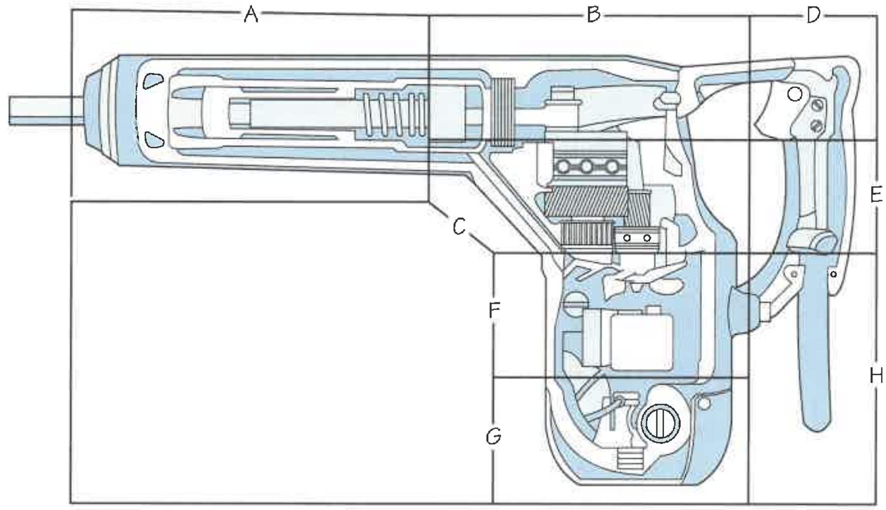


FIGURE 16

Hammer marks

TRADE TIP

To reduce hammer marks do not use chipping hammer until metal has cooled to the point where it does not glow.

Wire Brushes

Like chipping hammers, **wire brushes** can be used to scrub away rust, slag, or other materials from welding work. They are used to clean and polish, both before and after welding.

Wire brushes come in various shapes and sizes. Some wire brushes are even built into chipping hammers for efficiency. See Figure 17. Wire brushes can also come with scrapers. The wires on the brush can be made out of brass, steel, or stainless steel.

FIGURE 17
Combination wire brush and chipping hammer

Summary

There are three main types of welding machines: resistance welders, oxyfuel welders, and arc welders. Power sources for welding are AC-DC transformer, the DC transformer-rectifier, the inverter, and plug-in or alternator-motor-driven generators.

Additional required equipment for welding machines are the electrode holder, the ground clamp, and cables. There are different styles and sizes available for each. Which one to choose depends on the type of work being done and the machine being used.

Always inspect welding equipment before beginning to weld. Before or after welding, a chipping hammer and wire brush are needed to clean slag, rust, and other materials from the weld.

CHAPTER Review

Welding Equipment QUESTIONS

Show your understanding of the information in this chapter by answering the questions and filling in the blanks below.

1. ____ does not use electricity.

a. Arc welding

b. Oxyfuel welding

c. Resistance welding

d. Shield metal arc welding

2. Transformers convert ____.

a. high volt, low amp to low volt, high amp

b. DC to amps

c. AC to volts

d. AC to DC and DC to AC

3. A DC rectifier takes ______________ current and converts it to DC.

4. A MIG welder has a 70 percent duty cycle. This means that it can run ____.

a. 8 minutes out of 10 minutes

b. 2 minutes out of 10 minutes

c. 7 seconds of every 10 minutes

d. 7 minutes of every 10 minutes

5. Two types of electrode holders are ______________ and ______________.

6. It is better to use insulated electrode holders on most jobs. (True; False)

7. Why is it important to ground the welding machine's AC power supply?

____

____

8. What are the different ways to ground the welding circuit?

____

____

9. Why should a welder inspect the equipment before use? Give some examples of what might be found.

____

____

____

____

10. Cables should be of sufficient size to handle the amount of __________ flowing through them.

11. Chipping hammers are used to clean __________, __________, and other material from welding work.

12. Some chipping hammers come with a spring handle. This handle helps ____.

a. absorb sweat
b. absorb power
c. absorb shock
d. absorb work

13. Power hammers can be __________, __________, or __________.

14. Wire brushes are used to clean __________, __________, and other material from welded work.

15. Brushes can be made of ____.

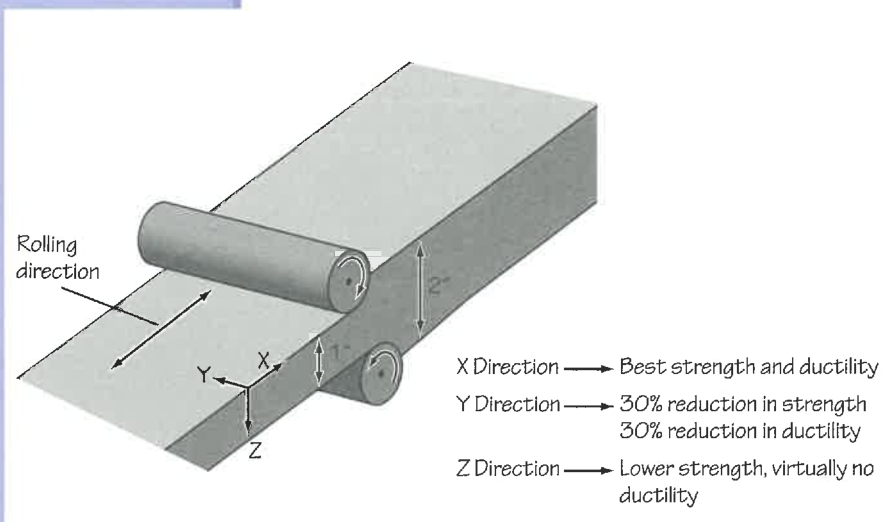
a. plastic
b. wood
c. copper
d. stainless steel

3 EQUIPMENT

CHAPTER 4

Metallurgy

CONTENTS



INTRODUCTION

Learning some basic metal manufacturing methods will help the welder understand the properties of the metal to be welded. Understanding the properties of metal will help the welder understand what happens to metal as heat is applied. Using the temperature data chart, welders can determine welding machine requirements for specific metals.

Knowing the atomic characteristics of metal is important for welders. One of the most important characteristics of metal is its tensile strength; in other words, how metal bends and stretches under force. Using a temperature data chart, welders can determine which welding method a specific metal will respond to, and what effects the temperature changes will have on the metal.

KEY TERMS

Key Terms are in order of appearance.

crucible vessel used for high-temperature chemical reactions, made of material that does not melt easily

metallurgy study of the characteristics of metals at the atomic level and the technologies of heating metals and working them so as to give them certain desired shapes or properties

ferrous refers to a metal containing iron

nonferrous refers to a metal containing little or no iron

thermal expansion rate at which a metal expands or contracts as heat is applied or removed

plasticity ability of metal to change shape without breaking

tensile strength point at which a metal will tear under force

brittle lacking plasticity and easily broken

OBJECTIVES

Upon successful completion of this chapter, the participant should be able to:

1. Describe steel manufacturing methods.
2. Demonstrate an understanding of the characteristics of metal.
3. Read the temperature data chart for metals.

1 Steel Manufacturing Methods

Manufacturing steel is a complicated process involving many steps, precise temperatures, and complex chemical reactions. The way steel has been manufactured determines which welding processes should or should not be used with the given steel. This section discusses the different processes that can be used to manufacture steel.

Bessemer Process

The Bessemer process was developed in 1856 by Henry Bessemer. In this process, molten *pig iron* is held in an egg-shaped furnace container, much like a cement mixer, while compressed air is blown into the bottom. The compressed air causes impurities in the pig iron to oxidize and form steel. Depending on the quality of the pig iron, various grades of steel can be made.

Variations on the basic Bessemer process yield different types of steel. In one process, air is injected into the molten pig iron from the sides, rather than the bottom. This process is frequently used to make steel castings.

Electric Furnace Process

The electric furnace process closely resembles the arc welding process in that it utilizes an electric arc, a large carbon electrode, and a lot of electricity to produce heat. The heat is usually used to convert scrap metal into its molten state. The charge is the scrap metal present at the start of the process. Today's furnaces can hold 200 tons of charge at a time and produce 800 tons of steel in 24 hours.

Once melted, the metal's impurities rise to the top and are raked off. When clear of impurities, the molten metal can be chemically adjusted to meet required specifications by adding *ferroalloys*, other alloys, or deoxidizers. When the desired temperature and chemical composition is achieved, the molten metal is poured into molds to create *blooms*, *slabs*, *rounds*, *billets*, or *beam blanks*.

Oxygen Process

This process is also called the Linz-Donawitz process, after the two cities in Austria where it was first utilized in 1952. This process began to be used in the United States in 1954.

Taking advantage of the chemical reaction that occurs when oxygen is injected onto a bath of molten metal, this process is used to convert pig iron and scrap iron into steel. Unlike the electric furnace process, this process requires a significant amount of hot metal to start the chemical process. Therefore, only 30 percent of the charge can be made up of scrap metal. By adding fluxes and nearly pure oxygen, the pig iron and scrap iron are converted into steel. Temperatures reach 3,000° Fahrenheit (F) and the refining reaction takes 20 to 25 minutes. While this is a short time compared to other manufacturing processes, the amount of time the molten steel must be held to reach a desired chemical composition means it actually takes longer to produce the finished product than in any other steel manufacturing process. Only carbon steels are produced via the oxygen process.

Vacuum Furnaces and Degassing Process

Melting steel and other alloys in a vacuum reduces the gases and other impurities found in most metals. There are three types of vacuum processes: vacuum induction melting, consumable electrode vacuum arc melting, and electroslag refining (ESR). These processes result in improved mechanical properties, close heat control, and better hot and cold characteristics.

Vacuum Degassing Processes Vacuum induction melting and consumable electrode vacuum arc melting are both vacuum degassing processes. Vacuum degassing refines steel by reducing the amount of hydrogen, oxygen, and nitrogen in it. When these impurities are removed from steel, flaking is eliminated, and transverse ductility is nearly double that of air-cast metals.

Electroslag Refining Electroslag refining works very much like basic welding. This process involves an electrode of the alloy that is to be melted, a water-cooled copper crucible and liquid slag. A **crucible** is a vessel used for high-temperature chemical reactions that does not melt easily. The slag is heated by passing an electric current through the electrode, through the slag to the copper crucible. The slag is hot enough to melt the end of the electrode. As the electrode melts, droplets of metal fall through the slag, which melts any oxides, and a purified metal collects on the copper crucible.

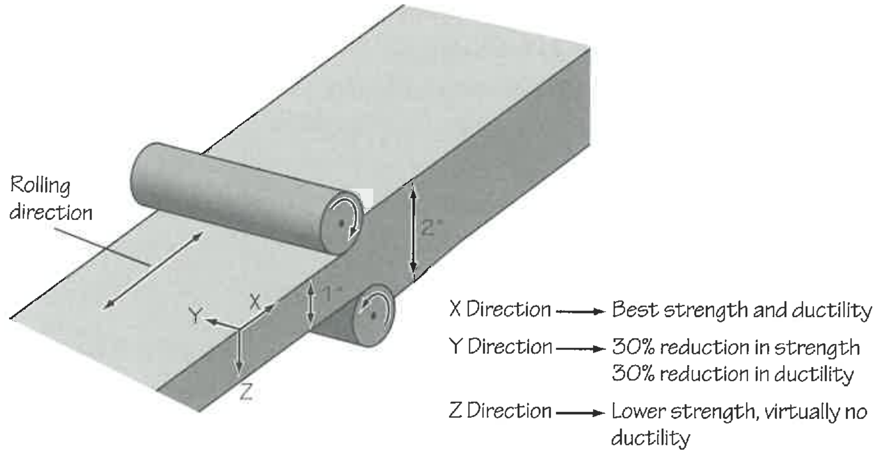
Rolling

During the manufacturing process, molten steel is poured into a continuous water-cooled mold and then moved through a roll for shaping into a bloom, slab, beam blanks, or billet.

- Blooms range from approximately 7″ square to 15″ × 23″.
- Slab castings range in thickness from 2″ to 16″ and can be 100″ wide.
- Beam blanks are rolled into beams.
- Billets have a cast section up to 7″ square.

These basic structures allow steel to be rolled into wires, bars, forgings, extrusions rails, and structured shapes. During the rolling operation, the steel grains are oriented in the direction of rolling. Just like a piece of wood, steel has more strength with the grain and less strength across or against the grain. See Figure 1.

FIGURE 1
Rolling direction



The thickness of the finished steel roll is determined by how many layers are put down. Steel plate that is ¾″ thick can have as many as four layers.

It is very important for a welder to know in which direction the grains are oriented. Welds should be made perpendicular to the grain, which is the X direction. Welding perpendicular to the grain will seal all the rolled layers together. Welding with the grain can cause steel layers to lose their bond and tears can occur between the layers.

SELF CHECK

1. When making steel, what does every manufacturing process try to eliminate?
2. What manufacturing process most resembles arc welding?
3. Why is it important to understand basic steel manufacturing methods?

2 Characteristics of Metal

The field of **metallurgy** involves the study of the characteristics of metals as well as of the technologies involved with the smelting of ore and other refining and metalworking processes. The characteristics of metals are developed at the atomic level. These characteristics can change depending on the state that the atoms are in. There are four states of matter.

- solid
- liquid
- gas
- plasma

When a metal, such as steel, is in the solid state, not much can be done to change its shape or affect it in any way. The atoms that comprise steel remain fixed and unmoving. However, when heat is applied to steel, the atoms begin to move, and as the temperature increases, so does the movement. If the temperature reaches 2600° F, the steel atoms lose their bond completely and the steel melts. If the temperature continues to rise, the melted steel becomes a gas. With even more heat applied, the gas ionizes, that is, it begins to conduct electricity. At this point, the steel gas has reached the plasma stage.

Why is this information important for the welder to know? Because knowing the characteristics of metal will help to make better welders. Since welding can create temperatures from 600° to 10,000° F, and a metal's characteristics can be changed by heat, the welder needs to know that the metal will not be damaged during the welding process.

Ferrous and Nonferrous Metals

Metals are divided into two major groups—**ferrous** and **nonferrous**. Ferrous metals are composed of iron or contain iron. Examples of ferrous metals are cast iron, low-alloyed steels, medium-alloyed steels, tool steels, and stainless steel. Except for a few stainless steel alloys, ferrous metals are attracted by a magnet. Nonferrous metals include aluminum, copper, lead, nickel, silver, and zinc. Nonferrous metals are not attracted by a magnet.

Coefficient of Thermal Expansion

The term **thermal expansion** is used to describe how much a metal expands as it is heated and how much it contracts upon cooling. Medium steel, also called mild steel, has an expansion rate of 0.000006 per unit per degree Fahrenheit (F). Aluminum, on the other hand, expands at a rate of 0.000012 per unit per degree F. The act of welding triggers thermal expansion and contraction.

Mild steel begins to undergo molecular changes at 300° F. That is, the metal begins to "move" and can be shaped without much effort when it reaches this temperature—yet it will still maintain its structural integrity.

There are a couple of ways to determine when this magic number has been reached on a piece of mild steel. One way involves using an oxyacetylene torch. Turn on the acetylene gas and light it. It will produce a heavy carbon smoke. Coat the weld area with the carbon smoke. Add oxygen to the flame and adjust the ratio of oxygen to fuel until a *neutral flame* is achieved. Then apply the flame to the metal. When the carbon smoke disappears from the workpiece, it has reached approximately 300° F.

Another way to determine the temperature of the steel is by the use of a *temperature paint stick*. Temperature paint sticks are special crayons manufactured to melt at a wide range of specific temperatures. If a 300° F paint stick is used to draw on the metal, the markings will melt when the steel reaches that temperature.

Table 1 gives some useful information on metals and their properties.

TABLE 1

Metals and their properties

Metal	Melting point (°F)	Linear expansion per 10-ft length per 100°F rise in temperature (in inches)	Heat conductivity (btu/hr per ft^2/inch of thickness per °F)	Density ($lb/inch^3$)
Aluminum-cast-8% copper	1,175			
Aluminum-pure	1,218	0.148	1,393	0.096
Aluminum-5% silicon	1,117	0.146		0.093
Brass-commercial high	1,660	0.115	756	0.306
Carbon	> 6,332			
Iron-wrought	2,900	0.078	419	0.278
Lead-pure	620	0.181	240	0.411
Steel-hard (0.40-0.70% carbon)	2,500	0.076	312 1% carbon	0.283
Steel-low carbon (less than 0.15%)	2,700	0.076		0.283
Steel-medium (0.15-0.40% carbon)	2,600	0.076		0.283
Steel-manganese	2,450			
Stainless steel -18-8	2,550	0.073		0.279
Stainless steel -18-8 low carbon	2,640			0.280
Tin	450	0.139	450	0.263

Plasticity

The ability of a metal to change shape without breaking is called **plasticity**. This characteristic, along with strength, is the most important characteristics that metal has. Plasticity enables a metal to distribute stress instead of concentrating it. Metals with good plasticity, such as steel and iron, are used in construction.

Tensile Strength

The concept of **tensile strength** is also important in welding. Tensile strength is the resistance of a material to a force tending to tear it apart.

Shrinkage allowance in castings (inch/ft)	Brinell hardness		Approx. tensile strength (psi)	Approx. analysis of chemical composition (%)	Metal
	Hard	Soft			
0.1875			20,000	Aluminum 92; copper 8	Aluminum-cast-8% copper
	40	23	12,000–28,000	Aluminum	Aluminum-pure
			18,000	Aluminum 95; silicon 5	Aluminum-5% silicon
0.1875			46,000	Copper 66; zinc 34	Brass-commercial high
				Carbon	Carbon
		90	48,000	Iron; slag	Iron-wrought
0.312		6	1,780	Lead	Lead-pure
	590	240	75,000		Steel-hard (0.40–0.70% carbon)
		138	50,000		Steel-low carbon (less than 0.15%)
		180	60,000		Steel-medium (0.15–0.40% carbon)
	255		70,000–100,000	Carbon 1.0–1.45; manganese 12–15; silicon 0.10–0.20; iron	Steel-manganese
		140	89,000–100,000	Chromium 18; nickel 9; carbon 0.16; iron (base)	Stainless steel -18-8
		140	80,000 (annealed)	Chromium 18; nickel 8; carbon 0.07; iron (base)	Stainless steel -18-8 low carbon
0.083	9 (Mohs scale)	15	5,000	Tin	Tin

It is measured as the maximum tension the material can withstand without tearing.

Both tensile strength and plasticity play an important part in welding. *Mild steel* contains between 0.15 and 0.40 percent carbon and has a tensile strength of 60,000 psi. *Low-carbon steel* contains less than 0.15 percent carbon and has a tensile strength of 50,000 psi. *Hard steel* contains between 0.40 and 0.70 percent carbon and has a tensile strength of 75,000. The higher the carbon content, the greater the tensile strength. However, the higher the carbon content, the less ductile, or malleable, and therefore less able to be welded. If carbon content is greater than 0.25 percent, the area next to the weld can become quite brittle with sudden cooling.

TRADE TIP

Even though carbon increases tensile strength, it is actually better to weld with a low- to medium-carbon-content welding rod.

Brittleness

When a metal is **brittle**, it lacks plasticity and tensile strength and can break more easily. The outer portion of a weld is prone to brittleness and extra care must be taken when working with this area.

SELF CHECK

1. In what four states can metal be?
2. What can affect the strength of steel?
3. In what direction should someone weld on steel?

3 Temperature Data

Since welding is the act of applying heat to metal to change its shape and properties, knowing at what temperature certain metals melt is crucial. The melting temperature of a metal will determine the method of welding. The higher the melting point, the more powerful a welding machine is needed. There is nothing more frustrating than welding on a piece of metal that won't reach melting temperature, only to discover the welding machine isn't powerful enough to reach that temperature in the first place.

Figure 2 lists the melting temperatures of common metals and alloys. This figure also includes a color scale. A color scale lets the welder visually determine the approximate temperature of a metal based on its color as heat is applied. The lowest color reading is faint red at 950° F; the highest color reading, white, is reached at 2,300° F, hence the saying "white hot."

Summary

Metallurgy is the study of the characteristics of metals at the atomic level and of the technology of refining ores and working and shaping metal. The movement of atoms gives metals their strength and weaknesses, their melting points and their stretching points.

Knowledge of the characteristics of the metal being worked with can make welding easier to perform correctly, and can help improve welding skills.

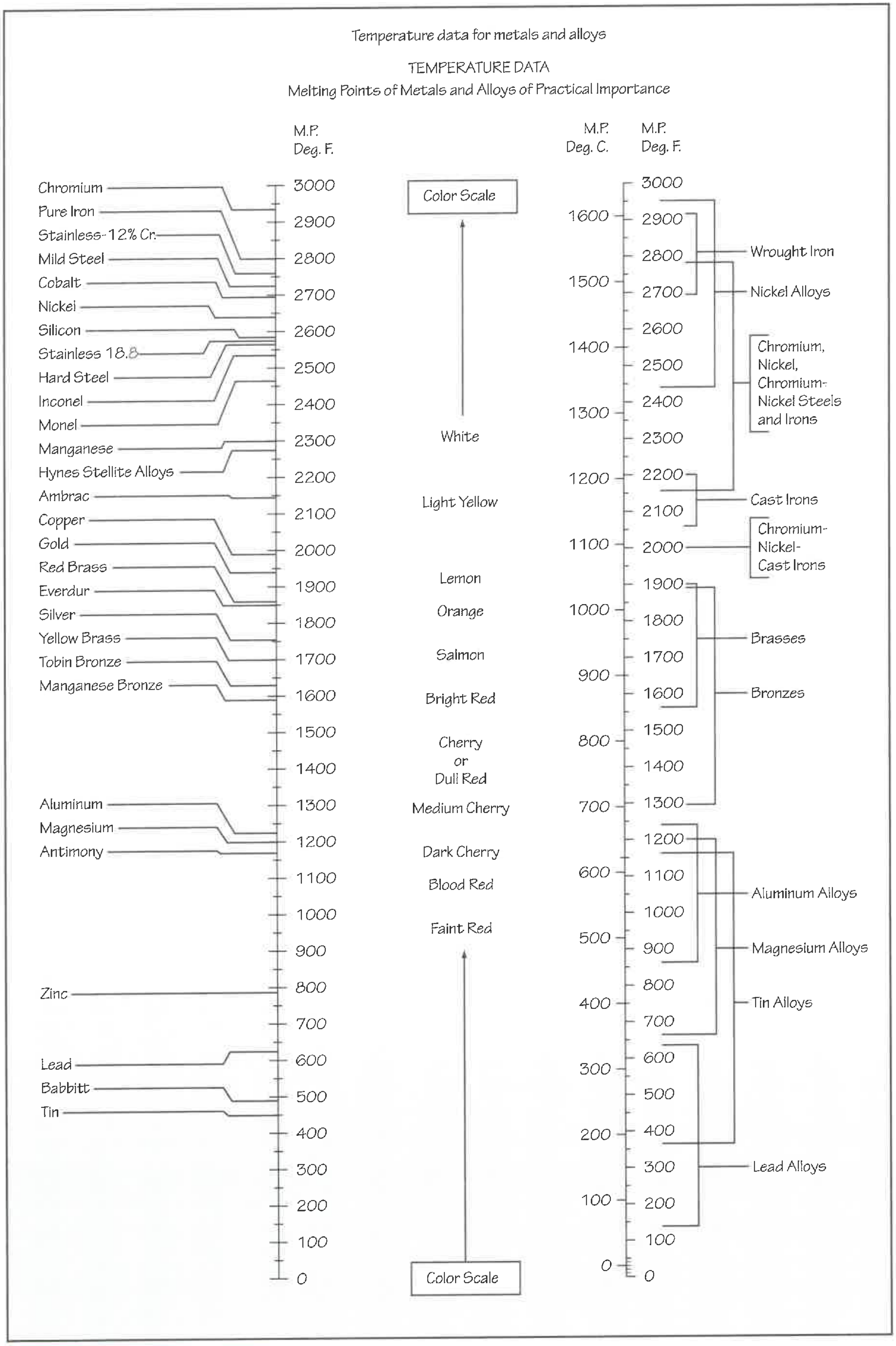


FIGURE 2
Temperature data

CHAPTER Review

Metallurgy QUESTIONS

Show your understanding of the information in this chapter by answering the questions and filling in the blanks below.

1. If a metal bends but doesn't break, it has a characteristic known as ____.
   a. tensile strength
   b. plasticity
   c. brittleness
   d. metallurgy
2. When metal is cool, what state is it in?
   a. liquid
   b. tensile
   c. solid
   d. plasma
3. The outer edges of a weld can be especially ______________, and care must be taken not to break it.
4. ______________ expansion occurs during welding.
5. Mild steel begins to "move" when it is heated to ______________.
6. Color can be used to roughly determine the temperature of a metal. (True; False)

Use the table and Figure 2 in this chapter to answer the following questions.

7. What is the melting point of tin? ______________
8. Which metal has the highest rate of linear expansion?
   ____
   ____
9. At what temperature does pure aluminum melt? ______________
10. What color is stainless steel when it reaches its melting point? ______________

CHAPTER 5

Oxyfuel Safety

CONTENTS

INTRODUCTION

Oxyfuel welding requires cylinders to store and dispense fuel gas and oxygen. Fuel gas can be acetylene, propane, natural gas, or MAPP® gas. The cylinder and hose requirements for each of these gases are different. Knowing how to safely handle and work with cylinders is essential for effective welding.

KEY TERMS

Key Terms are in order of appearance.

cylinder used to contain fuel gas and oxygen under pressure; usually made of steel

fuel gas gas used together with oxygen to preheat the metal to be cut, usually propane, acetylene, MPS (MAPP®), or natural gas

check valve device that restricts movement of gas to one direction only

flashback arrestor safety device that prevents flame from traveling upstream of the cutting tip

regulator device that converts gases under high pressure to lower pressures suitable for cutting; comes in single stage or two-stage varieties

manifold chamber used in conjunction with a single-stage regulator to reduce initial gas pressure before it reaches the regulator

OBJECTIVES

Upon successful completion of this chapter, the participant should be able to:

1. Describe aspects of cylinder safety including transportation, storage, and size.
2. List types of hoses and describe how they connect to cylinders.
3. Demonstrate an understanding of the proper amount to open valves on cylinders.

1 Cylinder Safety

There are numerous federal and state regulations governing all aspects of working with gas **cylinders**. Cylinders contain **fuel gas** under pressure. A fuel gas is a gas used together with oxygen to preheat the metal to be cut. The information below represents general gas cylinder safety and handling practices. For specific rules and regulations, consult the local regulatory agency.

Securing and Transporting Cylinders

When moving cylinders from job to job, special care must be taken to protect the cylinders, the people transporting them, and the general public. The following steps are recommended safety procedures:

Before moving a cylinder, remove the regulator and put the valve protection cap on. This should be done unless a transport that is specifically designed to transport cylinders is being used. Always secure cylinders in an upright position where they cannot fall over or be knocked over accidentally.

- Do not use the valve protection cap to lift a cylinder.
- If the valve under the protection cap becomes frozen, use warm, not boiling, water to thaw the valve. Never use a bar to force the cylinder open.
- A suitable cylinder cart, chain, or other steadying device must be used to keep cylinders from being knocked over while in use.
- When hoisting cylinders, secure them on a cradle, sling board, or pallet. Do not use magnets or choker slings.
- Move cylinders by tilting and rolling them on their bottom edges. Do not drop the cylinders or let them strike anything.
- When transporting cylinders in a vehicle, they should be secured in an upright position.
- When work is finished, when cylinders are empty, or when cylinders are moved at any time, close the cylinder valve, even when cylinders are on a portable cart.

Storing Cylinders

It is important to store cylinders correctly. Incorrectly stored cylinders can be damaged, their contents lost or a fire hazard created. The following are recommended ways to correctly store cylinders.

- Always secure cylinders in an upright position where they cannot fall over or be knocked over accidentally.
- Keep cylinders far enough away from the welding or cutting operation so that sparks, hot slag, or flame cannot reach them. If this is impractical, use a fire-resistant shield such as a fire blanket.

- Keep cylinders away from any source of artificial heat. Remember the 35′-0″ rule: sparks and molten metal can travel up to 35′-0″ horizontally from the work area!
- Do not place cylinders where they can become part of an electrical circuit; they must be a minimum of 10′-0″ away from an open power source.
- Do not accidentally touch the cylinder with an electrode.
- Always keep cylinders with the valve end up when in use or in storage. Never lay cylinders flat.
- Do not place cylinders in a confined space.
- Do not store oxygen and fuel cylinders together. They must be separated by at least 20′-0″, or separated by a 1.5-hour-rated, noncombustible, 5′-0″ tall barrier.

Choosing the Right Cylinder Size

Fuel cylinders come in various sizes. It is important to choose the right fuel cylinder for the job so that no time will be wasted changing an empty bottle for a full one. It takes a great deal of time to change the bottle during work procedure The size should be based on the amount of time it will take to perform a job. As a rule, the fuel cylinder should be of a size so that no more than 1⁄10 of the capacity of the cylinder per hour during intermittent use or 1⁄15 of the capacity of the cylinder per hour during continuous use.

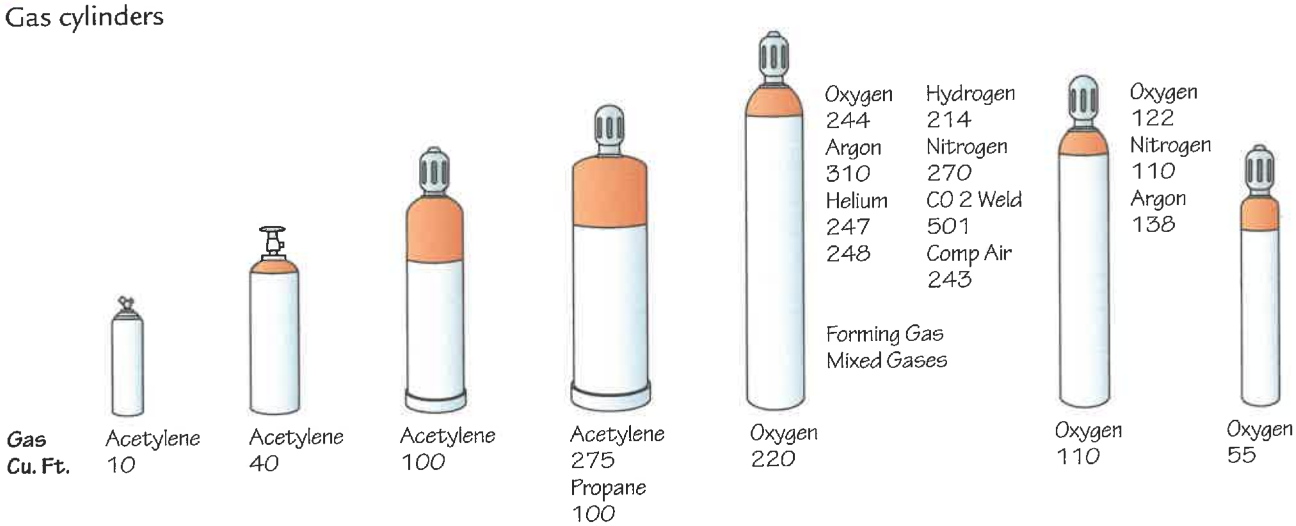
PRODUCTIVITY TIP

Choose the right size cylinder before starting to work so that an empty cylinder does not have to be swapped for a new, full one. It can take a lot of time to perform the swap.

Oxygen cylinders also come in various sizes. The oxygen cylinder should be large enough to finish the cutting task at hand.

Figure 1 shows the various capacities in which cylinders are available. The larger cylinders are constructed of steel. The smaller cylinders are made of aluminum. These smaller, lighter cylinders are typically used for medical gases only. They are not usually appropriate for welding gases.

FIGURE 1
Gas cylinders



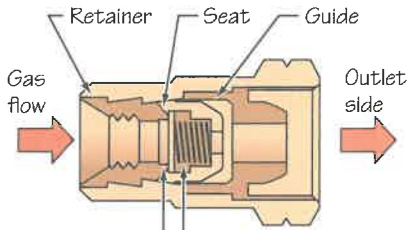


FIGURE 2
Check valve for an oxyfuel system

Additional Cylinder Safety Practices

Cylinders should always be kept upright, when storing, moving or in use. Acetylene cylinders have a honeycomb porous material with acetone inside. Acetylene gas is a compound of carbon and hydrogen and is *volatile* at more than 15 pounds per square inch (psi). The acetylene is only safe at pressures over 15 psi if it is saturated in acetone. If the welder attempts to use an acetylene cylinder after the cylinder has been on its side, the acetone, which is *corrosive*, will adversely affect the cutting torch parts and the welder.

If a cutting torch tip is blocked, if there is an excess or lack of gas pressure, or if an unsafe startup or shutdown procedure has been followed, gas can flow backward through the system. There are two devices welders use to prevent this from happening: check valves and flashback arrestors.

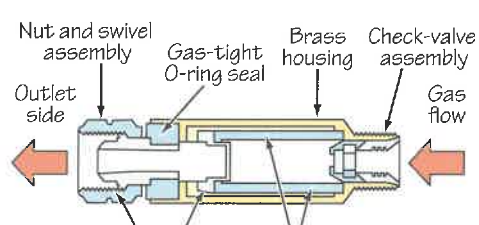
Check Valves A **check valve** allows gas to flow in one direction only. These valves prevent the reverse flow of gases. If check valves were not used, it would be possible for fuel gases to enter the oxygen tank or oxygen to enter the fuel tank, a condition called backflow. Figure 2 shows how a check valve works.

Flashback Arrestors A **flashback arrestor** is another important safety device. During a flashback, flame and gas from the torch pass upstream into either gas system: fuel or oxygen. Flashback arrestors prevent the gas from flowing backward and the flame from traveling upstream of the arrestor. The use of a flashback arrestor is encouraged to prevent this dangerous situation from occurring. Figure 3 illustrates the parts of a flashback arrestor.

SAFETY TIP

Local regulations frequently require the use of flashback arrestors. This eliminates backflow of gases into bottles that would cause an explosion.

FIGURE 3
Flashback arrestor for an oxyfuel system



SELF CHECK

1. When should valve protection caps be used?
2. When is it acceptable to store cylinders on their sides?
3. How is fuel cylinder size determined?

2 Hose Safety

It is important to understand all parts of the oxyfuel rig thoroughly, so that mistakes are not made in setting up the equipment. One such part involves the hoses that connect the cylinders to the torch.

Hoses are available in three sizes—3⁄16″, ¼″, and ⅜″ inner diameter (i.d.). Grade T hose is for fuel gas including acetylene. This replaces former grade M. Grades R and RM are for use with acetylene only. Hoses are usually colored to show which gas is being carried. The oxygen line is normally green; the fuel line is usually red.

The cylinder regulators and torch head are usually connected by double-line rubber hoses, known as twin weld.

Hose Connections

It is important to use only the correct hose connectors on the regulator and the cutting torch. To keep from mixing up the hoses, connectors, and regulators, there are different systems for oxygen and acetylene fittings.

The oxygen hose connectors consist of a barbed nipple that is pressed into the hose and clamped with a *swaged collar* and screws into the cutting torch or regulator using a nut. The oxygen nut has a right-hand thread pattern.

The fuel connectors use a similar setup; however, instead of a right-hand thread pattern, fuel connectors have a left-hand thread pattern.

TRADE TIP

Do not to mix hoses when oxyfuel welding. Always use the same hose for oxygen and always use the same hose for fuel. If hoses are switched, gas impurities could affect the welds.

SAFETY TIP

Small sections of the hoses may be taped together to avoid tangling the hoses. However, do not cover the hoses with tape because then the condition of the hoses could not be inspected.

3 Using Cylinder Regulators Safely

The oxygen and fuels used during oxyfuel welding are under tremendous pressure inside the cylinders. In the case of oxygen, its pressure is about 2,200 psi in its cylinder. If the oxygen were just released at that pressure, no welding could be performed. Therefore, regulators are used to reduce the pressure to a usable amount.

A **regulator** reduces the pressure that the fuel and oxygen is released at and smoothes the delivery to help keep the welding flame even. Each welding cylinder comes with its own regulator. Figure 4 illustrates two regulators.

TRADE TIP

The nuts for torch fittings provide a clue as to which way it threads. If the nut has a groove around it, it is a left-hand thread and is therefore a fitting for a fuel hose. If the nut is smooth, it indicates a right-hand thread and is the fitting for the oxygen hose.

FIGURE 4

Oxygen and acetylene regulators

Types of Regulators

There are two basic types of regulators: single-stage regulators and two-stage regulators. Each regulator works through gas pressure, screws, springs, and diaphragms.

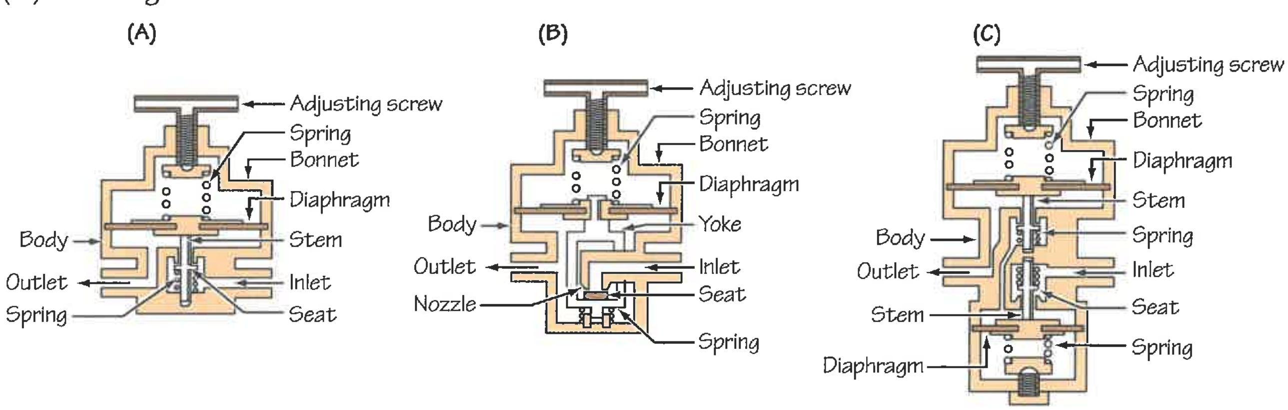
Single-Stage Regulators Single-stage regulators are mainly used with a separate manifold. In this system, the **manifold** reduces the initial gas pressure before it enters the regulator system. Through the manifold chamber, the initial gas pressure is reduced to a fixed amount determined by screws located on the manifold.

Two-Stage Regulators The two-stage regulator works without a manifold. Instead, the regulator has two chambers: a high-pressure chamber and a reducing chamber. The pressure in each of these chambers is set by adjusting screws.

Figure 5 illustrates the inner workings of the single-stage and the two-stage regulator.

FIGURE 5

Typical gas regulators
(A) Single-stage stem type
(B) Single-stage nozzle type
(C) Two-stage



SELF CHECK

1. Is it easy to mix up the oxygen and fuel hose connectors?
2. When is it acceptable to use a single-stage regulator?

Attaching Oxygen Cylinder Regulators Safely

Before connecting a regulator to an oxygen cylinder valve, the valve should be *cracked*, that is, it should be opened slightly and closed immediately. This action will clear the valve of dust or dirt that might otherwise enter the regulator. The person cracking the valve should not stand in front of the cylinder valve.

Other safety measures include the following.

- Visually inspect regulators and gauges for visible damage to gauge and fitting seats
- When attaching oxygen cylinders to the regulator, never over-tighten the connections as this can damage brass fittings on the regulator.
- Never oil the oxygen regulator or the cylinder valve. In the presence of high-pressure oxygen, oil and grease can spontaneously combust.
- Always check that the regulator's pressure adjustment screw is backed out to its fullest extent while remaining attached to the regulator prior to opening the cylinder valve.
- When opening the cylinder, the welder should stand on the opposite side of the cylinder from where the regulator is pointing. If the regulator has a damaged diaphragm or damaged threads on the adjustment screw, the 2,250 pounds of pressure can cause the regulator to fly into pieces, turning those pieces into dangerous projectiles.
- Finally, when properly positioned on the side away from the direction the regulator is pointing to, the oxygen cylinder valve should be opened slowly and completely, in order to avoid damaging the regulator.

TRADE TIP

Because oxygen cylinders are at typically 2,200 psi, they have a double-seat valve assembly. Due to the double-seat valve, oxygen cylinder valves and all other high pressure gas cylinder valves must be fully opened or fully closed.

Attaching Fuel Cylinder Regulators Safely

Before connecting a regulator to a fuel cylinder valve, the valve should be cracked, that is, opened slightly and closed immediately. This will clear the valve of dust or dirt that might otherwise enter the regulator. The person cracking the valve should not stand in front of it. The valve of a fuel gas cylinder should not be cracked where the gas can reach welding work, sparks, flame, or other possible sources of ignition.

Never oil the fuel regulator or the cylinder valve. In the presence of certain gases, oil and grease can spontaneously combust.

SAFETY TIP

Never open fuel cylinder valves more than 1 ½ turns.

SAFETY TIP

Never store anything on top of the cylinder.

SAFETY TIP

Back off regulators after every shift to stop valves from getting sticky.

TRADE TIP

Fuel cylinder valves have a single-seat valve assembly because their contents are not under a lot of pressure.

TRADE TIP

Only open acetylene cylinders from ¾ to 1 ½ turns.

Once the fuel cylinder valve has been cracked and the regulator has been attached, the cylinder valve should be opened slowly to prevent damage to the regulator. For safety purposes, never open fuel cylinder valves more than 1 ½ turns.

If a special wrench is required to open the fuel cylinder valve, that wrench should be left in position on the valve stem in case the gas flow needs to be quickly shut off. Never store anything on top of the cylinder. Placing objects there may interfere with the regulator operation or create a safety hazard if the gas needs to be quickly shut off.

Checking for Leaks

Before the torch can be turned on, the connections must be checked for leaks. If soapy water is not available on the jobsite to check for forming bubbles, there is a standard procedure frequently used.

PROCEDURE

How to Check for Leaks

1. Once the regulator has been properly attached to the cylinder and before touching the regulator adjusting screw, crack the oxygen bottle and watch the high-pressure gauge. The gauge should now read the amount of pressure that's in the cylinder. If the pressure reading starts to drop, there is a leak in the connection between the gauge and the cylinder. That fitting must be tightened, and the high-pressure gauge checked again to make sure the pressure is holding.
2. Once the torch head and hose are connected, open the oxygen cylinder and adjust the regulator adjustment screw until the desired pressure is shown on the low-pressure gauge.
3. Note the pressure on both gauges, shut the cylinder valve, and watch the low-pressure gauge to see if the pressure drops. If the pressure has gone down, a connection between the manifold and the torch head—or one of the valves in the torch head—is leaking. In this case, tighten the connections and repeat the check. If both gauges hold steady pressure, there are no leaks.

4 Pressure Settings

Once the regulator is in place, it is time to adjust the pressure settings. A good general rule is to have a 5 to 1 ratio of oxygen to fuel (5:1). In other words, there should be five parts oxygen for every one part fuel. However, the correct pressures depend on the size of the cutting tip and the thickness of the metal being used.

When lighting an oxyacetylene torch, follow the procedure below to determine the correct ratio of oxygen to fuel.

PROCEDURE

How to Determine the Correct Pressure Settings

1. Turn on acetylene gas and light it.
2. Turn acetylene gas up until there is a fine smoke (not a thick carbon smoke).
3. Add oxygen. As oxygen is added, the blue flame at the tip of the torch will begin to sharpen.
4. When the flame is sharp and clear, not thick and blurry, the system is getting close.
5. Depress the cutting trigger, which adds more oxygen to the system. Adjust the oxygen valve while the cutting trigger is depressed until the blue flames are sharp and clear, not thick and blurry. Then, there is a good usable flame.

Summary

Following good safety procedures when welding is very important. The gases used in oxyfuel welding should be treated with respect. Always check hoses, nozzles, and cylinders before starting any welding job. Always secure cylinders when transporting them from job to job. Equipment that is in good working order and that is operated safely increases job efficiency.

Oxyfuel Safety QUESTIONS

Show your understanding of the information in this chapter by answering the questions and filling in the blanks below.

1. A welder is working on a big job 25 miles from the shop. What is the first thing he or she should do to begin safely moving the oxyacetylene rig?

____

____

____

2. Cylinders may never be stored on their sides. (True; False)

3. You should consume _____ of fuel on a job if the tank is of a sufficient size.
   - a. ⅛ volume or less per hour
   - b. ⅐ volume or less per hour
   - c. ¼ volume or less per hour
   - d. ½ volume or less per hour

4. What is the thread orientation for oxygen cylinders? ________________-

   ____

5. The oxygen hose is normally green. (True; False)

6. A single-stage regulator should be used only when there is a(n) ________________.

7. A fuel cylinder valve should be opened _____.
   - a. ¼ to ½ turn
   - b. ⅓ to ⅔ turn
   - c. not more than 1 ½ turns
   - d. ½ to ¾ turn

8. What could possibly happen if you mixed up the hoses or connectors of the oxygen cylinder and the fuel cylinder?

____

____

9. Why is it important to "crack" the oxygen cylinder before use?

____

____

____

10. The general rule for the ratio of fuel to oxygen is _____.

a. 1:5
b. 1:7
c. 5:1
d. 7:1

CHAPTER 6

Oxyfuel Cutting

CONTENTS

INTRODUCTION

A widely used method for cutting metal is oxyfuel cutting (OFC). Several different fuel gases can be used with oxygen. Whichever one is used depends on the type of metal being cut. There are several types of torches that can be used. The type of torch chosen should be best suited for the job at hand.

KEY TERMS

Key Terms are in order of appearance.

oxyfuel cutting (OFC) using oxygen and a fuel gas to cut a ferrous metal

ferrous metal metal that contains iron

fuel gas used with oxygen to create cutting flame; heats the metal enough to produce the desired chemical reaction with oxygen

acetylene popular fuel gas for cutting

MAPP® brand of acetylene-based fuel gas used in oxyfuel cutting

MPS cutting gas acetylene-based fuel gas used in oxyfuel cutting

propane fuel gas used in oxyfuel cutting

natural gas fuel gas used in oxyfuel cutting

cutting torch mixes a fuel gas for heating flames and a stream of pure oxygen to cut metal

backflow gas flowing backwards in a hose

kerf width of the cut

OBJECTIVES

Upon successful completion of this chapter, the participant should be able to:

1. Demonstrate an understanding of and describe how oxyfuel cutting works.
2. Identify types of fuels used for cutting and list their advantages and disadvantages.
3. List the different torches used in cutting and their uses.

1 Personal Protection Equipment

It is important to wear approved clothing and accessories when cutting with an oxyfuel torch.

- Wear dry gloves that have no tears or holes.
- Wear protective garments such as leather gloves, a heavy shirt, cuffless pants, high shoes or pull-on boots or boots with leather laces, and a cap.
- Wear approved safety goggles with side shields in addition to wearing a shaded face shield. Either the goggles or the face shield must have a minimum shade value of 5.
- Use approved helmets that protect the face, neck, and ears.
- Wear leggings, aprons, sleeves, shoulder covers, and bibs.

2 What Is Oxyfuel Cutting?

The process called **oxyfuel cutting** (**OFC**), uses oxygen and some other fuel gas to cut **ferrous metals**. Ferrous materials are those metals that contain iron. It is the chemical reaction that takes place between ferrous metal and the oxygen present in oxyfuel welding that enables the metal to be cut. If there is no iron in the metal, that is, if it is a *nonferrous* metal, the chemical reaction described below will not take place.

Ferrous metals have an affinity for oxygen. Think of an old rusted engine that has been sitting out behind the shed, exposed to the elements. The iron present in that engine has reacted with the oxygen in the air to form an iron oxide—rust. This rusting process can take a long time as the oxygen content in the air is only about 20 percent.

This process works to our benefit in oxyfuel cutting. When oxyfuel cutting is introduced to a metal that contains iron, the heat produced from the flame raises the metal to 1,500° F to 1,600° F, a cherry red color. As part of the cutting process, oxygen is blasted onto the hot metal. This causes the metal to burn; in essence, it burns just like kindling wood burns once it reaches the right temperature.

When wood burns, it gives off smoke as one by-product of the chemical breakdown induced by heat. Metal also has a by-product when it burns. While there is some smoke, the main by-product of burning metal is iron oxide—rust. However, the melting point of iron oxide, or rust, is below that of the steel. The heat from the burning steel and the oxyfuel torch is enough to melt the rust as soon as it forms. The melted iron oxide forms a *slag* that runs off of the metal being worked, exposing more metal. Therefore, clean cuts can be made with oxyfuel flame.

Looked at in this way, oxyfuel cutting is simply very rapid rusting. It is therefore considered to be a chemical process, unlike arc welding which is considered a mechanical process. Oxyfuel cutting utilizes a **fuel gas** in addition to oxygen. The type of fuel gas depends on the material being cut. Remember though, it is the oxygen portion of the rig that is actually doing the cutting. The fuel gas merely heats up the metal enough so that it reacts with the oxygen.

SELF CHECK

1. What chemical process happens to ferrous metal when it is oxyfuel cut?
2. What are some by-products of oxyfuel cutting?

3 Cutting Fuels

As mentioned above, cutting fuels are used in conjunction with oxygen to create a heat source strong enough to melt metal containing iron oxide.

There are several types of fuel gases available to choose from, and each has its strengths and weaknesses. The properties of the most common gases are listed in Table 1.

TABLE 1

Cutting fuel gas chart

	Acetylene	Methylactylene-propadiene* MAPP®	Propane*	Propylene	Natural gas (methane)
Neutral flame temperature, °F	5,589°	5,301°	5,250°	4,579°	4,820°
Oxygen fuel combination ratio	2.5:1	4.0:1	4.5:1	5.0:1	2.0:1
British thermal units (BTUs) per cu. ft.	1,470 BTUs	2,460 BTUs	2,400 BTUs	2,243 BTUs	1,000 BTUs
Burning velocity in oxygen	22.7 ft./sec.	15.4 ft./sec.	15.0 ft./sec.	12.2 ft./sec.	15.2 ft./sec.
Flammability limits in oxygen**	3–93%	2.5–60%	2.5–60%	2.4–57%	5–59%
Flammability limits in air	2.5–80%	3.4–10.8%	2.0–11.1%	2.3–9.5%	5.3–14%
Specific gravity (air = 1@60° F)	0.91	1.48	1.48	1.52	0.62
Maximum allowable regulator pressure, psi	15	150	150	150	Line

* MAPP® and propane fuels are heavier than air and will collect in low areas such as basements. The accumulated fuels are very toxic and highly flammable. Always use extreme caution when using these fuels around holes or closed-in areas.

** Use caution when missing fuel gases with an oxidizer. When fuels are mixed in the proper proportion, they can become a potentially explosive material.

Each of these gases has advantages and disadvantages. Each also uses different torch tips. Understanding how each gas performs will enable the welder to make an educated choice on which gas to use for a particular job.

Acetylene Gas

By far the most popular fuel gas today, **acetylene** is used for both welding and cutting purposes. Most other gases are compared against acetylene with regard to performance and cost.

Advantages An oxyacetylene flame has reached approximately 5,600° F, making it the hottest fuel available. However, acetylene's average *British thermal unit*, (Btu), a measure of heat production, is only 1,450 Btu. While less than MAPP® or propane, the concentration of the Btus is greater than that of the other two gases. Therefore it is more efficient—it heats up much faster than other fuels. Acetylene is ideal for cutting steel plate or for surfaces coated with grease, paint, or rust.

Not only is acetylene widely available commercially but it also uses less oxygen per cubic foot of fuel than any other fuel gas. Acetylene requires 1 unit of oxygen per 1.5 units of acetylene. This makes it an efficient gas.

Acetylene is easy to light, because it has a low *flash point*. The flash point is the amount of heat required for it to burst into flame.

Disadvantages Unfortunately, acetylene is considered a "dirty fuel." When acetylene burns, it burns with a heavy, sooty carbon smoke.

Acetylene is also quite volatile and can only be used up to a maximum 15 psi. Although it is packed with porous materials and filled half full with acetone that makes it safe, it still must be handled with great care due to its volatility.

Acetylene is also an expensive fuel gas compared to the other gases.

Tip Styles The style and size of the tip used depends on the thickness of the metal being cut and the torch manufacturer. Oxyacetylene cutting typically uses a one-piece tip. Tips for acetylene are flat on the flame end.

Oxyacetylene tips range in size to produce a variety of flame sizes. The size of the tip is marked by numbers, commonly ranging from 000 to 15. The larger the number, the larger the flame hole and the greater the heat produced. The larger the tip size, the greater amount of gases is required.

See Figure 1 for types of special cutting tips.

MPS Gas

MAPP® is the trade name of an **MPS cutting gas**. It is a specially formulated liquefied methylacetylene-propadiene gas. The gas is distributed in

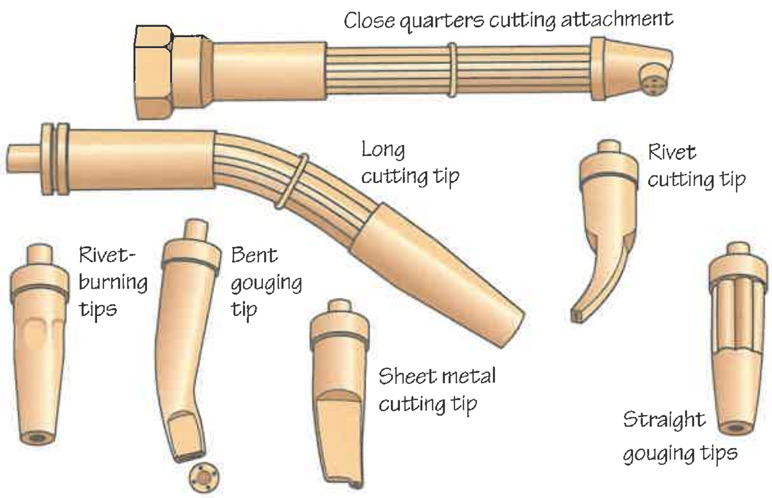


FIGURE 1
Special cutting tips

steel cylinders similar to acetylene cylinders. It is the most common of the MPS cutting gases used in the United States.

Advantages There are two main advantages MAPP® has over acetylene.

- It is less expensive than acetylene.
- It is less volatile than acetylene.

MAPP® gas can be used at pressures of up to 375 psi. Therefore, a 120-pound cylinder contains as much gas as five 240-pound cylinders of acetylene. This reduces handling expense.

Because MAPP® has a strong odor, leaks are easily detectible—even at concentrations as low as 0.01%. It is about as volatile as propane or natural gas—both of which are much less volatile than acetylene gas.

Disadvantages While MAPP® can be used at a much higher psi than acetylene, its flame temperature is 5,300° F, about 300 degrees less than acetylene's. Although MAPP®'s Btu is higher than acetylene (2,460 compared to 1,470). Therefore, it takes longer to reach working temperature. Also, more fuel and oxygen is consumed while cutting with oxy-MAPP®. MAPP® gas requires 4.0 units of oxygen per 1 unit of MAPP®.

Tip Styles The typical tip for cutting with MAPP® has a flat surface on the flame end, just like the tip for acetylene. The tip can be a single or a two-piece. See Figure 1 for types of special cutting tips.

Propane Gas

The gas called **propane** is a *hydrocarbon gas* present in petroleum and natural gas. In liquefied state, it is transported and stored in steel cylinders ranging in size from 20 to 100 pounds. Propane is widely used for oxyfuel heating, cutting, *soldering*, and *brazing*. It has a distinct smell added to it during processing that makes detecting leaks easy.

Advantages One advantage of propane over acetylene is that it costs less. It is also less volatile than acetylene.

Disadvantages While propane has a Btu of 2,400, the flame is less concentrated than acetylene and therefore it takes longer to heat metal to working temperature. Propane gas requires 4.7 units of oxygen per 1 unit of propane.

Tip Styles Propane cutting tips are typically one- or two-piece units. These tips have a deeper recess or a cupped end to direct the flame. See Figure 1 for types of special cutting tips.

Natural Gas

A mixture of combustible hydrocarbons, especially *methane*, **natural gas** has many uses for oxyfuel cutting. Because it can be safely compressed to high pressures, it is a good gas for underwater cutting.

Advantages Natural gas is widely available and can be stored in large compressed tanks or hooked directly up to city gas services. Therefore, it works well in production shops.

Natural gas is also less expensive than any of the other fuel gases. Natural gas is safer to handle and less volatile. Natural gas requires two units of oxygen per one unit of natural gas. This makes it somewhat more efficient to use than MAPP® and propane.

Disadvantages At 918 Btu, natural gas does not pack the heating power of the other fuel gases. The combined intensity of the flame is only 5,600 Btu, less than half of acetylene's. In addition, since natural gas is not available in portable cylinders, it cannot be moved from job to job.

Tip Styles Natural gas cutting tips are typically one- or two-piece units. These tips have a deeper recess or a cupped end to direct the flame. See Figure 1 for types of special cutting tips.

SELF CHECK

1. What range of cutting tip sizes is available to welders?
2. What characteristics of acetylene make it a popular fuel gas for cutting?
3. Which cutting fuel is also widely used for household appliances?

4 Cutting Torches

The oxyfuel **cutting torch** is designed to supply a fuel gas for heating flames and a stream of pure oxygen to cut the metal. Figure 2 illustrates the inner workings of a typical cutting torch.

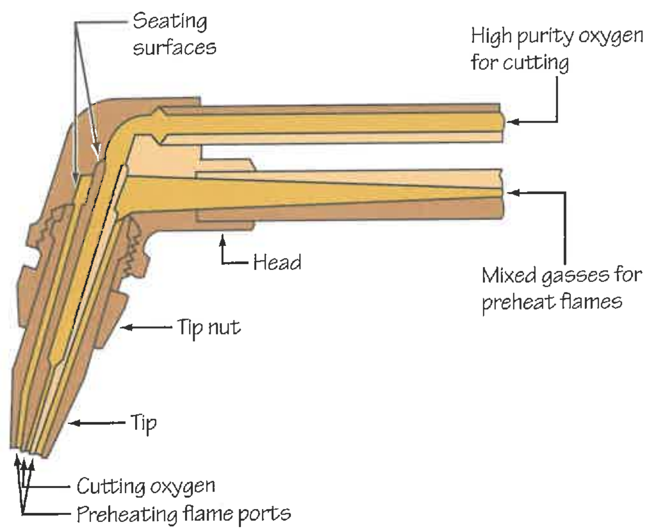


FIGURE 2
Oxyfuel cutting torch

There are a number of types of torches available and each is suitable for a particular gas or job. There are even welding/cutting torch combinations available. See Figure 3.

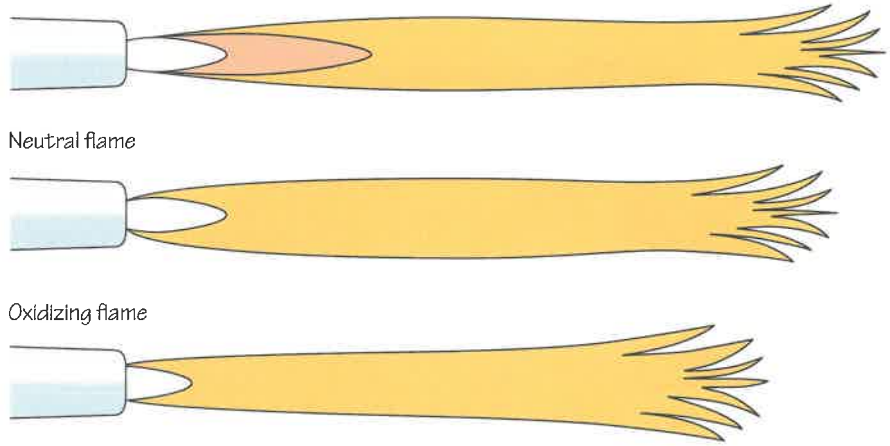
Cutting torches can produce a variety of flames. See Figure 4 for a full range of flame types.

Fuel Lines

It is important to only use the correct hose connectors on the regulator and the torch.

FIGURE 3
Combination welding/
cutting torch

FIGURE 4
Oxyfuel cutting flames



Hose Connectors To keep from mixing up the hoses, connectors, and regulators, there are different systems for oxygen and fuel gas fittings.

- The oxygen hose connectors consist of a barbed nipple that screws into the torch or regulator using a nut. The oxygen nut has a right-hand thread pattern.
- The fuel connectors use a similar setup. However, instead of a right-hand thread pattern; fuel connectors have a left-hand thread pattern.

See Figure 5 for an illustration of the left-hand and right-hand thread patterns on standard oxygen and acetylene hose connections.

Check Valves and Flashback Arrestors A condition that can affect an oxyfuel torch is gas flowing in reverse. The *check valve* and *flashback arrestor*

FIGURE 5
Hose connections

are special valves that prevent this from occurring. Check valves and flashback arrestors are similar. The check valve is used to prevent reverse flowing backwards in a hose, which is known as **backflow**. The reverse flow is stopped by the check value before it can enter the hose.

Check valves allow gas to flow in one direction only. See Figure 6. A *flashback arrestor* is a device installed at the hose/barrel connection point to stop a flashback from reaching the regulator or gas cylinder. The flashback is stopped at the flame block. It is important to use a flashback arrestor to prevent this from occurring. See Figure 7.

Valves

Torch valves and levers are used to adjust the amount of oxygen and fuel gas mixture. Figure 8 shows a standard oxyfuel cutting torch and adaptable cutting head.

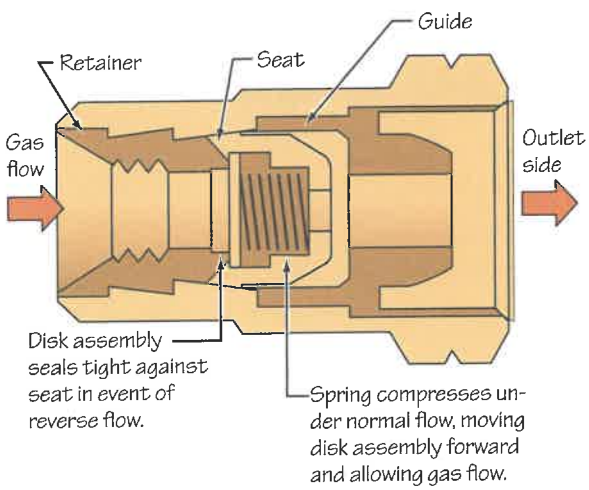


FIGURE 6
Check valve for an oxyfuel system

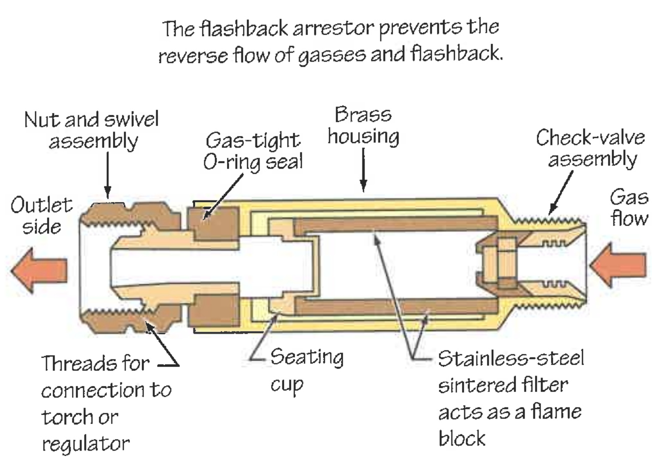
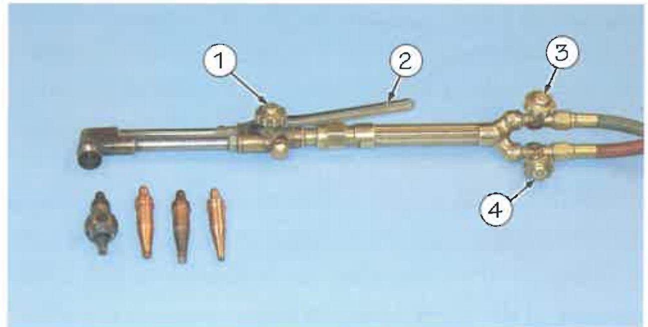


FIGURE 7
Flashback arrestor for an oxyfuel system

FIGURE 8
Oxyfuel cutting torch and adaptable head



1. Cutting oxygen control valve 2. High pressure oxygen lever
3. Oxygen preheat valve 4. Fuel preheat valve

There are three valves and one lever on the standard oxyfuel cutting torch. The cutting oxygen valve controls the amount of high-pressure oxygen coming through the base of the torch. The fuel preheat valve controls the amount of fuel gas entering the torch. The oxygen preheat valve adjusts the amount of lower-pressure oxygen used in the preheating process in the torch. The high-pressure oxygen lever controls the cutting oxygen pressure in the torch.

Using the Valves to Achieve a Neutral Flame To create a neutral cutting flame on an oxyacetylene cutting torch, follow the procedure below.

PROCEDURE

How to Achieve a Neutral Flame

1. Check that the oxygen preheat valve is closed.
2. Open the fuel preheat valve slightly, and light the torch with a friction lighter. The resulting smoky yellow flame will give off fine black soot.
3. Continue adding fuel gas until the soot mostly disappears.
4. Open the oxygen preheat valve slowly. The flame will slowly change color from yellow to blue. There will be three parts to the flame:
   - a brilliant feathery inner cone
   - a secondary cone on the edge of the inner core
   - a bluish outer envelope
5. Open the oxygen cutting valve fully. This will blur the cones.
6. Adjust the oxygen preheat valve until the bright blue cones are as bright and sharp tipped as they can possibly be. When they are as sharp and bright as they can be, a neutral cutting flame has been achieved.

SELF CHECK

1. Which hose has a left-hand thread pattern?
2. What is backflow?
3. What changes the flame size on a torch?

Torch Tips

Most tips are made of pure drawn copper since this metal rapidly loses heat. Since copper is a soft metal and the torch tips undergo much use, they must be treated with care.

Tip Selection There are a variety of tips available. Choice of tip should be based on the following qualifications:

- the type of fuel gas being used
- the type of cutting that needs to be performed
- the thickness of the metal to be cut

Consult the manufacturer's guide for the torch that being used. See Table 2 for an example of a manufacturer's guideline to tip selection.

TABLE 2

Tip and pressure selection for oxyfuel cutting

Thickness of metal in inches	Tip size number	Cutting orifice drill size	Cutting speed (I.P.M.)	Oxygen pressure (P.S.I.G.)	Acetylene pressure (P.S.I.G.)	Methylactylene-propadiene (MAPP)® (P.S.I.G.)	Propane (P.S.I.G.)	Propylene (P.S.I.G.)	Natural gas (methane) (P.S.I.G.)
Light gauge–3/16	000	#68	16–30	15–20	5–15	10	10	10	10
3/16–3/8	00	#64	14–25	20–25	5–15	10	10	10	10
3/8–5/8	0	#60	13–23	35–40	5–15	10	10	10	10
5/8–1	1	#56	10–18	35–40	5–15	10	10	10	10
1–2	2	#52	6–14	40–45	5–15	10	10	10	10
2–3	3	#48	5–11	45–50	5–15	10	10	10	10
3–6	4	#42	3–11	50–75	10–15	10	12	10	10

Keeping Tips Clean Torch tips are subject to wear, tear, and splatter. It is important to keep the torch tip clean and in good working order. A clean tip is vital for the following results:

- making a clean cut
- using less gas
- being a more productive welder

To get tips completely clean, use a tip cleaner. See Figure 9. Tip cleaners clean the outside as well as the delicate inside of the torch tip. Use the correct sized tip cleaner. A tip cleaner that is too large could accidentally increase the size of the fuel holes, and therefore change the effectiveness of the tip. A tip cleaner that is too small won't completely clean the openings.

TRADE TIP

When cleaning a torch tip, be sure to leave the oxygen valve slightly open. Then file the tip flat and use the correct size tip cleaner for the holes.

Tip reamers are used to ensure the end of the cutting tip is flat and smooth. A flat, smooth tip with clean fuel and oxygen holes will produce a flame that is even across the cutting tip. A smooth file may be used in place of a tip reamer. When using a file, make sure the tip is filed perpendicular to the flow of the gases.

Flame

The flame is a critical part of the welding process. Understanding how to start, control, and utilize flames can mean the difference between a mediocre weld and a good weld.

SAFETY TIP

Use only a friction lighter to light an oxyfuel torch.

Lighting the Torch Always light the oxyfuel torch using a friction lighter. See Figure 10. Never use matches or a butane lighter as these put the welder's hands too close to the lit flame. Also, a pack of matches or a butane lighter carried in a pocket might catch fire or explode during welding or cutting and cause serious burns.

PRODUCTIVITY TIP

Do not set fuel pressure too high. Using too much fuel and oxygen does not produce a quicker cut but wastes gases and empties the cylinders faster.

MAPP® gas, propane, and natural gas fuel torches are more difficult to light than acetylene. For these types of fuels, lay the tip of the torch against a metal plate to light with the friction lighter. The metal plate serves to concentrate the sparks and flame.

Types and Sizes of Flame Flame sizes and types vary according to the tip size, the type of fuel gas that is being used, and the fuel-to-oxygen ratio in the tip. Figure 11 shows the difference in Btu concentration between the acetylene flame and the flame of other gases.

FIGURE 9
Tip cleaner

FIGURE 10
Triple-flint torch friction lighter

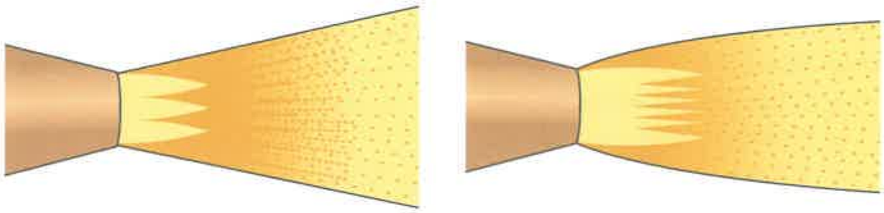


FIGURE 11
Btu concentration of the oxyfuel flame

Flames can be adjusted to perform different cutting functions. These adjustments are made by varying the oxygen-to-fuel ratio. Figure 4, earlier in this chapter, shows the different kinds of oxyacetylene flames and how they are used.

There are three basic types of cutting flames: neutral, carburizing, and oxidizing.

1. The *neutral flame* is the correct flame for efficient cutting. This flame is approximately 5,100° F to 5,600° F, depending on fuel.
2. The *carburizing flame* contains an excess of acetylene. It is not as hot as the neutral flame.
3. The *oxidizing flame* contains an excess of oxygen. While it reduces preheating time, it is used only for rough work.

Flame Temperature Flame temperatures vary according to the fuel gas being used. Table 3 shows the gas efficiencies for various fuel gases.

TABLE 3
Various fuel gas efficiencies

Fuel gas	Btus (ft^3)	Combined intensity (suitable heat) Btu (s/ft^2 of flame cone area)	Flame temperature	Oxygen per ft^3 of fuel	Approx. normal velocity (ft/s)
Acetylene	1,433	12,700	5,420° F	1.04	17.7
MAPP®	2,381	5,540	5,301° F	2.4	7.9
Propane	2,309	5,500	5,190° F	4.00	11.9
Natural gas	918	5,600	5,000° F	1.50	15.2
Hydrogen	275	7,500	4,600° F	0.25	36

Flame temperatures can be adjusted higher or lower for any oxyfuel combination by adjusting the fuel-to-oxygen ratio. An oxidizing flame, that is, a flame that contains a higher proportion of oxygen than fuel gas, burns hotter than a neutral flame. This is the case no matter what fuel gas is used.

An experienced welder can tell by looking at the shape and color of the flame what the approximate temperature of the flame is. Refer to Figure 4 to view different kinds of flames for an oxyacetylene flame.

5 Cutting With Oxyfuel

When metal cutting needs to be done, there are several factors the welder must determine.

- What is the metal to be cut?
- How thick is the metal?
- What is the best fuel gas for this job based on the previous two answers?

Once these factors are determined and the appropriate fuel gas is chosen, it is time to begin cutting.

Before the Cut

The first thing the welder needs to do is to prepare the metal to be cut by preheating it.

Preheating the Metal Preheating is accomplished by lighting the torch, achieving a neutral flame and directing the heat to the initial cutting location. Once the ignition temperature of the metal is reached, usually when it turns a bright cherry red color, it is time to apply the oxygen for cutting by depressing the high pressure oxygen lever.

Positioning the Torch It is important to hold the torch in the correct position. See Figures 12 and 13 for correct torch position. Remember, the fuel gas flame heats the metal while the oxygen stream does the cutting. The flame must travel first along the area to be cut followed by the oxygen stream.

FIGURE 12
Correct torch position for cutting, view 1

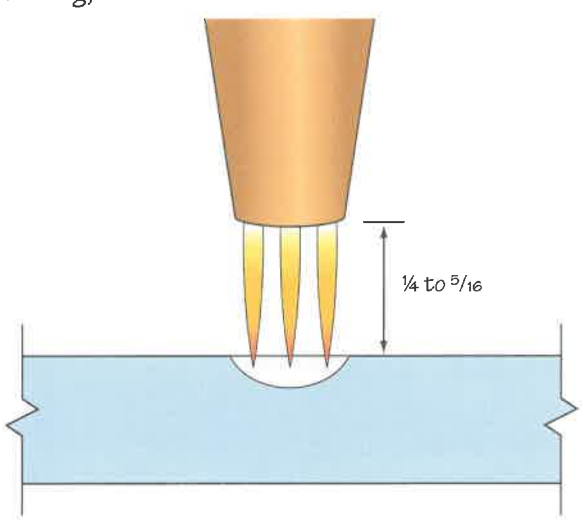
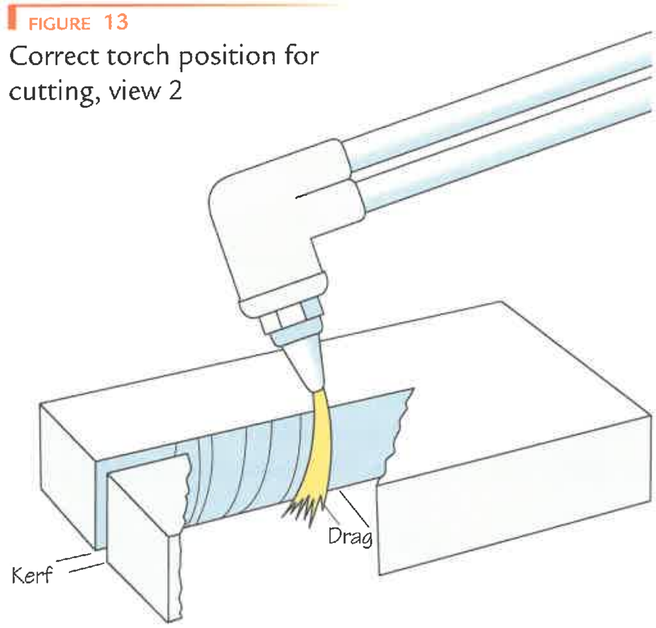


FIGURE 13
Correct torch position for cutting, view 2



Cutting Terminology

Cutting can involve many angles and types of cuts. These are terms that a welder needs to know to describe cuts and their characteristics.

Kerf The **kerf** is the width of the cut.

Draglines *Draglines* are lines that appear on the oxygen-cut surface. Their contours and directions do not affect the quality of the cut surface.

Roughness The term *roughness* is used to mean the recurring peaks and valleys in the oxygen-cut surface. This can be determined by samples of acceptable quality or by comparison to the AWS C4.1 Surface Roughness Guide for Oxygen Cutting.

Top Edge Rounding When the welder melts the top edge of an oxygen-cut surface it is known as *top edge rounding*.

Notch A *notch* is a gouge in an oxygen-cut surface that is significantly deeper than the overall surface roughness.

Troubleshooting Oxyfuel Cutting

Figure 14 shows examples of oxyfuel cuts. Their defects are listed below.

(A)

FIGURE 14
(A) Proper mixture creates a good cut
(B) Too much oxygen in mixture
(C) Too much acetylene in mixture

(B)

(C)

SELF CHECK

1. Why is it important to use the correct-sized tip cleaner?
2. What can happen if the flame isn't hot enough?
3. What happens if a cut is made too slowly?

Summary

Oxyfuel cutting is used to cut straight shapes and to scrap obsolete ferrous metal. A variety of fuel gases is available. Choosing the right one to use depends on the type of metal to be cut. Acetylene gas is the most widely used fuel gas in oxyfuel cutting.

CHAPTER Review

Oxyfuel Cutting QUESTIONS

Show your understanding of the information in this chapter by answering the questions and filling in the blanks below.

1. Oxyfuel cutting is used on ________________ metals.

   ____

2. _____ has the lowest flash point.
   a. Acetylene
   b. MAPP®
   c. Propane
   d. Natural gas

3. _____ is preferred for underwater cutting.
   a. Acetylene
   b. MAPP®
   c. Propane
   d. Natural gas

4. The oxygen hose end has a left-handed thread. (True; False)

5. A(n) ________________ ________________ should be used to light a torch.

6. Under certain circumstances, matches can be used to light MAPP® gas. (True; False)

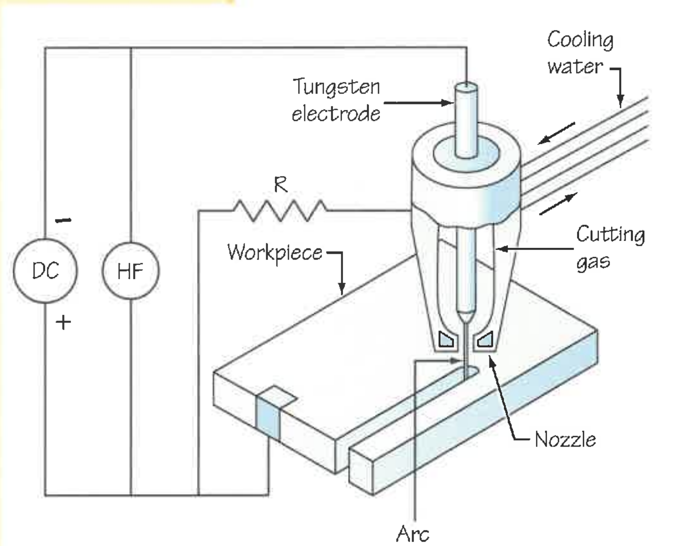
7. What flame type most efficiently cuts steel? ________________

8. An oxidizing flame can only be used for ________________ cutting.

CHAPTER 7

Plasma Arc Cutting

CONTENTS



INTRODUCTION

Since its introduction in 1955, plasma arc cutting has filled an important role in metal cutting. Unlike oxyfuel cutting, which relies on metal oxidation to perform cutting, plasma arc cutting is capable of cutting nonferrous metals, such as aluminum.

Plasma arc cutters work by using a high-voltage electrical arc and a compressed gas, usually air. An electrical arc is generated by an internal electrode that ionizes the gas passing through the nozzle thus creating a concentrated arc of plasma at the cutter's tip. The arc's contact with a metal surface makes a high heat circuit that melts a section less than 1⁄16″ wide. The force of the plasma flow then literally blows out the molten area on the workpiece, creating a fairly clean cut with little or no slag. The plasma arc travels through the nozzle at a speed of up to 20,000′-0″ per second, and at temperatures as high as 30,000° Fahrenheit (F).

KEY TERMS

Key Terms are in order of appearance.

plasma arc cutting or **plasma cutting** use of electricity to change the structure of the metal while directing forced air to oxidize the metal

ferrous containing iron

nonferrous not containing iron

plasma fourth state of matter; atoms are electrically charged in this highly heated state

kerf width of the cut

cutting gases (in plasma arc cutting) compressed air, nitrogen, hydrogen, oxygen, argon, or a mix of these

OBJECTIVES

Upon successful completion of this chapter, the participant should be able to:

1. Describe the safety aspects of plasma arc cutting.
2. Demonstrate an understanding of how the plasma arc cutting process works.
3. List the metals that can be cut with this process.
4. List the power sources and describe their capacities.
5. Describe the role compressed air plays.
6. Explain how the ground works.
7. Demonstrate an understanding of the torch used.
8. Identify cutting techniques.
9. Describe troubleshooting techniques.

1 Plasma Arc Cutting Safety

Plasma arc cutting has the same hazards that oxyfuels cutting has: fires, burns, slag, etc. However, plasma arc cutting carries special hazards in the form of electric shock, fumes and gases, noise, and non-ionizing radiation.

Personal Protection Equipment

It is important to wear approved clothing and accessories when plasma cutting.

- Wear dry, leather gloves that have no tears or holes.
- Wear protective garments such as a heavy shirt, cuffless pants, high shoes or pull-on boots or boots with leather laces, and a cap.
- Wear approved safety goggles with side shields in addition to wearing a shaded welding hood or helmet with a shade rating of 10.
- Use approved helmets that protect the face, neck, and ears.
- Wear leggings, aprons, sleeves, shoulder covers, and bibs.
- Wear flame-resistant earplugs, protective earmuffs, or both to keep sparks out and to protect hearing.
- Remove all flammable objects, such as butane lighters and matches, from pockets.

Metal Fumes and Gases

Metal fumes and gases are by-products of most welding processes. Metal *fumes* are solid particles originating from welding consumables such as coated electrodes, the base metal, or any coatings on the base metal. The amount and makeup of these fumes depends on several factors such as composition of filler and base material and the type of cutting process being used.

Coated metals present a greater health hazard than noncoated materials. Always ask the supervisor for specific safety related issues or consult a Safety Data Sheet (SDS) if applicable, before starting.

Care must be taken to avoid contact with these by-products as they pose a health risk. Several things can be done to avoid exposure to fumes and gases.

- Position the head to avoid the fume plume.
- Do not breath fumes or gases.
- Make sure the working area is well-ventilated.
- If the area cannot be adequately ventilated, wear an appropriate respirator.

SAFETY TIP

If safety questions arise about a material being worked with, consult its Safety Data Sheet (SDS).

Non-Ionizing Radiation

Plasma arc cutting generates intense *non-ionizing radiation*. There are three types of non-ionizing radiation: visible, infrared and ultraviolet.

The welder can see the visible radiation in the form of light but infrared and ultraviolet cannot be seen. Infrared and ultraviolet light, along with visible light, are present when most welding processes are conducted. Non-ionizing radiation can cause eye damage and skin burns. Eye protection should be at the level recommended by the American Welding Society in Table 1.

TABLE 1

Recommended eye protection for plasma arc cutting

Cutting current amperes	Lens shade number
Up to 300	9
300–400	12
400–800	14

Choosing a Shade Number for Comfort A welder can determine if the right shade is being used. The welder should find something to read at a distance, but not so far that it causes eye strain. Then he or she should weld for about 15 minutes and return to the same location. If the welder then strains to read, the lens may be too dark. If the welder sees a light dot while trying to read, then the lens may be too light.

Electrical Safety

Plasma arc cutting uses voltages ranging from 15 to 400 volts direct current (DC). To avoid electric shock, the safety precautions below should be followed.

1. Keep all electrical circuits dry.
2. Keep all electrical ground connections mechanically tight.
3. Use high-voltage cable; make sure the cable is in good repair.
4. Do not touch live circuits.
5. When replacing torch parts, make sure that all power to control circuitry is disconnected
6. Always practice safe cutting techniques.

In addition to the rules listed above, always use the ground cable properly. Place the ground cable as near to the work as possible. Placing the ground cable on the work itself is the best practice, if this is possible. Make sure the clamp is firmly attached to the ground surface. Electrocution could occur if the ground clamp slips off while cutting is being performed. Remember, the ground cable is there to protect the welder from being electrocuted.

2 What Is Plasma Arc Cutting?

The use of **plasma arc cutting**, or **plasma cutting**, is relatively recent cutting technique that uses a concentrated arc and removes the molten metal with a high velocity jet of ionized gas issuing from the constricting orifice. Plasma arc cutting is capable of cutting **ferrous** metals, those containing iron, and **nonferrous** metals, such as aluminum, using a high-temperature *arc stream*. **Plasma** is the fourth state of matter. The other three states are solid, liquid, and gaseous. In this superheated plasma state, gas atoms are moving around at such a rate that they take on an electric charge. The electric arc used for cutting is maintained by this plasma gas.

Plasma arc cutting can utilize several gases including argon, nitrogen-oxygen, and nitrogen-hydrogen and argon-hydrogen mixes. Regular compressed air can also be used.

The high-pressure gas flows through the arc in the nozzle where the gas is ionized in the torch by heating it to approximately 25,000° F. At this temperature, the gas reaches a plasma state. Then it is forced through the small torch nozzle at a speed of up to 20,000′-0″ per second. This hot gas can melt any metal, ferrous or nonferrous.

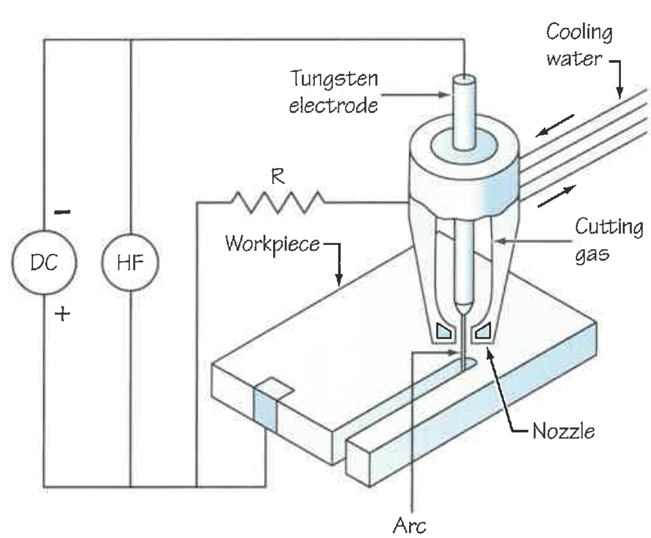
To maintain maximum transfer of heat to the work, both the metal being cut and the torch act as electrodes in the electric circuit. Figure 1 presents a schematic diagram of the equipment.

Cutting Metals

Plasma arc cutting was developed specifically to cut nonferrous metals like aluminum and manganese. As noted above, however, plasma arc cutting works on any known metal. Plasma arc cutting results in slag-free cuts on carbon and stainless steels, nickel, Monel®, Inconel®, cast iron, clad steels, aluminum, copper, and magnesium.

Metals up to 5″ thick can be cleanly cut using plasma arc cutting. Most cuts using plasma arc cutting are so clean that no additional machining is required. In addition, these cuts will have a narrow **kerf** and the metal

FIGURE 1
Plasma arc cutting equipment



will suffer no distortions. Plasma arc cutting is also fast, cutting as much as 300″ per minute is possible.

SELF CHECK

1. Why is it important to protect from electric shock when plasma arc cutting?
2. How hot are the ionized gases when they leave the torch?

3 Plasma Arc Cutting Equipment

Several manufacturers make plasma arc cutting machines. No matter who manufactures the machine, plasma arc cutters need two things to function: compressed gas and electricity.

Plasma Arc Cutting Machines

Most portable plasma arc cutters simply use ordinary air for the compressed gas. Plasma arc cutting machines are versatile and can use whatever gas is best suited for the job. Some plasma arc cutters come with a built-in air compressor, which cuts down on cylinder handling costs.

Determining the capacity of a plasma arc cutter should not be based on the unit's amperage. Plasma machines use relatively low amperage but high voltage. Refer to each manufacturer's unit specifications to determine the maximum size metal that can be cut based on the plasma arc cutter's amperage/voltage rating.

Plasma cutters can work off household current or generators at remote work sites. So long as the voltage stays within the manufacturer's recommended range, the machine should operate smoothly.

Plasma cutters are not complicated to operate. Follow the procedure below to operate a plasma arc cutter.

PROCEDURE

How to Operate a Plasma Arc Cutting Machine

1. Read the owner/operator manual before using a machine for the first time.
2. Plug in the unit.
3. Choose the correct amperage based on the thickness of the metal to be cut.
4. Place the ground clamp near or on the work itself.
5. Use either a high-frequency start or a contact start to create the arc, depending on the machine.
6. Begin the cut.

Compressed Gases

Plasma arc cutters are versatile when it comes to the compressed cutting gases they can use. Plasma arc cutters use compressed air, nitrogen, hydrogen, oxygen, argon, or a mix of these as **cutting gases**. Ordinary air works well for most tasks. However, certain gases do work better with certain metals in plasma arc cutting activities. To cut aluminum, stainless steel, and other nonferrous metals, a nonferrous gas should be used. Nonferrous gases include argon-hydrogen and nitrogen.

To cut carbon steel, cast iron, and some alloy steels, an oxidizing gas is required. The oxidizing gas will provide additional heat from the iron-oxygen reaction. Nitrogen, oxygen, or regular compressed air is useful for these metals.

Table 2 lists the typical conditions for plasma arc cutting of carbon steel. Note the speeds at which the plasma leaves the torch.

TABLE 2

Typical conditions for plasma arc cutting of carbon steel

Thickness		Speed		Orifice diameter[1]		Current (DCEN) (A)	Power (kW)
Inches	Millimeters	Inches/ minute	Millimeters/ minute	Inches	Millimeters		
¼	6	200	86	⅛	3.2	275	55
½	13	100	42	⅛	3.2	275	55
1	25	50	21	5/32	4.0	425	85
2	51	25	11	3/16	4.8	550	110

[1] Plasma gas flow rates vary with orifice diameter and gas. The equipment manufacturers should be consulted for each application.

SELF CHECK

1. What was plasma arc cutting specifically developed to do?
2. What kinds of metals can the plasma arc cut?

Plasma Arc Cutting Torches

Plasma arc cutting torches are specifically designed to accommodate the high-speed plasma gases and the intense heat they produce. The very nature of plasma arc cutting requires that the torch be held very near the work—no farther than ⅛″ above it for thick metals—while the torch is dragged along. Some plasma torches are equipped with a *drag shield*, which supports the torch on the work as the torch is dragged along the area to be cut. This provides more stability for the welder.

Figure 2 illustrates the parts of a typical plasma arc torch and its inspection points.

SAFETY TIP

Wear approved safety goggles or glasses with side shields and a welding hood, with a shade rating no less than 10.

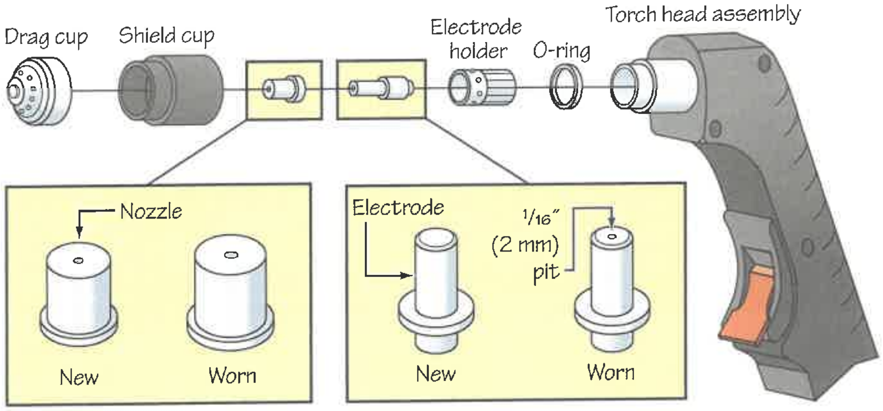


FIGURE 2
50- to 80-amp plasma arc torch

In addition to the drag shield, there is a tip called a *gouge tip* that is also useful in plasma arc cutting. Gouge tips are especially useful in edge preparation and for removing tack welds, welded braces, or defective welds. Gouge tips work by reducing the arc stream velocity. The lower-velocity arc stream forms a softer, wider arc while still maintaining the correct stream velocity. The torch angle and the speed of travel determine the gouging depth.

PRODUCTIVITY TIP

Use of a template or cutting guide can speed up the work.

4 Plasma Arc Cutting

The amperage setting on the plasma arc cutting machine will be determined by the type and thickness of the metal to be cut. Once the correct amperage is set, the only variables left are torch position and travel speed. Some torches can be dragged directly on the metal while others need to be positioned slightly above it. Be sure to check the manufacturer's recommended practices before starting a job.

For the cutting sequence, see Figure 3. Note that the torch takes a few seconds to light after the trigger is depressed. The torch also continues to flow some 30 seconds after the trigger has been released. These two characteristics must be accounted for by the welder to successfully cut metal.

See Table 3 for recommended current and air pressure flow rate settings based on metal thickness. Always remember to consult the manufacturer's recommendations.

TABLE 3
Plasma arc cutting settings based on job thickness

Metal	Thickness (inch)	Minimum output rating	Minimum air pressure and flow rate
Carbon steel	⅜	25 A @ 90 V	60 psi @ 4.5 ft^3/min
Carbon steel	⅜	50 A @ 110 V	70 psi @ 5.3 ft^3/min
Carbon steel	¼	50 A @ 110 V	70 psi @ 5.3 ft^3/min
Carbon steel	¼	25 A @ 90 V	60 psi @ 4.5 ft^3/min

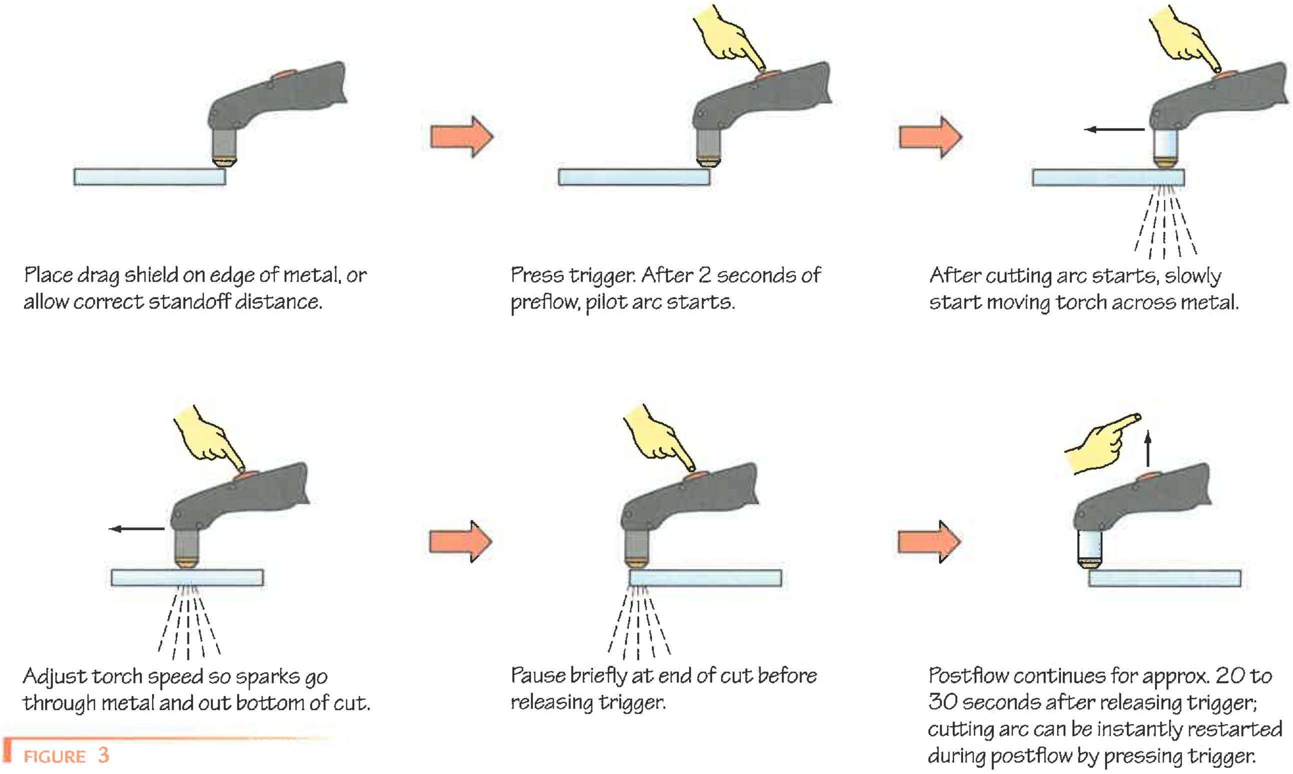


FIGURE 3
Plasma arc cutting sequence

The heads on most plasma arc cutting torches are large, which makes it difficult to see the cut line. It is advisable to use a template or positioning bar to guide the torch while cutting. Using guides or templates can speed up work as well, since the welder does not have to constantly stop and check the cut.

SELF CHECK

1. What are the two main factors that determine the quality of a plasma arc cut?
2. At what distance should a torch be held from the work to gain maximum cutting force?

5 Troubleshooting

Typical problems that show up in plasma arc cutting are curvy or irregular draglines, heavy slag on bottom of the kerf, a kerf that has a melted top edge, and more. These problems can be remedied with power and speed adjustments. See Figure 4 for specific remedies to stated problems with plasma arc cutting.

Plasma Arc Cutting Troubleshooting

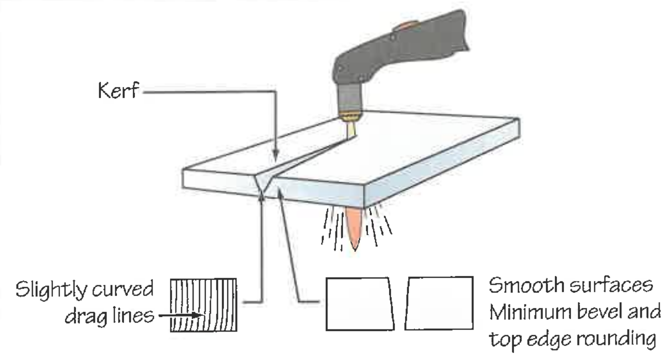
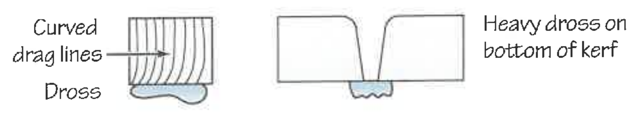
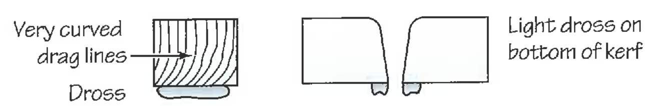
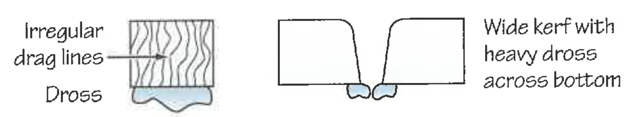
<table>
<tr><th>Problem</th><th>Correction</th><th>View</th></tr>
<tr><td>Acceptable cut</td><td>• Minimum beveling of edges
• Minimum top edge rounding
• Smooth surface, minimal or no grinding required
• No dross
• Kerf approximately 1 ½–2 times orifice diameter</td><td>
</td></tr>
<tr><td>Top edge of kerf melted and rounded, heavy dross on bottom of kerf easily removed.</td><td>• Increase travel speed.
• Reduce power level and maintain current speed.</td><td>
</td></tr>
<tr><td>Drag lines very curved, dross on bottom of kerf hard to remove. Cut not completely through part.</td><td>• Decrease travel speed.
• Increase power level.</td><td>
</td></tr>
<tr><td>Wide kerf, irregular drag lines, rough cut and heavy dross on bottom of kerf.</td><td>• Check tip and electrode for wear, clean and or replace.
• Check standoff distance (too far away likely)</td><td>
</td></tr>
</table>

FIGURE 4
Troubleshooting

Summary

Plasma arc cutting fills an important metal-cutting role in many different industries. Plasma arc cutting can cut not only ferrous metals, but also nonferrous metals, such as stainless steel and aluminum. The only requirement for plasma arc cutting is that the metal to be cut must be capable of conducting electricity. Combining electricity with compressed gases allows plasma arc cutting to occur.

Plasma Arc Cutting QUESTIONS

Show your understanding of the information in this chapter by answering the questions and filling in the blanks below.

1. Goggles should have a shade rating of ______________ for plasma arc cutting.

2. ____ ionizes the gas in plasma arc cutting.
   a. A portable proton pump
   b. Electricity
   c. The compression generator
   d. Contact with a nonferrous metal, such as aluminum

3. A drag shield helps steady the cutting process. (True; False)

4. What two factors determine the proper current setting for plasma arc cutting?

   ____

   ____

5. The two types of starts used for begin a plasma arc are ______________ ______________ and contact.

6. To cut carbon steel and cast iron, a(n) ______________ gas, such as oxygen, must be used.

7. If cutting draglines are very curvy, size of tip should be adjusted. (True; False)

8. A gouge tip works by increasing stream velocity. (True; False)

9. Plasma arc cutting machines typically run on ____.
   a. high amps and high volts
   b. low amps and high volts
   c. high amps and low volts
   d. low amps and low volts

CHAPTER 8

Carbon Arc Cutting (CAC-A)

CONTENTS

INTRODUCTION

Carbon arc cutting (CAC-A) melts the work with an electric arc and blows away the molten metal with a jet of compressed air. Unlike oxyfuel cutting, this process does not depend on oxidation; therefore it works on virtually all metals. Because there is a lot of molten material that is blown out of the cuts created by the electric arc, safety is of prime concern when utilizing this process.

KEY TERMS

Key Terms are in order of appearance.

ozone gas by-product of carbon arc cutting

nitrogen dioxide gas by-product of carbon arc cutting

carbon monoxide gas by-product of carbon arc cutting

carbon arc cutting (CAC-A) electric arc between the carbon electrode and the parent metal melts the metal; the molten metal is blown away with a jet of compressed gas, usually air

duty cycle length of time that a machine can run at full capacity in 10-minute increments

alternating current (AC) electric current that reverses direction at regular intervals

ferrous metal metal containing iron

nonferrous metal metal that contains little or no iron

direct current (DC) electric current that flows in a constant direction

OBJECTIVES

Upon successful completion of this chapter, the participant should be able to:

1. Demonstrate an understanding of the safety issues associated with carbon arc cutting.
2. Describe where and when to use this method.
3. Demonstrate an understanding of the power supply.
4. Explain the machine's duty cycle.
5. Explain how to set the machine up.
6. Describe the torches used.
7. Identify the types of electrodes to use.
8. Describe the washing and cutting procedures.

1 Carbon Arc Cutting Safety

To prevent contact with sparks and flying particles, welders should wear the following personal protection gear.

- Wear dry, leather gloves that have no tears or holes
- Wear protective well-fitting garments such as a heavy shirt, cuffless pants, high shoes or pull-on boots or boots with leather laces, and a cap.
- Wear approved safety goggles with side shields in addition to wearing a welding hood or helmet with a shade rating no less than 12.
- Use approved helmets that protect the face, neck, and ears.
- Wear leggings, aprons, sleeves, shoulder covers, and bibs.
- Wear flame-resistant earplugs, protective earmuffs, or both.

Fumes and Gases

Carbon arc cutting produces metal fumes and a number of gas by-products. The metal fumes can be controlled through natural ventilation, local exhaust, or by the welder wearing respiratory protective equipment. It is important for the welder to stay out of the smoke plume.

The gases that are a by-product of carbon arc cutting include **ozone**, **nitrogen dioxide**, and **carbon monoxide**. These gases are hazardous when breathed in high enough concentrations, so it is especially important to observe all ventilation safety rules when using carbon arc cutting.

Welding coated metals presents a greater health hazard than welding non-coated materials. Always ask the supervisor for specific safety related issues or consult a Safety Data Sheet (SDS) if applicable, before starting.

Ozone The ultraviolet light emitted from the arc interacting with the surrounding oxygen produces ozone. The amount of ozone produced depends upon the amount of ultraviolet light and the humidity, among other things.

Nitrogen Dioxide High concentrations of nitrogen dioxide are found only very close to the arc. It is important for the welder to stay away from the fumes. It is important to have good ventilation when using carbon arc cutting.

Carbon Monoxide A small amount of carbon monoxide will be produced in high concentrations between 3″ and 4″ from the welding plume. With good ventilation, this gas will dissipate quickly enough to not cause harm to the welder. In whatever welding circumstances, good ventilation is essential. Welders should always avoid the plume.

Sparks

Sparks present a special problem with carbon arc cutting due to the process of removing molten metal. The compressed gas can spread sparks up to 35′-0″

away. Any combustible material within the 35′-0″ range should be removed. If that is not possible, metal screens should be placed in the direction of the spark spray.

Electrical Safety

Carbon arc cutting uses voltages ranging from 35 to 55 volts. To avoid electric shock, these safety precautions should be followed.

- Keep all electrical circuits dry.
- Keep all electrical ground connections mechanically tight.
- Use high-amperage cable; make sure the cable is in good repair.
- Do not touch live circuits.
- When replacing torch parts, make sure that all power to control circuitry is disconnected.
- Always practice safe welding techniques.

In addition to the rules listed above, always use the ground cable properly. Place the ground cable as near to the work as possible. Placing the ground cable on the work itself is the best practice, if this is possible. Make sure the clamp is firmly attached to the ground surface. Electrocution could occur if the ground clamp slips off while cutting is being performed. Remember, the ground cable is there to protect the welder from being electrocuted.

SELF CHECK

1. What are some specific dangers associated with carbon arc cutting?
2. What are some precautions the welder should take?

2 What Is Carbon Arc Cutting?

In **carbon arc cutting** (CAC-A), an arc is struck between the carbon electrode and the metal to be cut. When this occurs, the metal melts immediately, and the molten metal is blown out of the cut by a blast of compressed air. This compressed air blows continuously, behind the arc. The compressed air is provided by a compressor. The typical psi requirement to assure a clean cut is between 40 and 125.

Figure 1 shows a typical carbon arc cutting equipment setup.

FIGURE 1
Typical CAC-A setup

The carbon arc cutting process is used in steel foundries to remove casting defects and it is also used in metal fabrication. The process is good for removing weld defects and cleaning out the roots of welds. It can also widen grooves of welds that have pulled together. It is also useful to make U-grooves in plates.

Carbon arc cutting is also used to prepare metal parts for repair welding. This process is good for all carbon, manganese, stainless steels, copper and nickel alloys, cast iron, and other hard metals.

3 Power Sources

Standard welding power sources work for the carbon arc cutting process. The arc voltages used in this process range from 35 to 55 volts. The actual arc voltage is governed mostly by the size of the electrode and the application. Common amperage varies from 200 to 600 amps.

Be sure the manufacturer's power supply approves the use of their machine with carbon arc gauging before setting up the equipment.

Direct current electrode positive (*DCEP*) is the most common polarity; it is also called *reverse polarity*. However, *direct current electrode negative* (*DCEN*), also called *straight polarity*, can also be used, as can alternating current (AC). The electrode used must match the polarity of the power source.

Machine Duty Cycle Requirements

A **duty cycle** is how long a machine can run at full capacity in ten-minute increments. Therefore, if a machine has a 30 percent duty cycle, it can run at full power for three minutes and must then be cooled for seven minutes before work begins again.

Some welders will purchase a more powerful machine than they actually need just to be able to get 100 percent duty cycle from the lower amperage.

When using a carbon arc cutting machine, be sure to read the manufacturer's specifications on that machine before starting work. Pushing a machine beyond its rated duty cycle can permanently damage the machine.

4 Carbon Arc Cutting Equipment

Carbon arc cutting uses compressed air along with an electrode holder, often called a torch, and a variety of electrodes.

SAFETY TIP

The combination of compressed air and electrical noise created by the use of a carbon electrode requires the use of earplugs, earmuffs, or both.

Compressed Air Supply

The air supply used in carbon arc cutting is supplied by an air compressor. Most welding applications use from 40 to 125 psi. The air pressure should be sufficient to provide a clean, slag-free cut.

Torches

Torches for carbon arc cutting come in manual and mechanized varieties. Manual torches are similar to heavy-duty shielded metal arc welding (SMAW) holders. Figure 2 shows a typical 400-amp manual carbon arc cutting electrode holder.

These manual torches are held so that the compressed air is underneath the electrode. Figure 3 shows the typical torch setup for carbon arc cutting.

Types of Torches Torches are broken up into use categories: light-duty, general-purpose, heavy-duty, and mechanized.

- Light-duty torches are for use in small shops with limited air supply. These torches use a maximum of about 450 amps D.C. The hoses and fittings for light-duty torches should have an inside diameter (i.d.) of ¼″.
- General purpose torches are used in fabrication shops and for general maintenance. They are limited to 1,000 amps. Hoses and fittings for general-purpose torches should have a minimum i.d. of ⅜″.
- Heavy-duty torches are for high-amperage work in fabrication shops. These torches are limited to 1,600 amps with air-cooled cables and 2,000 amps with water-cooled cables. Hoses and fittings for heavy-duty torches should have a minimum i.d. of ⅜″.
- Mechanized torches are used in high-production applications. They are used with 5⁄16″ through ¾″ jointed carbons. Mechanized torches require fittings and hoses with an i.d. of ½″.

FIGURE 2
Carbon arc cutting torch

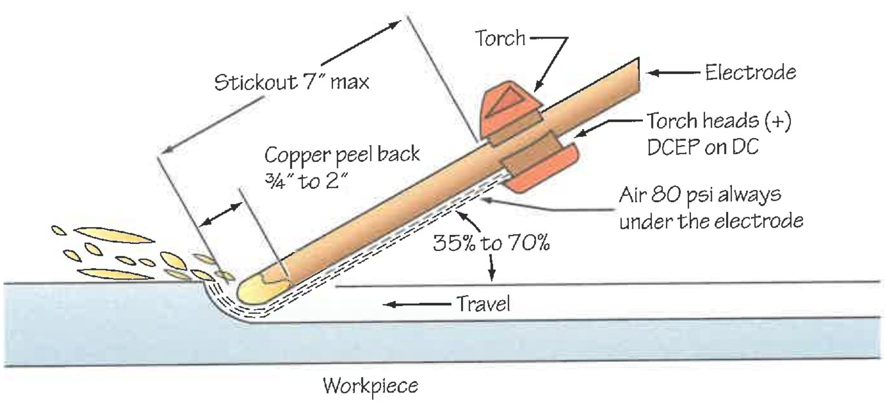


FIGURE 3
Torch setup

8 CAC-A

SELF CHECK

1. What directly removes the molten metal from cuts in carbon arc cutting?
2. What indirectly removes the molten metal from cuts in carbon arc cutting?
3. What kind of air is used in carbon arc cutting?

Electrodes

Three types of electrodes are used in carbon arc cutting. These are DC copper-coated, DC plain, and AC copper-coated. These electrodes are commonly round, but flat and half-round are available to produce rectangular grooves or wash wide areas. **Direct current** (AC) is electric current that flows in a constant direction. **Alternating current** (AC) is electric current that reverses direction at regular intervals.

DC Coated Electrodes These electrodes are the most commonly used in carbon arc cutting. They have a long life, possess stable arc characteristics and make a uniform groove. They are made of a special carbon and graphite mixture. They are coated with a specific thickness of copper. They are available in diameters ranging from ⅛″ to ¾″.

DC Plain Electrodes This type of electrode is not commonly used. They are called "plain" because they have no copper coating. They are used up much more quickly than the coated electrodes. Plain electrodes are available from ⅛″ to 1″.

AC Coated Electrodes These electrodes are made from a combination of graphite and carbon with rare-earth materials added that provide arc stabilization when cutting with alternating current (AC). These electrodes are coated with copper and are available in diameters of 3⁄16″ to ½″. When in use, these electrodes should stick out no more than half of the rod length from the torch.

SELF CHECK

1. What is the maximum length an electrode should protrude from the torch?
2. How many types of electrodes are available in carbon arc cutting?

5 Procedures

Two common functions performed in carbon arc cutting are cutting and washing.

Carbon Arc Cutting

For carbon arc cutting of **ferrous metals**, the electrode should protrude from the torch no more than half the length of the rod. For **nonferrous**

metal, only 3″ should protrude from the torch. Follow the procedure outlined below to use carbon arc equipment for cutting.

PROCEDURE

How to Perform Carbon Arc Cutting

1. Turn on the air jet before striking the arc.
2. Hold the torch as illustrated in Figure 4.
3. Strike the arc by touching the open or blunt end of the electrode to the work.
4. Do not draw back the electrode once the arc is struck.
5. Maintain a short arc and move quickly enough in the direction of the gouge to maintain metal removal.

Quick removal of thin layers of metal maintains a better cut. The smoothness of the cut depends upon steady progression.

A 35° push angle from the surface of the work usually works well. A smooth hissing sound in the arc indicates a good angle and good travel speed.

When cutting a vertical workpiece, work from top to bottom so that gravity assists with metal removal. The welder should hold the torch and electrode in such a manner to prevent molten metal from falling on him or her. Cutting horizontally can be done either to the left or right but always in the forehand direction.

The depth of the cut is controlled by travel speed. Slow speeds produce deep grooves, and fast speeds produce shallow grooves. Grooves up to 1″ deep can be made, but this requires an experienced operator. The width of the groove is determined by the size of the electrode. Usually the groove is ⅛″ wider than the electrode diameter.

SAFETY TIP

Arc cut in well-ventilated areas or wear appropriate PPE.

PRODUCTIVITY TIP

Only open the air jet control on the air arc torch enough to clear the molten metal from the cutting area. Opening the air jet control 100 percent causes the molten metal to be spread over more of the work area.

TRADE TIP

A 35° push angle from the surface of the work usually works well.

TRADE TIP

A smooth hissing sound in the arc indicates good angle and good travel speed.

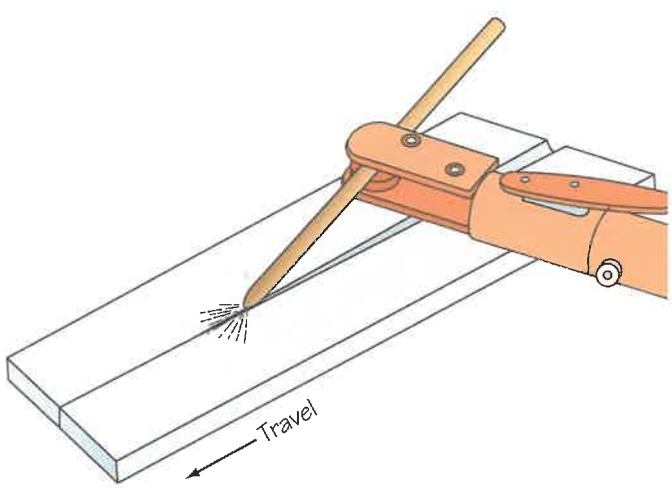


FIGURE 4
Manual CAC-A in the flat position

Washing

A process called *pad washing* is used to remove metal from large areas. Figure 5 shows the correct technique to employ this procedure.

PROCEDURE

How to Perform Pad Washing

1. Turn on the air jet before striking the arc.
2. Hold the torch as illustrated in Figure 5.
3. Strike the arc by touching the open, or blunt, end of the electrode to the work.
4. Oscillate the electrode from side to side while pushing forward to remove a thin layer. Repeat this process until the desired depth is reached.
5. Hold the electrode at between a 15° angle and a 70° angle to the work. The 15° angle is best for lighter work and up to a 70° angle for deeper cutting.

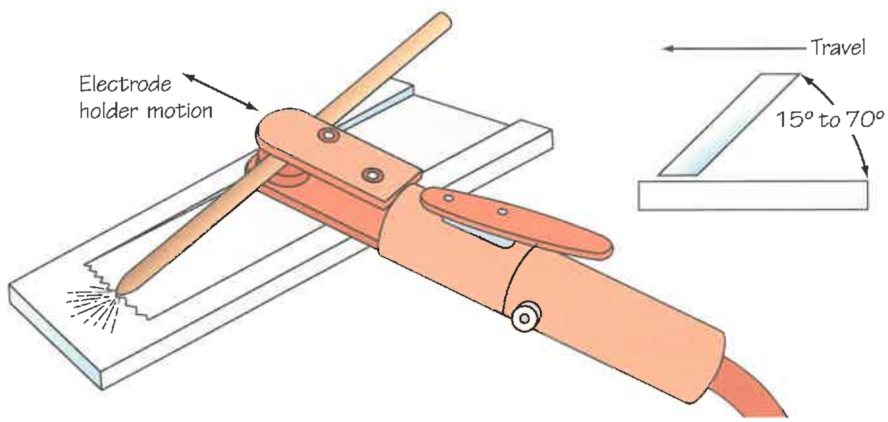


FIGURE 5
Pad washing technique

Summary

Carbon arc cutting melts the work with an electric arc and blows away the molten metal with a jet of compressed air. This process works on virtually all metals. Regular compressed air is the most common gases used in this process.

Carbon Arc Cutting (CAC-A) QUESTIONS

Show your understanding of the information in this chapter by answering the questions and filling in the blanks below.

1. ____ can be cut using the carbon arc cutting process.
   a. Steel
   b. Aluminum
   c. Manganese
   d. All hard metals
2. Because fumes and smoke are produced in abundance, good ______________ is necessary.
3. The air jet should be turned on before the arc is struck. (True; False)
4. How far away can sparks fly during carbon arc cutting? ______________
5. Carbon arc cutting can not be used when only alternating current is available. (True; False)
6. In carbon arc cutting, most electrodes are coated with ____.
   a. aluminum
   b. carbon
   c. copper
   d. manganese
7. When operating the torch, it is vital to keep the flow of compressed air in front of the arc. (True; False)
8. The faster the travel speed, the ______________ the cut.
9. A heavy-duty torch with water-cooled cables can operate at a maximum of ______________ amps.
10. When cutting a vertical piece, it is important to work from ______________ to ______________.

CHAPTER 9

Shielded Metal Arc Welding (SMAW)

CONTENTS

INTRODUCTION

Shielded metal arc welding (SMAW), also known as stick welding, is perhaps the most widely used form of arc welding today. Shielded metal arc welding works on a wide range of metals. There are many important aspects of shielded metal arc welding to learn about, including safety issues, how the SMAW welding machine operates, and how to make good welds.

When welding, it is important to understand what the welding symbols mean to be able to effectively follow directions.

KEY TERMS

Key Terms are in order of appearance.

non-ionizing radiation visible, ultraviolet, or infrared radiation; heat or light transfer from welding work

flash burn painful eye injury that doesn't start hurting for hours after the injury; may have a cumulative effect that can cause permanent eye damage

shielded metal arc welding (SMAW) or **stick welding** welding process that uses an electric current (AC or DC) to form an arc between an electrode coated in flux and the metals to be joined

electrode metal rod that is coated to provide an oxygen-free atmosphere, arc control, and a slag layer to protect the weld when cooling

stinger common term for the electrode holder

inverter changes frequency to convert high-voltage, low-amperage AC current to low-voltage, high-amperage DC current

direct current (DC) electric current that flows in a constant direction

polarity direction in which current travels

direct current electrode positive (DCEP) or **reverse polarity** electrode lead is the positive side and the workpiece lead is the negative side of the circuit

direct current electrode negative (DCEN) or **straight polarity** electrode lead is the negative side and the workpiece lead is positive side of the circuit

alternating current (AC) electric current that reverses direction at regular intervals

bead or **weld bead** continuous deposit of fused metal

stringer bead bead made with very small movements; should be no more than twice the width of the diameter of the electrode

weave bead bead made with small movements; should be no more than four times the width of the diameter of the electrode

backing plate used as support when creating a joint weld

OBJECTIVES

Upon successful completion of this chapter, the participant should be able to:

1. Describe the safety issues associated with shielded metal arc welding (SMAW).
2. Describe how SMAW works.
3. Describe electrodes used in SMAW.
4. Identify the specific electrode classifications.
5. Describe welding techniques used with this process.
6. Demonstrate a knowledge of the types of electrodes to select.
7. Describe how backing plates are used.
8. Interpret weld bead examples.
9. Demonstrate a knowledge of what the welding symbols mean.

1 Shielded Metal Arc Welding Safety

Shielded metal arc welding (SMAW) can be dangerous. Welders must follow safety guidelines below.

Personal Protective Equipment

To prevent contact with sparks and flying particles, welders should wear the following personal protection equipment (PPE):

- dry, insulated gloves that have no tears or holes
- protective garments such as leather gloves, a heavy shirt, cuffless pants, high shoes or pull-on boots or boots with leather laces, and a cap
- approved safety goggles with side shields in addition to wearing a welding hood or helmet with the minimum shade rating recommended for the procedure
- approved helmets or hoods that protect the face, neck, and ears
- leggings, aprons, sleeves, shoulder covers, and bibs
- flame-resistant earplugs or protective earmuffs, or both

Shaded welding helmets should be worn while performing shielded metal arc welding. Table 1 lists the appropriate shading to wear for shielded metal arc welding as well as other welding processes. The welder should wear the recommended minimum shade during all welding activities. Anyone observing or working near the welding activity should also wear at least the minimum shade.

TABLE 1

Shielded metal arc welding (SMAW) guide for shade numbers

Process	Electrode size		Arc current	Minimum protective shade	Suggested shade number (comfort)
	1/32 inch	Millimeters			
Shielded Metal Arc Welding (SMAW)	< 3	2.5	< 60	7	—
	3–5	2.5–4	60–160	8	10
	5–8	4–6.4	160–250	10	12
	> 8	6.4	250–550	11	14

Shade 'Comfort' Number A welder can determine if the right shade is being used. The welder should find something to read at a distance, but not so far that it causes eye strain, weld for about 15 minutes, and return to the same location. If the individual must then strain to read, the lens may be too dark. If the individual sees a light dot while trying to read, then the lens may be too light.

Fumes and Gases

Shielded metal arc welding produces metal fumes and a number of gas byproducts. The metal fumes can be controlled through natural ventilation, local exhaust, or by wearing respiratory protective equipment. It is important for the welder's face to be kept out of the smoke plume.

Welding coated metals presents a greater health hazard than welding non-coated materials. Always ask supervisor for specific safety related issues or consult a Safety Data Sheet (SDS) if applicable, before starting.

Sparks

Sparks can travel up to 35′-0″ away from the metal work. Any combustible material within the 35′-0″ range should be removed. If that is not possible, metal screens or welding curtains should be placed in the direction of the spark spray. In addition, the welder should wear the personal protective equipment listed above to prevent burns.

These sparks are particles of metal that have been sheared or burned off the welded metal. They can range in size up to ¼″ and even larger. Something that size that is hot and traveling at a high rate of speed will do damage if it comes into contact with unprotected skin. Even when sparks come to rest on work leathers, they can burn through the leather if they are not brushed off.

Arc

The electric arc created during shielded metal arc welding contains **non-ionizing radiation**: that is, visible, ultraviolet, and infrared radiation. These three types of radiation can burn eyes and skin. It is important to wear the PPE listed above when welding. In addition, anyone working in the vicinity of the welding work should also wear PPE.

The ultraviolet light can cause **flash burns** on people up to 50′-0″ away from the actual welding activity. Flash burn is a painful eye injury that doesn't start hurting for hours after the injury. It may also have a cumulative effect that can cause permanent eye damage. The recommendations below should be followed to protect against ultraviolet light:

- Wear proper eye and skin protection, even if the work is of very short duration.
- Wear appropriately shaded helmets, goggles, or shields (see Table 1).
- Avoid wearing contact lenses.
- Wear appropriate gloves to protect hands and upper arms and to keep hands dry.
- Wear clothing to protect the neck area, such as cap sleeves, shoulder covers, and bibs.

Welding curtains are useful for protecting the surrounding environment and other workers or bystanders from the damaging radiation caused by shielded metal arc welding. These curtains are portable and easy to set up and their use is encouraged for everyone's protection.

SAFETY TIP

Never carry matches or butane lighters and never wear polyester when welding.

Electrical Hazards

Shielded metal arc welding utilizes electricity to create the welding arc. Any time electricity is used as a tool, there is a danger of shock. Electrodes are electrically charged. To avoid electric shock, do not touch the bare end of the electrode.

SAFETY TIP

To avoid electric shock, do not touch the bare end of the electrode.

Shielded metal arc welding uses voltages ranging from 17 to 45 and approximately from 100 to 500 amps DC or AC. To avoid electric shock, the safety precautions below should be followed.

- Keep all electrical circuits dry.
- Keep all electrical ground connections mechanically tight.
- Only use cables that are designed to carry the amount of voltage that will be used; make sure the cable is in good repair.
- Do not touch live circuits.
- When replacing torch parts, make sure that all power to control circuitry is disconnected.
- Always practice safe welding techniques.

SAFETY TIP

Always attach the ground cable securely to the workpiece.

In addition to the rules listed above, always use the ground cable properly. Place the ground cable as near to the work as possible. Placing the ground cable on the workpiece itself is the best practice, if this is possible. Make sure the clamp is firmly attached to the ground surface.

SELF CHECK

1. Why do sparks present a danger in welding?
2. What is an effective method to protect bystanders and the surroundings from radiation, sparks, and splatter?

2 What Is Shielded Metal Arc Welding?

In **shielded metal arc welding** (**SMAW**), commonly known as **stick welding** or sometimes *arc welding*, the weld occurs when the heat from the electric arc brings the metal to be welded and the electrode to a molten state. The heat melts the electrode and the work surface near it. The molten droplets from the electrode gather in a molten pool on the work area to create the weld. This molten pool is often called the puddle. The arc can reach temperatures above 9,000° F.

Shielded metal arc welding is used on *ferrous* and some *nonferrous* metals. It is especially effective on these metals.

- carbon steel
- low-alloy steel
- stainless steel

- cast iron
- nickels and nickel alloys
- aluminum and aluminum alloys

Figure 1 shows a generator-welder set up for SMAW.

A visual explanation of the heating, melting and welding area is shown in Figure 2.

Shielded metal arc welding is extremely portable. It can be performed indoors, outdoors, or in any position. It is used in a wide variety of trades and industrial settings and maintenance operations.

FIGURE 1
Gas-powered SMAW welding machine

Welding Essentials

There are five essentials of welding. Each of these must be present to generate a good quality weld.

- correct electrode
- correct amperage
- correct welding arc length
- correct travel speed
- correct electrode angle

In shielded metal arc welding, **electrodes** heat the workpiece and provide supplementary metal for the weld. It is important that the correct electrode for the work be used. If the incorrect electrode is used, the weld may not take or quickly fail due to incompatible metals. The position in which the welding is to be done affects the selection of electrodes. Certain electrodes work better in the flat position. Other electrodes work well in all positions.

PRODUCTIVITY TIP

For efficient welding, the electrode must be at the correct angle for the work being done.

The correct amperage is critical. If the amperage is incorrect proper fusion may not be maintained and the metal may not melt.

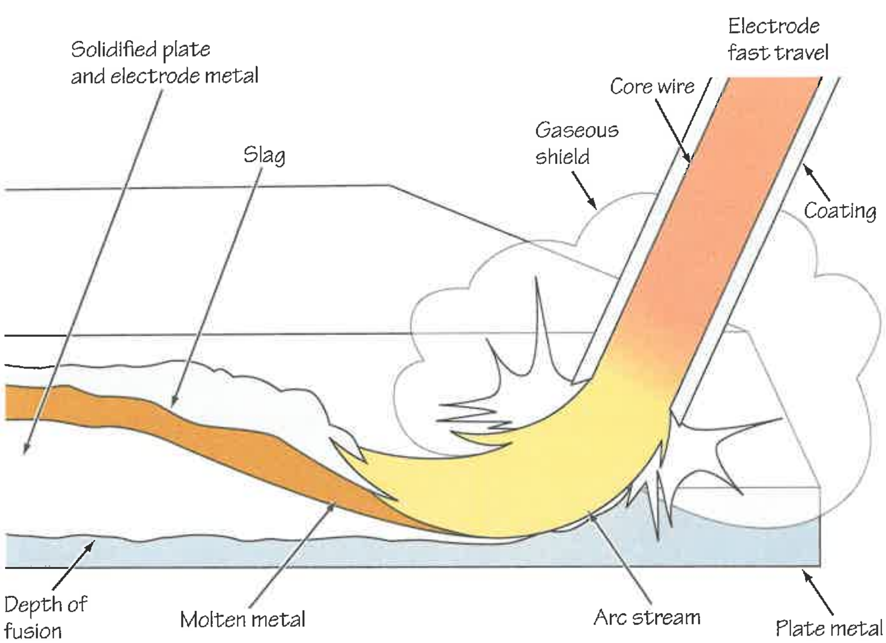


FIGURE 2
How SMAW works

9 SMAW

FIGURE 3
Welding with SMAW

The welding gap is important as well, because if the electrode is held too close or too far from the work, the weld will not be of good quality.

Travel speed is also important. Travel too quickly and the weld may be uneven. Travel too slowly and the weld will be too large.

The electrode must be held at the correct angle to weld most efficiently. In shielded metal arc welding, the electrode holder is commonly called a **stinger**.

Shielded metal arc welding is a manual process. The quality of the weld is in the hands of the welder. Figure 3 illustrates the versatility of the welding technique.

SELF CHECK

1. Where can shielded metal arc welding be used?
2. Why is it important to choose the correct electrode?

Power Sources

Welding power sources are also called power supplies and welding machines. There are different types of power sources used for shielded metal arc welding.

Transformers If AC power is supplied at a jobsite, the voltage present will be too high for the machine. A *transformer* operates to reduce the AC voltage to a level that can be used by the AC welding unit. It is called a step-down transformer.

Rectifiers A *rectifier* is used when the power source is AC but the welding unit requires DC. The rectifier converts the current from AC to DC so that the welding machine can operate.

Inverters An **inverter** changes frequency to convert high-voltage, low-amperage AC current to low-voltage, high-amperage DC current. It does this by running the current through a series of rectifiers, gating transistors, and transformers.

Generators A generator produces DC power. Gas- or diesel-powered alternators or generators can be used where there is no other power source available.

Polarity

In **direct current** (**DC**) electricity flows in a constant direction. The direction of the current is its **polarity**. The choice of polarity can affect the quality of the weld. Polarity should be chosen based on the type of metal and electrode being used.

Direct Current Electrode Positive (Reverse Polarity) In **direct current electrode positive** (**DCEP**), also called **reverse polarity**, the electrode lead is the positive side of the circuit. The ground lead is the negative. This is the most common form of shielded metal arc welding. It is called reverse polarity because the electrical current flows from the base metal to the electrode and the filler metal is deposited in the reverse direction—from the electrode to the base metal.

DCEP produces a deep, penetrating weld. See Figure 4 for a photo of a machine in DCEP mode.

Direct Current Electrode Negative (Straight Polarity) In **direct current electrode negative** (**DCEN**), also called **straight polarity**, the electrode lead is the negative side and the work lead is positive side of the circuit.

DCEN produces a shallow weld but allows for a greater rate of deposition than DCEP. In DCEN mode, the electrical current and the deposited filler metal flow in the same direction—from the electrode to the base metal. Figure 5 shows a machine in DCEN mode.

Alternating Current Changing the polarity on an AC welder does not have an effect on the weld because **alternating current** (**AC**) alternates from positive to negative. In SMAW, AC is sometimes used for welding aluminum. The most efficient current for shielded metal arc welding is DC, either DCEP or DCEN.

FIGURE 4
Machine in DCEP

FIGURE 5
Machine in DCEN

FIGURE 6
Location of the electrode classification number

Polarity Switch Some shielded metal arc welding power sources have a polarity switch. This switch allows the welder to switch polarities, based on which one is best suited for the job. Welding machines without a polarity switch must be physically switched by switching the ends of the leads from the positive terminal to the negative terminal.

SELF CHECK

1. What is the most common polarity used for SMAW?
2. How are polarities switched on a SMAW welding machine?

3 Electrode Identification

All electrodes use the same system of identification/classification, developed by the American Welding Society (AWS). Covered arc welding electrodes have the classification number printed or stamped on the electrode covering within 2 ½″ of the base of the electrode.

Each number and letter in the classification system has a meaning. The following figures and tables provide the breakdown of the coding system.

Figures 6 and 7 illustrate the electrode numbering system.

See Table 2 for a listing of the welding characteristics of mild steel electrodes.

Setting Welding Current

The diameter, length, and type of electrode have a direct bearing on which current should be used in shielded metal arc welding. Table 3 illustrates the correct current range based on the electrode indicated.

It is important to understand that the core of electrodes, no matter their classification, is the same basic core wire. The differentiating factor is the coating.

Specific Electrode Classifications

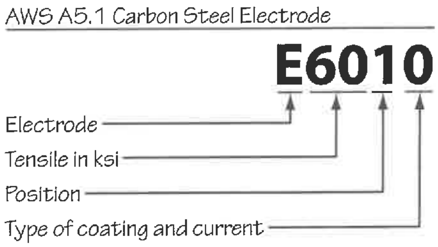
The following information decodes the classifications of common electrodes. These electrodes are for carbon steel, low hydrogen, and other covered electrodes.

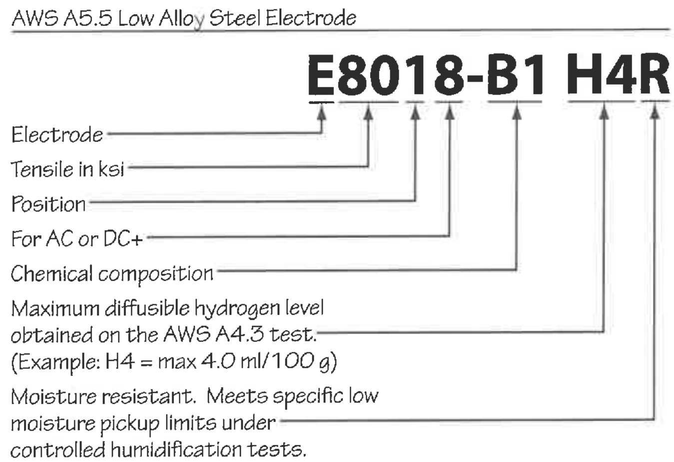
Carbon Steel Electrodes Below is a list of common kinds of carbon steel electrodes.

- E6010: All-position, DCEP (fast-freeze type)
- E6011: All-position, alternating current and DCEP (fast-freeze type)
- E6012: All-position, alternating current and DCEN (fill-freeze type)

PRODUCTIVITY TIP

Electrode suppliers have booklets containing information about electrodes and welding machine settings. Every welder should carry an electrode booklet.





Position

1 – Flat, horizontal, vertical, overhead
2 – Flat and horizontal only
4 – Flat, horizontal, vertical down, overhead

Types of Coating and Current

Digit	Type of Coating	Current
0	Cellulose sodium	DC+
1	Cellulose potassium	AC, DC±
2	Titania sodium	AC, DC–
3	Titania potassium	AC, DC +
4	Iron powder titania	AC, DC±
5	Low hydrogen sodium	DC+
6	Low hydrogen potassium	AC, DC+
7	Iron powder iron oxide	AC, DC±
8	Iron powder low hydrogen	AC, DC±

Chemical Composition of Weld Deposit

Suffix	%Mn	%Ni	%Cr	%Mo	%V
A1				.50	
B1			.50	.50	
B2			1.25	.50	
B3			2.25	1.00	
C1		2.50			
C2		3.25			
C3		1.00	.15	.35	
D1/D2	1.25-2.00			.25-.45	
G[1]		.50 min.	.30 min.	.20 min.	.10 min.

[1] Only one of the listed elements is required

FIGURE 7

AWS SMAW rod classifications

- E6013: All-position, alternating current and DCEN or DCEP (fill-freeze type)
- E7014: All-position, alternating current and DCEN or DCEP (fast-fill type)

Low-Hydrogen Electrodes Below is a list of common kinds of low-hydrogen electrodes.

- E7015: All-position, DCEP (low hydrogen)
- E7016: All-position, alternating current and DCEP (low hydrogen)
- E7018: All-position, alternating current and DCEP (low hydrogen, iron powder)
- E7028: Horizontal and flat position alternating current and DCEP (low hydrogen, iron powder).
- E7048: Flat, horizontal, overhead, and vertical down positions, alternating current and DCEP (low hydrogen, iron powder)

TRADE TIP

A general rule for setting the correct amps based on the chosen electrode is: rod diameter converted to a decimal (but ignoring the decimal point), minus 20, equals approximate current setting. Example:

⅛″ (0.125″) rod = 125
− 20
105 amps

TABLE 2

Welding characteristics of mild steel electrodes

Electrode	Type of coating	Position of welding	Type of current	Penetration	Rate of deposition
E6010	High cellulose sodium	All positions	DCEP	Deep	Average
E6011	High cellulose potassium	All positions	DCEP, AC	Deep	Average
E6012	High titania sodium	All positions	DCEN, AC	Medium	Good
E6013	High titania potassium	All positions	DCEP, DCEN, AC	Mild	Good
E7014	Iron powder titania	All positions	DCEP, DCEN, AC	Medium	High
E7015	Low hydrogen sodium	All positions	DCEP	Mild to medium	Good
E7016	Low hydrogen potassium	All positions	DCEP, AC	Mild to medium	Good
E6020	High iron oxide	Flat horizontal fillets	Flat: DC, AC horizontal fillets: DCEN, AC	Deep	High
E7024	Iron powder titania	Flat horizontal fillets	DCEN, DCEP, AC	Mild	Very high
E6027	Iron powder iron oxide	Flat horizontal fillets	Flat: DC, AC horizontal fillets: DCEN, AC	Medium	Very high
E7018	Iron powder low hydrogen	All positions	DCEP, AC	Mild	High
E7028	Iron powder low hydrogen	Flat horizontal fillets	DCEP, AC	Mild	Very high
E7048	Iron powder low hydrogen	All positions vertical down	DCEP, AC	Mild	High

Appearance of bead	Spatter	Slag removal	Minimum tensile strength (psi)	Yield point (psi)	Minimum elongation in 2 inches (%)	Electrode
Rippled and flat	Moderate	Moderately easy	62,000	50,000	22	E6010
Rippled and flat	Moderate	Moderately easy	62,000	50,000	22	E6011
Smooth and convex	Slight	Easy	67,000	55,000	17	E6012
Smooth and flat to convex	Slight	Easy	67,000	55,000	17	E6013
Smooth and flat to convex	Slight	Easy	70,000	60,000	17	E7014
Smooth and convex	Slight	Moderately easy	70,000	60,000	22	E7015
Smooth and convex	Slight	Very easy	70,000	60,000	22	E7016
Smooth and flat to concave	Slight	Very easy	62,000	50,000	25	E6020
Smooth and slightly convex	Slight	Easy	72,000	60,000	17	E7024
Flat to concave	Slight	Easy	62,000	50,000	25	E6027
Smooth and flat to convex	Slight	Very easy	72,000	60,000	22	E7018
Smooth and slightly convex	Slight	Very easy	72,000	60,000	22	E7028
Smooth and slightly convex	Slight	Easy	72,000	58,000	22	E7048

TABLE 3

*Approximate electrode amperage settings**

Diameter of Electrode		Fast Freeze E6010–E6011	Fill Freeze E6013–E7014	Fast Fill E7024–E7014	Low Hydrogen E7018
		Current Setting	*Current Setting*	*Current Setting*	*Current Setting*
Inches	**Millimeters**	**Amperes**	**Amperes**	**Amperes**	**Amperes**
3/32 in	2.4 mm	40–90	75–105	85–155	70–140
1/8 in	3.2 mm	75–130	100–165	100–175	90–185
5/32 in	4.0 mm	80–160	135–225	160–270	140–230
3/16 in	4.8 mm	110–225	185–280	220–330	210–300
7/32 in	5.6 mm	200–260	235–340	270–410	230–380
1/4 in	6.4 mm	220–325	260–425	315–520	290–440

*Amperage settings are a guideline to be used as a place to start.

Other Covered Electrodes Below is a list of common kinds of other covered electrodes.

- E6020: Horizontal fillet and flat position, alternating current and DCEN or DCEP, high iron oxide
- E7024: Horizontal fillet and flat position, alternating current and DCEN or DCEP (iron powder, titanium)
- E6027: Horizontal fillet welds and flat position, alternating current and DCEN or DCEP (iron powder, iron oxide)

SELF CHECK

1. How does the electrode classification system work?
2. What are some factors that determine which electrode is used?

4 Techniques of Shielded Metal Arc Welding

Knowing the basic techniques of shielded metal arc welding is essential before beginning to practice in the classroom or the lab. Below are some of the essentials that a welder must understand in order to make good welds.

Essentials

As we mentioned briefly earlier in this chapter, there are five welding essentials necessary to make a good weld.

Choosing the Correct Electrode Choice of electrode should be based on several factors: the metal to be welded, the position of the metal, and the thickness of the metal. Refer to Tables 2 through 5 to help guide the electrode choice.

Correct Amperage The current setting should be chosen based on the choice of electrode. Rod diameter converted to a decimal, minus 20, equals approximate current setting. Refer to Table 5 above to find the correct current setting.

Rod Angle One of the factors that determine the quality of the weld is the angle of the electrode. The angle at which an electrode is held affects surface tension of the metal, as does the force of gravity. Holding the electrode at the correct angle allows the weld to be uniform and of a better quality. Typically, the rod will be held at between a 10° angle and a 20° angle in the direction of travel when depositing the weld.

Arc Length Shielded metal arc welding requires a short, consistent arc length. The shorter distance from the work allows the heat to concentrate more efficiently and it reduces the effect of *arc blow,* a wandering of the arc stream due to fluctuation of the magnetic field. The closer distance also protects the weld from being damaged or destroyed by the surrounding air.

The arc distance depends on the electrode type and size, the welding position, and the amount of current. A welder can tell if the arc is the correct length by how well the metal is being transferred. A short arc makes a sharp crackling sound while a long arc hisses and explodes at steady intervals.

Travel Speed Another factor that determines the quality of the weld is travel speed. Travel speed in turn depends on a number of elements, including the following.

- type of welding current, amps, and polarity
- position of welding (flat, vertical, overhead)
- melting rate of electrode
- thickness of metal
- surface condition of the parent metal
- electrode manipulation

A sixth essential for a good weld is *slag.* Although one might think it is only an irritating by-product that must be removed, it actually performs a vital function during the welding process.

Slag A combination of the heated steel, the electrode, and the electrode covering is referred to as slag. It protects the electrode deposit (weld) from the air during cooling; it must be chipped or brushed off once the weld has cooled.

SELF CHECK

1. What is the importance of slag?
2. What is the typical angle at which an electrode should be held while performing SMAW?

Striking an Arc

> **TRADE TIP**
> The arc length should be a maximum of one rod diameter when welding flat position. When welding out of position, shorten arc length slightly.

To begin the welding process, the welder must first strike an arc. Once the ground connection is connected to the work, lightly tap the workpiece with the tip of the electrode (the *tap start*). An arc can also be struck by scratching the workpiece with the tip of the electrode as well (the *scratch start*). This movement is similar to striking a match.

Figure 8 shows the tapping and scratching methods of striking an arc. The electrode will have a tendency to stick to the work upon touching it. If the electrode does stick, quickly break it free by wiggling it loose, not by pulling with free hand.

Weld beads and Electrode Manipulation

The **bead**, or **weld bead**, is a continuous deposit of fused metal. There are two types of bead: a stringer bead and a weave bead. These are created by the manipulation of the electrode.

A **stringer bead** is made with very small movements, and should no more than twice the width of the diameter of the electrode. A **weave bead** is produced by slightly larger movements of the electrode, and be no more than four times the width of the diameter of the electrode.

Electrodes can be manipulated in various ways. Although these motions don't work well with fast fill or "drag" rods, the three basic motions when working with electrodes are the following.

- whip and pause
- crescent
- circular motion

Whip and Pause In the whip and pause method, the welder strikes an arc, builds a puddle, and whips the electrode out of the puddle in the direction of travel. The welder then whips it back into the leading edge of the first puddle, builds another puddle, and whips the electrode out of the puddle in the direction of travel. This process is repeated, maintaining

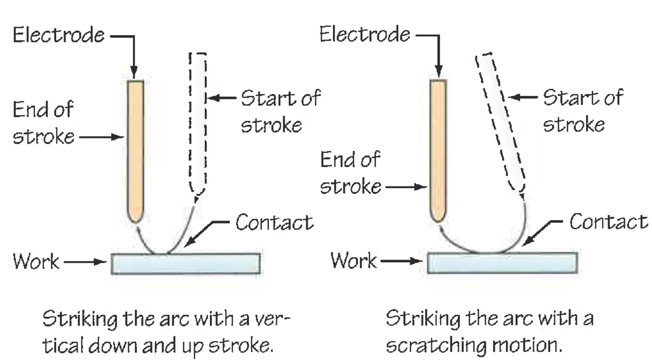


FIGURE 8
Striking an arc

uniform size and shape of the consecutive puddles, for the length of the weld. See Figure 9A.

The whip and pause technique should only produce stringer beads.

Crescent In the crescent method, the welder strikes an arc, builds a puddle, and moves the electrode out across the direction of travel and back to the puddle in a motion that moves the electrode about a quarter of the way along the perimeter of a small circle before returning to the puddle. This motion is repeated, all the while moving forward in the direction of travel approximately 1⁄16″ as each crescent is inscribed by the electrode. Do this repeatedly, keeping size and shape of the crescent uniform; a single puddle will be maintained. See Figure 9B.

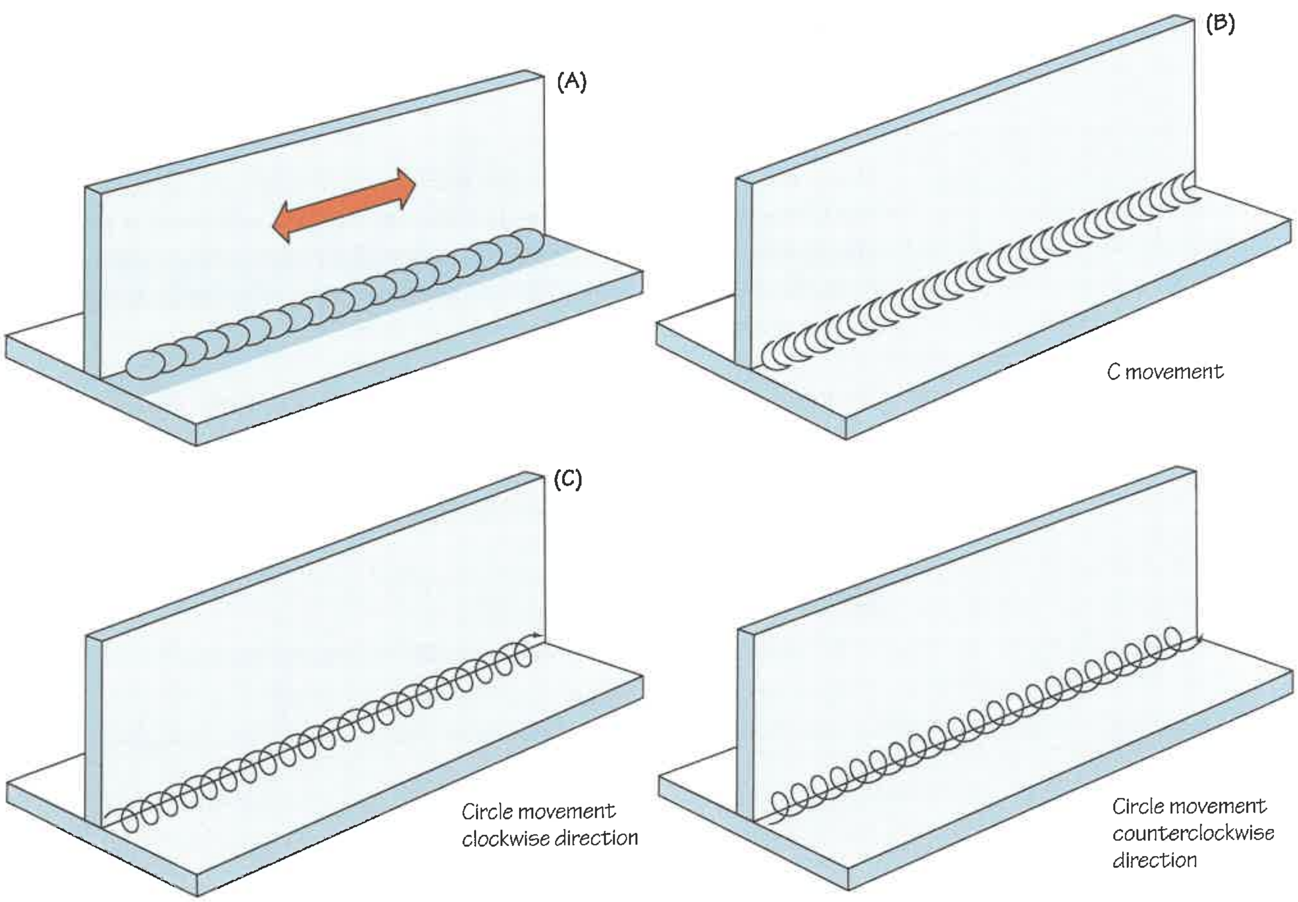
The crescent technique can produce either a stringer bead or a wash bead.

Circular Motion Strike an arc, build a puddle, and move the electrode in the direction of travel about ¼″, using a circular motion. Repeat this motion, while moving forward in the direction of travel, approximately 1⁄16″ of an inch forward with each circle. If the motion begins by moving the electrode clockwise, it must continue in a clockwise direction; if the motion begins counterclockwise, it must continue in a counterclockwise direction. Do this repeatedly, keeping the circular motion uniform; a single puddle will be maintained. See Figure 9C.

TRADE TIP

The whip and pause, crescent, and circular welds are used as a cleaning action and for filling large gaps used with fast freeze rods.

FIGURE 9
(A) Whip and pause
(B) Crescent
(C) Circular motion



The circular motion technique will produce either a stringer bead or a weave bead, depending on the diameter of the circle.

Weld Positions

There are four basic positions in which welding can be performed: flat, horizontal, vertical up and vertical down, and overhead. Which electrode is used depends in a large part to which position the welding will occur. Some electrodes are better suited to horizontal and flat while others are more suitable for overhead welding. Check the electrode codes to determine which one should be used.

The position in which the welding occurs also will impact the choice of current as well. It is more difficult to weld in the overhead position using AC current. This is due to the longer arc needed.

Weld Progression

The direction of the weld is influenced by the weld position. For instance, if welding in the vertical position, it is easier to start from top to bottom. That way, gravity assists with the filling and slag removal. For structural welding however, vertical up is the method recognized. This is to keep out slag inclusions that occur using the vertical down technique. This is also the case with overhead welding.

When welding on a flat or horizontal surface, the welder should choose the direction that best suits the job at hand.

Welding Joints

When creating a joint weld in shielded metal arc welding a **backing plate** is used. The backing plate is attached during the first weld pass. It should be able to be removed once the joint is made. The backing plate should always be made of a metal compatible with the base metal. The backing plate must be free of slag and fit properly.

Backing plates can also be made of copper, since it has a high thermal conductivity. This thermal conductivity lets the copper avoid fusion with the base metal. The copper must be of sufficient size as to avoid melting. If the copper melts, it could contaminate the weld.

SELF CHECK

1. What can happen to an electrode during arc striking?
2. In what positions can gravity help in welding?

SMAW Weld beads

Shielded metal arc weld beads vary according to the direction of the weld, the power usage, the chosen electrode, and the skill of the welder. Figure 10 shows what different beads look like under different conditions.

In Figure 10, the elevation and plan views of welds are shown under the following conditions.

- A shows current, voltage, and speed normal.
- B shows current too low.
- C shows current too high.
- D shows voltage too low, short arc.
- E shows voltage too high, long arc.
- F shows speed of travel too low.
- G shows speed of travel too high.

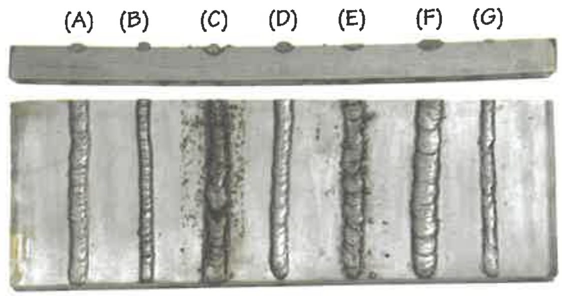
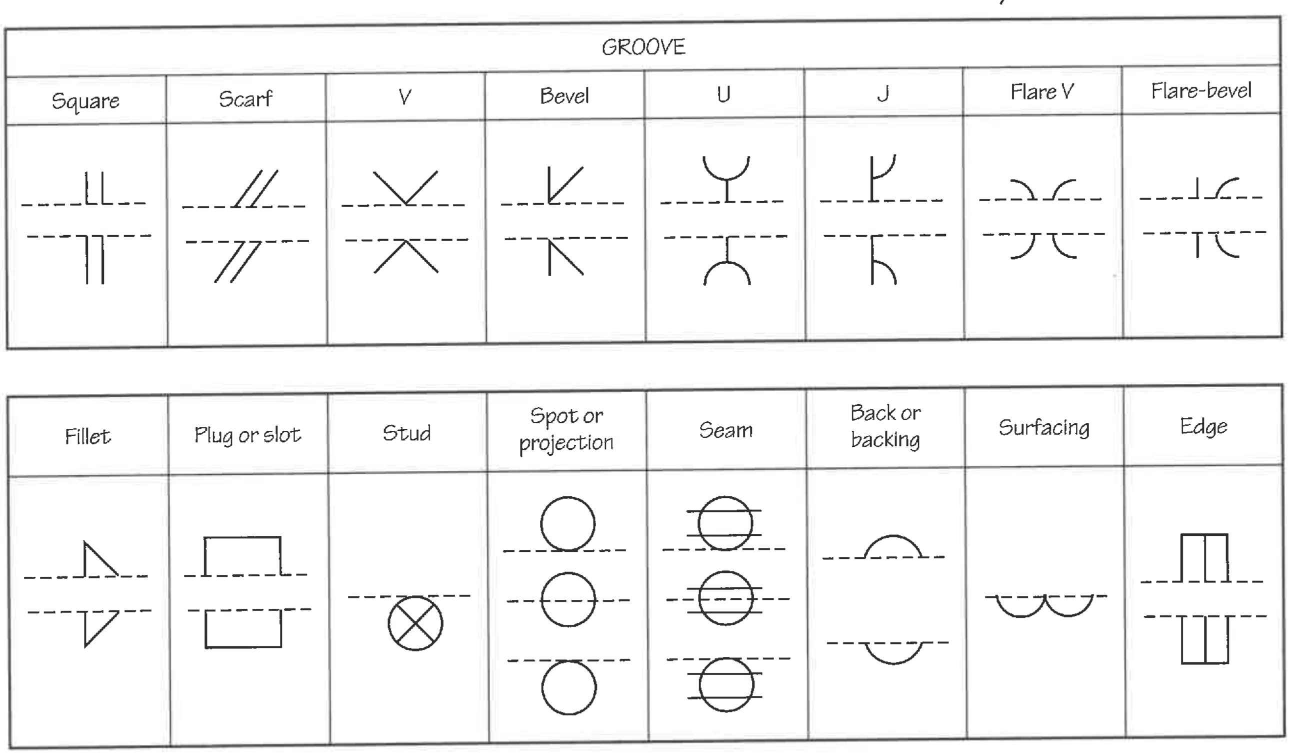


FIGURE 10
Understanding poor welds

5 Weld Symbols

There are 16 basic weld symbols. These symbols are illustrated in Figure 11.

FIGURE 11
Weld symbols



Summary

Shielded metal arc welding is probably the most widely used form of arc welding today. It is easy to master and works on a wide range of metals. Knowing how to operate the shielded metal arc welding machine correctly and safely will help increase welding quality.

Shielded Metal Arc Welding (SMAW) QUESTIONS

Show your understanding of the information in this chapter by answering the questions and filling in the blanks below.

1. Which SMAW safety hazard can be reduced by good cables?

   ____

2. The choice of electrode should be based on the metal to be welded, the welding position, and the ____________ of the metal.

3. DCEP stands for ____________ ____________ ____________ ____________.

4. To change welding current polarity, the welding lead in connections must be reversed at the positive and negative terminal posts on machines that don't have a polarity reversing switch. (True; False)

5. Which organization helped develop and maintains the electrode classification system?

   ____

6. The most efficient power source for SMAW is alternating current. (True; False)

7. ____________ and ____________ the electrode against parent metal are two ways to strike an arc.

8. The most difficult position to weld in is the ____________ position.

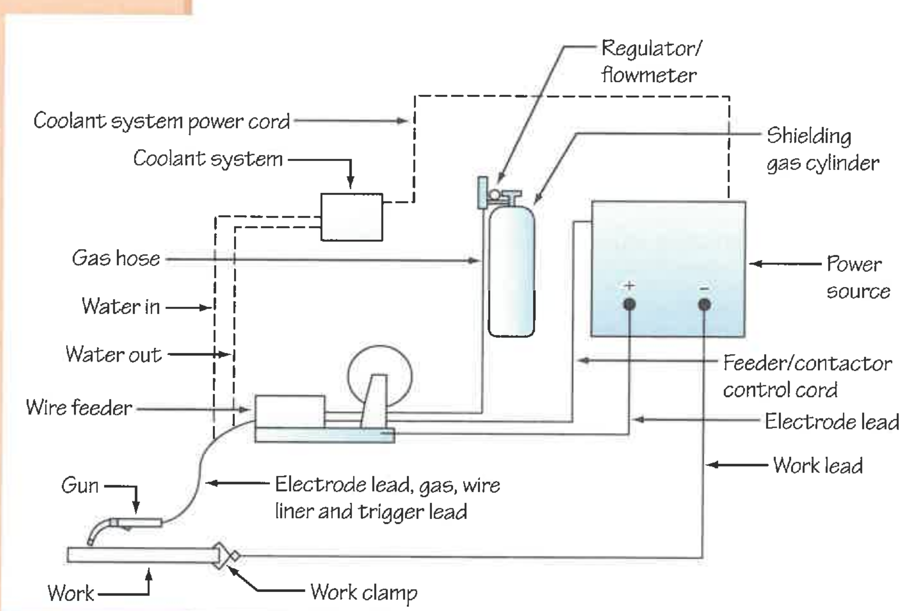
9. Travel speed is not dependent on ____.
   - **a.** position of welding (flat, upright, overhead, and so on)
   - **b.** melting rate of electrode
   - **c.** thickness of metal
   - **d.** condition of ground cable

10. ____ is not within the adverse effects of non-ionizing welding radiation.
    - **a.** 20′-0″
    - **b.** 35′-0″
    - **c.** 50′-0″
    - **d.** 65′-0″

CHAPTER 10

Gas Metal Arc Welding (GMAW)

CONTENTS



INTRODUCTION

Gas metal arc welding, commonly called wire feed welding, is a welding process that involves an electric arc, a consumable electrode, and an externally added gas. The GMAW process is useful on a wide range of ferrous and nonferrous metals. The power sources, gases, electrodes, and equipment available are presented and welder safety is discussed.

KEY TERMS

Key Terms are in order of appearance.

gas metal arc welding (**GMAW**) or **wire feed welding** or **MIG** or **MAG** welding process that transfers electric current to the parent metal through a wire that is melted and deposited into the puddle

electrode continuous-feed wire electrodes for the GMAW process

shielding gas variety of gases used to protect the newly formed GMAW weld from the air

GMAW gun guides the arc, releases the shield gas, and feeds the electrode on the weld

wire feeder automatic unit that feeds electrode wire from a spool to the GMAW gun

travel speed rate of deposition of welding bead

stick out amount of electrode that protrudes from the gun

running start method of starting an arc at the start of a weld by directly touching the parent metal at that point

scratch start method of starting an arc on a scratch tab or beyond the weld starting point

OBJECTIVES

Upon successful completion of this chapter, the participant should be able to:

1. List the safety issues associated with gas metal arc welding.
2. Describe the gas metal arc welding process.
3. Identify the types of power sources.
4. List the uses of shielding gas.
5. Demonstrate an understanding of welding gun variables.
6. List the different equipment used with this process.

1 Gas Metal Arc Welding Safety

As with most welding processes, gas metal arc welding (GMAW) produces non-ionizing radiation, sparks, and fumes. GMAW also involves electricity, which means there is an opportunity for shock. There are several safety precautions that should be taken before beginning to weld.

To prevent contact with sparks and flying particles, welders should wear the following personal protective equipment (PPE).

- Wear dry, leather gloves that have no tears or holes.
- Wear protective well-fitting garments such as a heavy shirt, cuffless pants, high shoes or boots, and a cap.
- Wear approved safety goggles with side shields in addition to wearing a welding helmet or hood with a shade rating no less than 10.
- Use approved helmets that protect the face, neck, and ears.
- Wear leggings, aprons, sleeves, shoulder covers, and bibs.
- Wear flame-resistant earplugs or protective earmuffs, or both.

SAFETY TIP

Never carry matches or butane lighters and never wear polyester when welding.

Fumes and Gases

Gas metal arc welding produces metal fumes and a number of gas by-products. The metal fumes can be controlled through natural ventilation, local exhaust, or by the welder wearing respiratory protective equipment. It is important for the welder to stay out of the smoke plume, especially to keep the fumes away from his or her face.

The gases that are a by-product of GMAW include ozone, nitrogen dioxide, and carbon monoxide. These are all hazardous gases when breathed in high enough concentrations. It is important to observe all ventilation safety rules when welding.

Welding coated metals presents a greater health hazard than welding non-coated materials. Always ask supervisor for specific safety related issues or consult a Safety Data Sheet (SDS) if applicable, before starting.

Ozone The ultraviolet light emitted from the arc interacting with the surrounding oxygen produces *ozone*. The amount of ozone produced depends upon the amount of ultraviolet light and the humidity, among other things. The ozone concentration will also increase when using argon as the shielding gas and when welding highly reflective metals. Natural ventilation should reduce the concentration of ozone to safe levels. However, if natural ventilation is not sufficient, make sure that the area receives a fresh air supply or the welder wears a respirator.

Nitrogen Dioxide High concentrations of *nitrogen dioxide* are found only within 6″ of the arc. This gas quickly dissipates with normal ventilation and should not prove hazardous to the welder. However, it is important for the welder to stay away from the fumes.

Carbon Monoxide If carbon dioxide is used as the shielding gas for GMAW, the heat of the arc will produce a small amount of *carbon monoxide* in high concentrations between 3″ and 4″ from the welding plume. Normally, this gas will dissipate quickly enough to not cause harm to the welder. In whatever welding circumstances, good ventilation is essential. Welders should always avoid the plume.

Sparks

Sparks are a by-product of the GMAW process. The sparks can travel up to 35′-0″ away. Any combustible material within the 35′-0″ range should be removed. If that is not possible, metal screens should be placed in the direction of the spark spray.

Arc

Gas metal arc welding produces higher radiant energy than shielded metal arc welding. This is due to the higher arc energy, lower welding fumes, and a longer arc. The greatest amount of radiant energy is produced when using argon as the shielding gas and when welding on aluminum.

Ultraviolet light from GMAW can cause a *flash burn* up to 50′-0″ away from the arc. If it is not possible to keep nonessential personnel out of the area, protective screens should be set up around the work area. Anyone directly involved with the welding process must use safety glasses and an approved welding hood with a shaded lens no lighter than a 10.

Electrical Safety

Gas metal arc welding uses voltages ranging from 12 to 80 volts and amperage up to 575 amps. As with any electrical welding process, care should be taken not to come into contact with the electrical current. To avoid electric shock, the following safety precautions should be observed:

- Keep all electrical circuits dry.
- Keep all electrical ground connections mechanically tight.
- Use high-voltage cable; make sure the cable is in good repair.
- Do not touch live circuits.
- When replacing torch parts, make sure that all power to control circuitry is disconnected
- Always practice safe welding techniques.

In addition to the rules listed above, it is especially important to always use the ground cable properly. Place the ground cable as near to the work as possible. Placing the ground cable on the work itself is the best practice, if this is possible. Make sure the clamp is firmly attached to the ground surface.

SELF CHECK

1. What are some specific dangers associated with gas metal arc welding?
2. Why is it important to use a ground cable?

2 What Is Gas Metal Arc Welding?

Gas metal arc welding (**GMAW**), commonly called **wire feed welding**, or **MIG** or **MAG** depending on the shielding gas used, is a welding process that involves an electric arc, a consumable wire **electrode**, and an externally added shielding gas. MIG stands for "metal *inert* gas" and MAG stands for "metal active gas." The continuous-feed wire electrode is melted by the arc and shielded by a gas supplied externally. No pressure is applied in this process.

Figure 1 illustrates how the GMAW process works. Figure 2 shows how the machine is set up.

Uses of Gas Metal Arc Welding

Since gas metal arc welding works on *ferrous* and *nonferrous* metals alike, it has proven quite useful in many industries. There are several advantages that GMAW has that make it popular.

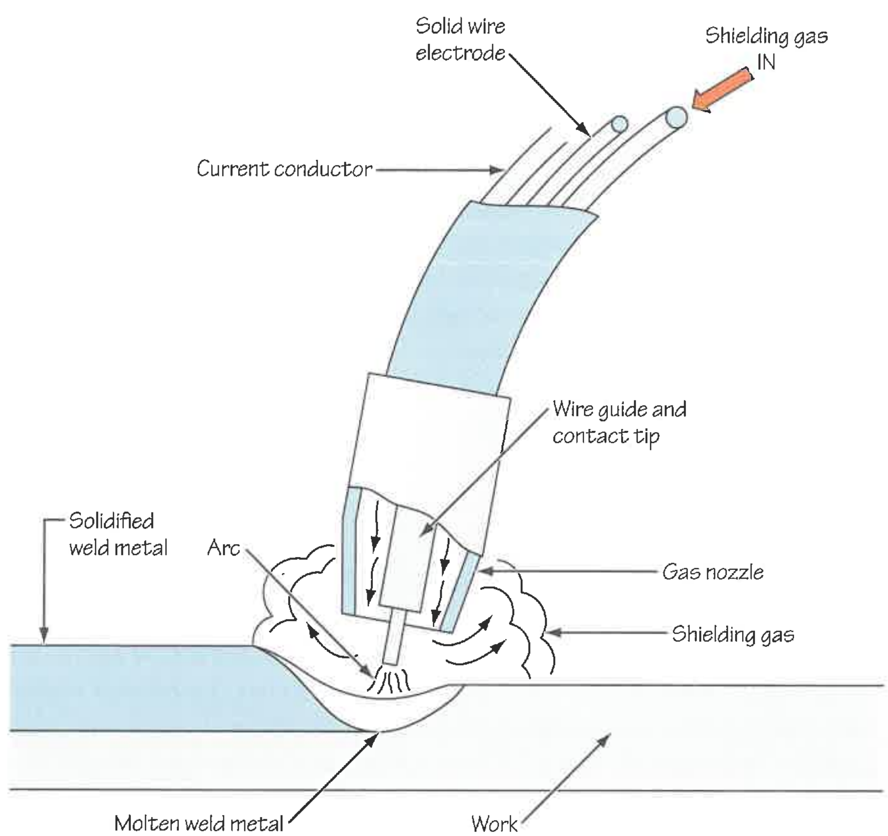


FIGURE 1
Schematic representation of GMAW process

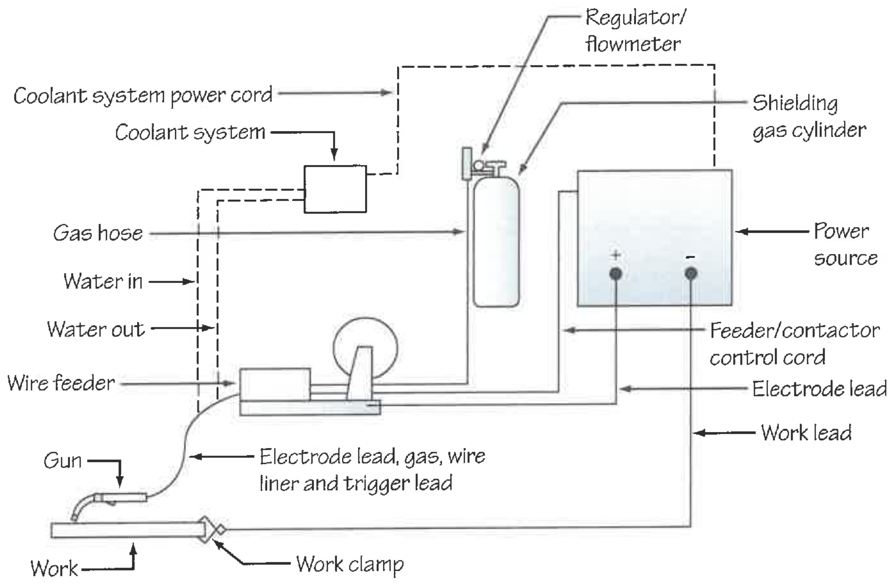


FIGURE 2
Schematic diagram of a gas metal arc installation

Advantages of GMAW Below is a list of some of the major advantages of using gas metal arc welding.

- It is the only consumable electrode process that can weld all commercial metals and alloys.
- Gas metal arc welding does not have the limited electrode length found in shielded metal arc welding.
- Welding can be done in all positions.
- Deposition rates are high.
- Welding speed is high due to the continuous electrode feed and high deposition rates.
- Long welds can be made without stops and starts due to the continuous electrode feed.
- Spray transfer allows smaller fillet welds.
- Absence of heavy slag means little post-weld cleaning is needed.

Disadvantages of GMAW While there are fewer disadvantages to gas metal arc welding than advantages, they still exist. Below are the drawbacks to the process.

- The welding equipment is complicated, expensive, and not very portable.
- The large welding gun makes it more difficult to reach hard-to-reach spaces.
- The welding gun must be between ¼″ to ½″ for short circuit-ing transfer, and ½″ to 1″ for globular or spray mode.
- Air drafts can disperse the shielding gas. This makes outside work difficult.
- The relatively high levels of heat and arc intensity are unpleasant for many welders.

SELF CHECK

1. What two types of metal will the GMAW process weld?
2. What type of electrode does the GMAW process use?
3. What are some of the drawbacks to the GMAW process?

3 Power Sources

There are three basic gas metal arc welding power sources used with GMAW: DC rectifier, inverter, and motor-driven generator. Each type has advantages and disadvantages. For the majority of GMAW machines, direct current with electrode positive is used.

DC Rectifier In shops where a source of either 230 volts or 460 volts are available, the DC rectifier GMAW is preferred. When arc conditions change, this type of GMAW responds more quickly. Figure 3A shows what one model of DC rectifier GMAW looks like.

Inverter

The inverter converts high-voltage, low-amperage AC current by changing the frequency to low-voltage, high-amperage DC. It does this by running the current through a series of rectifiers, gating transistors, and transformers. The inverter is a popular power source, for a number of reasons.

- It is lightweight and highly portable.
- It has a lower purchase price.
- It is cheaper to run because uses much less electricity to generate the necessary power.
- There are fewer maintenance issues and fewer breakdowns.
- It produces a more stable current, which is better for welding.

Figure 3B shows an AC power inverter.

FIGURE 3
(A) 350-amp DC transformer-rectifier
(B) Inverter

(A)

(B)

Generators

There are two types of motor generators; they are classified according to the motor that provides the power.

The first type of generator has an AC motor, a DC generator, and an exciter built on a single shaft. This type of motor is powered by AC electricity found on the jobsite.

The second type is an engine-driven generator alternator/rectifier, which generates its own electricity from a gas or diesel powered engine. This type of generator is used when jobsite power in not available. Figure 4 shows a 600-amp engine-driven generator. This is a very versatile generator, allowing FCAW, GMAW, SMAW, and CAC-A welding.

FIGURE 4
Engine-driven generator

Power Source Controls GMAW is typically available in semiautomatic machine modes for construction or hand use. For semiautomatic operation, the voltage can be step stages or infinite control. The speed control is used to control the speed of the wire. When the wire feed speed is increased, the welding current automatically increases. By the same token, decreasing the wire feed speed results in lower welding currents.

There is also a start/stop switch for the wire feed located on the gun switch. This start/stop switch is separately powered by 115-volt AC.

4 Shielding Gases

Molten metal is protected from air by a **shielding gas**. This shielding is necessary because most metals form oxides when they are heated to their melting point and exposed to air. The oxygen in the air will also react with the carbon in molten steel to form carbon monoxide and carbon dioxide. These can produce defective welds. The shielding gas keeps out damaging nitrogen and oxygen, so the weld stays pure.

There are several types of shielding gases that can be used in GMAW. Some have properties that work better with certain metals. The following common gases are used in GMAW.

- argon
- helium
- carbon dioxide
- argon-helium mixes
- argon-oxygen-carbon dioxide mixes
- argon-helium-carbon dioxide mixes
- argon-helium-carbon dioxide-oxygen mixes

Metal Transfer in Gas Metal Arc Welding

There are two basic modes of metal transfers that can be used: spray metal transfer and globular metal transfer.

Spray Transfer Spray transfer occurs when the electrode metal is transferred to the work in tiny droplets across a stable arc. See Figure 5 for an illustration of the process.

Globular Transfer Globular transfer occurs when the metal droplets formed at the end of the electrode are actually larger than the electrode itself. This method produces a lot of spatter and the weld deposit is rough and uneven. Globular transfer can also occur when carbon dioxide is used as a shield. Figure 6 illustrates the process.

Short Circuit Transfer Metal transfer in which molten metal from a consumable electrode is deposited during repeated short circuits is referred to as short circuit transfer. See Figure 7 for an illustration of circuit transfer.

FIGURE 5
Spray welding

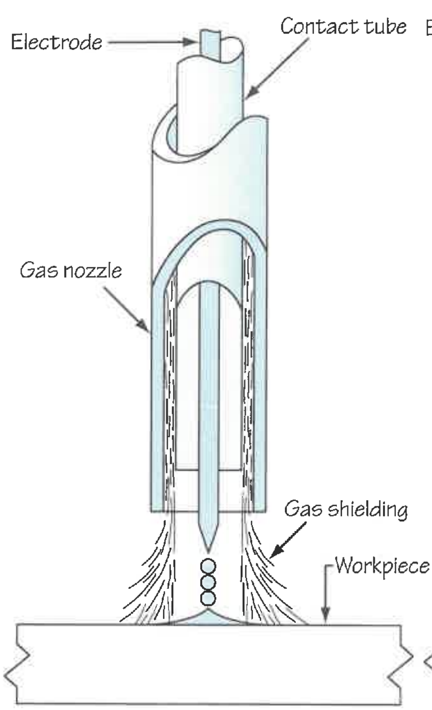


FIGURE 6
Globular welding

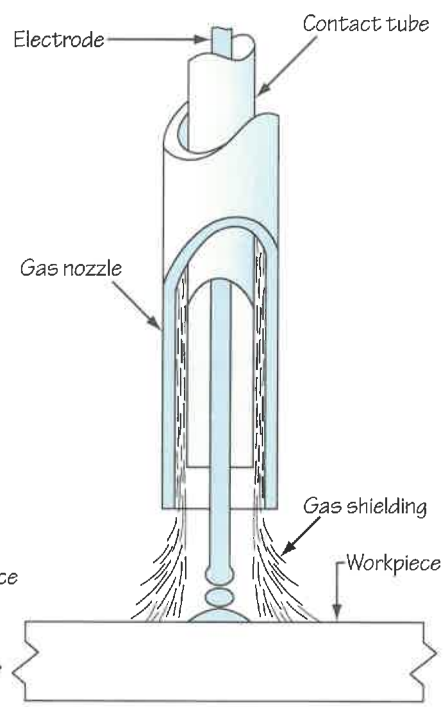
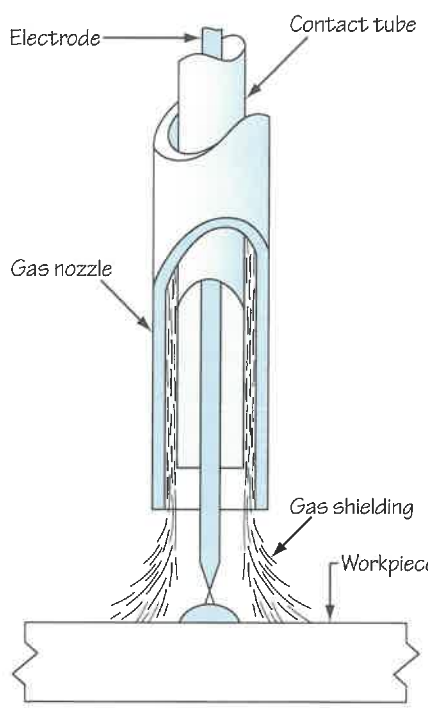


FIGURE 7
Short circuit welding



SELF CHECK

1. What is the most common gas to use as a shield gas in GMAW?
2. What are the two methods of metal transfer in GMAW?

5 Electrode Holders and Wire Electrodes

In gas metal arc welding, the wire *is* the electrode, and the electrode holder is generally referred to as a gun. It is a multipurpose tool.

Types of Guns

The **GMAW gun** is used to guide the arc, release the shield gas, and feed the electrode on the weld. GMAW guns are manufactured in many sizes and are classified by the maximum and minimum wire diameters they can run on. They are also rated on their current capacity. GMAW guns should be chosen based on the type and amount of welding to be done.

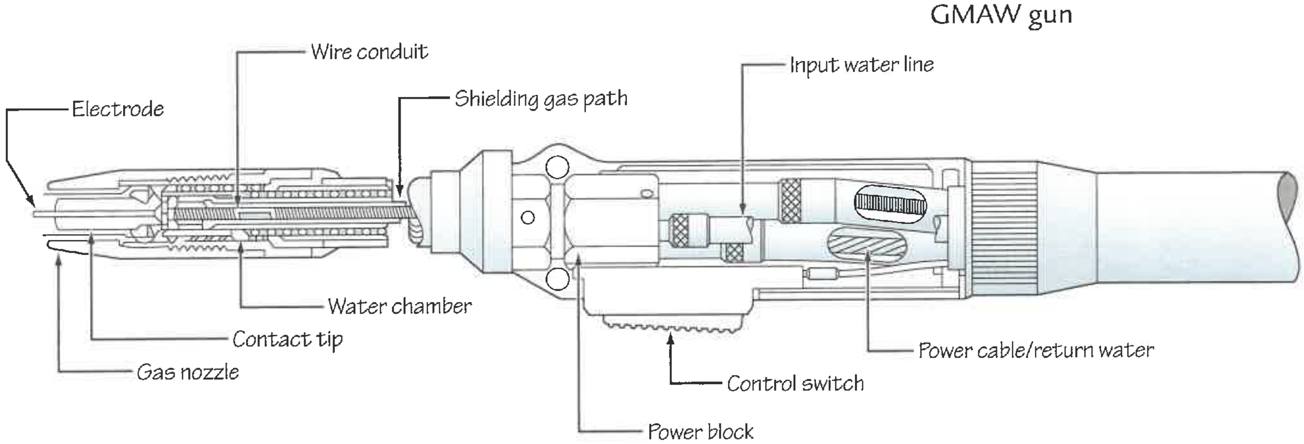
Cooling Mechanisms GMAW guns can be either water-cooled or air-cooled. The air-cooled gun weighs substantially more than the water-cooled gun due to the inefficiencies of air-cooling. Figure 8 shows the inner workings of a water-cooled GMAW gun.

Nozzles Guns can have a straight or a curved guide tube, depending on the type and location of work. Nozzles are usually made of copper or copper alloys. They are available in various diameters and lengths. The size chosen should be large enough to allow for gas shielding but small enough to access joints.

The GMAW process involves a consumable constant-speed wire feed. The wire is fed through the GMAW gun but there are several options for supplying the wire.

Spool-In Gun Some GMAW guns are designed to house the electrode wire within a compartment attached to the gun. The size of the compartment affects how long the welding activity can go before switching wire rolls. The spool-in gun is commonly used with aluminum. See Figures 9 and 10 for two examples of GMAW guns.

FIGURE 8
Cross-sectional view of typical GMAW gun



10 GMAW

FIGURE 9
GMAW spool gun

FIGURE 10
Industrial GMAW spool gun

PRODUCTIVITY TIP

When threading a new spool of wire, push the wire through a clean foam earplug and position the foam earplug between the drive rollers and the liner. Dust and debris will be cleared off, improving the weld quality and increasing the lifespan of the liner.

Semiautomatic Wire Feeder The most common and efficient way to get wire to the gun, when the wire can be pushed, is through a semiautomatic **wire feeder**. This unit drives the wire from the roll through the lead to the gun. The wire feeder's speed adjustments affect the current. Wire feeders are rated based on the amount of wire they can hold. Some wire feeders are attached externally to the welder. Others are found inside the welder. Still other units are completely separate—mounted to overhead cranes or a great distance from the power source for maximum portability and reach.

Figures 11 and 12 show the outside and inside construction of a typical bench-style constant-speed wire feeder.

FIGURE 12
Internal makeup of wire feeder

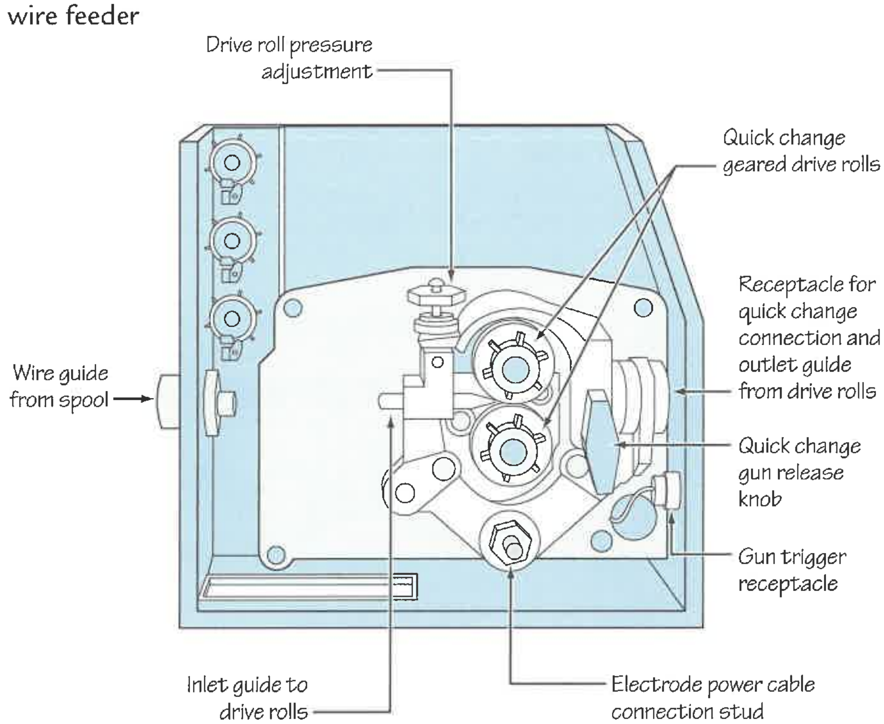


FIGURE 11
Bench-style wire feeder

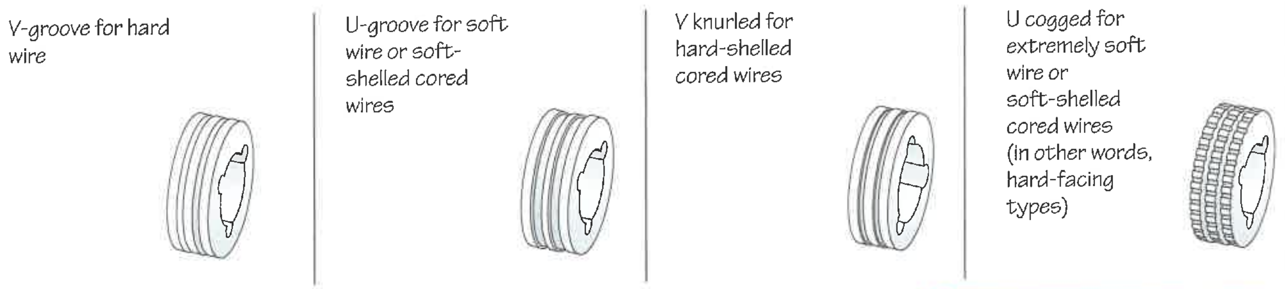


FIGURE 13
Drive rolls

Semiautomatic wire feeders allow the welder to choose from a variety of electrode wire. To accommodate the different wire styles, the semiautomatic feeders need to have the drive rolls changed. The drive rolls are shaped differently to work best with the electrode needed for a particular welding job. Figure 13 illustrates the various types of drive rolls available and their applications.

Electrodes

There are many varieties of continuous-feed filler wire available for GMAW. Each is better suited to one particular job rather than another. The American Welding Society (AWS) maintains a classification system to help distinguish one group of filler wires from another. Some of these classifications include solid electrodes, metal-cored electrodes, tubular flux cored electrodes, and flux and electrode combinations.

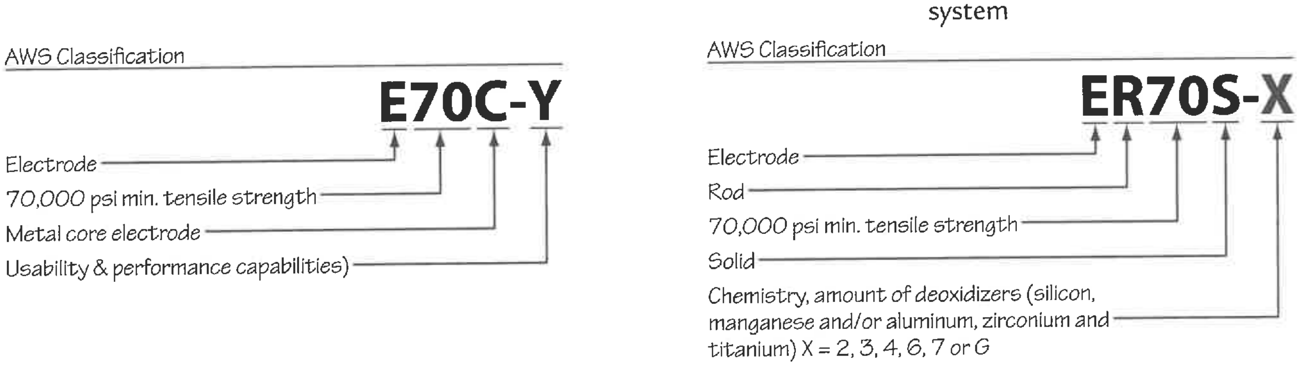
Figure 14 shows two examples of how the classification system works for GMAW metal-cored and GMAW solid electrodes.

Equipment Maintenance for Efficient Welding

It is important to maintain the gun in order to work efficiently and well.

- Keep the gun nozzle clean and free of slag and other welding particles.
- Do not allow the gun tube and liner to become kinked; this can cause inconsistencies in the wire speed.
- Keep power cables in good shape.

FIGURE 14
AWS electrode classification system



PRODUCTIVITY TIP

Keeping the gun lead, commonly called the whip, as straight as possible helps avoid kinks or sharp bends. This extends the life of the liner and maintains weld quality.

- When a jam occurs in the gun, learn to quickly shut off the machine to avoid wasting electrode wire.
- Keep the cooling fan clean and clear of debris so it can run at maximum efficiency.
- Always keep an extra spool of electrode wire on hand so that welding can continue when one roll runs out.

SELF CHECK

1. In what different ways can wire be fed for GMAW?
2. How can the welder distinguish different kinds of electrode feeder wire?
3. Why is it important to keep the GMAW gun in good working order?

6 Welding Basics

Several factors will influence the quality of a weld. These factors need to be adjusted based on the type of metal being welded, its thickness, the position of the welding that is being done, the required deposition rate and the welding specifications.

Welding Variables

Each of the factors below influences the others. Therefore, when changing one, another is affected as well. Establishing the correct combination of the variables discussed below will result in a good quality weld.

Welding Amperage (Electrode Feed Speed) The manufacturer of the electrode sets parameters that the electrode is capable of being properly operated within such as in between 150 inches per minute (ipm) and 375 ipm. This has to be balanced to the proper amount of voltage.

Polarity The electrode manufacturer determines which polarity should be used with which electrode. Some GMAW electrodes require DCEN, and others require DCEP.

TRADE TIP

Arc and travel speed will affect the bead size, penetration, and fusion. The rate of travel should be adjusted to maintain a good weld based on the work. Although a longer arc is quieter and smoother, it results in an inferior weld.

Arc Voltage (Arc Force) The manufacturer of the electrode sets parameters of voltage for proper operation of the electrode, such as between 18 volts and 32 volts. The welder controls the voltage within the manufacturer's range to best balance the voltage-to-amperage ratio, which is determined by the electrode feed speed.

Travel Speed The amount of weld bead that can be applied over a given period of time the **travel speed**. It is measured in inches per minute (ipm). It is determined by the electrode feed speed balance to the voltage. For example: if the electrode feed speed is set at 275 ipm and the voltage is set at 22 volts, the travel speed is 14″ of 5⁄16″ inch bead per minute.

Electrode Extension The electrode extension, commonly referred to as **stick out**, is the distance between the end of the contact tip and the metal to be welded. It is set by the manufacturer. For example, the electrode stick out range is between ½″ and 1″ and the optimum stick out is ¾″, providing that the electrode feed speed is balanced with the proper amount of voltage. Fluctuations in stick out length affect the ratio of voltage to amperage, which affects the quality of the welding bead.

Electrode Orientation (Trail or Lead Angle) The orientation of the electrode refers to its position in relationship to the weld puddle and whether the weld is being pushed or dragged (pulled). This depends on the electrode being used; some create a better weld bead when pushed, other when dragged. If the wrong orientation is used, the weld quality will be affected.

Electrode Diameter The diameter of the wire is measured in millimeters or inches. Common sizes are .020mm, .025mm, .030mm, .035mm, .045mm, .068mm, .072mm, 1⁄16″, 5⁄64″, and 3⁄32″.

Electrode Composition The type of wire being used affects the strength and quality of the weld. Choice of electrode will depend on the parent metal being welded. It also depends on the position to be welded in, as certain electrodes are not suitable for all positions.

Weld Joint Design A welder should be qualified to weld the specified joint.

Shielding Gas The strength and quality of the weld will depend on the shielding gas used, as will the travel speed.

Flow Rate The volume of shielding gas needed to protect the weld bead while welding and as it cools is referred to as the flow rate. If too little is used, the weld will be contaminated by atmospheric gases. If too much is used, turbulence may cause atmospheric contamination.

Starting the Arc

To start the arc, use either a running start or a scratch start. A **running start** is when the arc is started at the beginning of the weld. The welder touches the electrode to the base metal and presses the gun trigger. This starting method often does not allow the electrode to heat up enough before starting and poor bead formation results at the beginning of the weld.

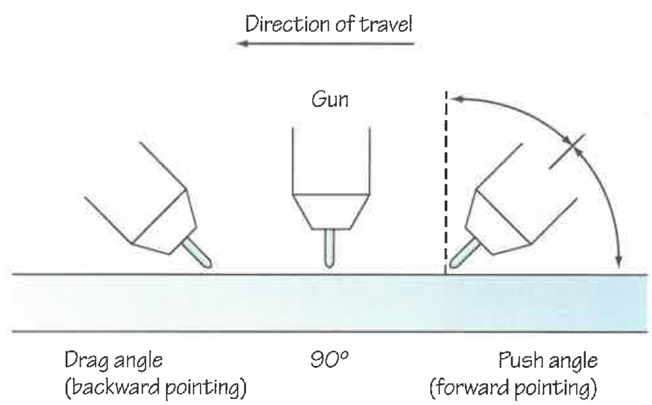
The **scratch start** is usually preferred. In this method, the arc may be struck on a starting tab or approximately 1″ ahead of where the weld needs to begin. The electrode is then moved back to the starting point.

Gun Angle

There are two angles to be aware of when holding a GMAW gun: the travel angle of the gun and the work angle. Guns may be moved via a drag or a push angle. See Figure 15 for an illustration of gun angle and movement.

When welding in the flat position, it is usually best to hold the gun between a 5° angle and a 15° angle. Be careful not to change the angle as the end of the weld approaches.

FIGURE 15
Drag and push angles



Summary

Gas metal arc welding involves an electric arc, a consumable wire electrode, and an externally added shielding gas. The GMAW process is useful on a wide range of ferrous and nonferrous metals. This is a popular industrial welding technique because long welds can be made without stopping. It is an automatic or semiautomatic process.

Gas Metal Arc Welding (GMAW) QUESTIONS

Show your understanding of the information in this chapter by answering the questions and filling in the blanks below.

1. It is not necessary to wear a shaded lens when using the GMAW process. (True; False)

2. Ultraviolet light can affect people and things up to ____ away.
   a. 10′-0″
   b. 20′-0″
   c. 35′-0″
   d. 50′-0″

3. Shielding gas ______________ the weld from the air.

4. The two methods of transferring metal to a weld in the GMAW process are ______________ and ______________.

5. GMAW can only be used on nonferrous metal. (True; False)

6. Automatic wire feeder speed is adjustable based on ______________.

7. The GMAW gun's nozzle is usually made of ____.
   a. aluminum
   b. brass
   c. copper
   d. tin

8. An air-cooled GMAW gun is heavier than a water-cooled one. (True; False)

9. To start the arc in GMAW, use either a(n) ______________ or a(n) ______________ start. Which is preferred? ______________

10. When welding in the flat position, it is best to hold the GMAW gun between a ____.
    a. 5° angle and a 10° angle
    b. 5° angle and a 15° angle
    c. 5° angle and a 25° angle
    d. 15° angle and a 45° angle

CHAPTER 11

Flux Cored Arc Welding (FCAW)

CONTENTS

INTRODUCTION

Flux cored arc welding (FCAW) involves an electric arc and a consumable electrode that contains a flux. The required shielding gas is provided by the flux and therefore no external gas is required. Another type of flux cored arc welding can also utilize a shielding gas.

The FCAW process is useful on a wide range of ferrous and nonferrous metals. The power sources, gases, electrodes, and equipment available are presented and welder safety is discussed.

KEY TERMS

Key Terms are in order of appearance.

flux cored arc welding (FCAW) uses a continuous-feed consumable wire electrode whose core is filled with flux and alloying agents

electrode any of a large variety continuous-feed flux cored filler wires for the FCAW process

self-shielded flux cored arc welding (FCAW-S) welding process that uses a continuous-feed consumable electrode whose core is filled with flux and alloying agents

gas-shielded flux cored arc welding (FCAW-G) welding process that uses a continuous-feed consumable electrode whose core is filled with flux and alloying agents and additional shielding gas

wire feeder automatic unit that feeds electrode wire from a spool to the FCAW gun

stick out amount of electrode that protrudes from the gun

filler wire flux cored wire that contains a flux to shield the weld from the air

travel speed rate of deposition of welding bead

OBJECTIVES

Upon successful completion of this chapter, the participant should be able to:

1. Demonstrate an understanding of the safety issues associated with flux cored arc welding (FCAW).
2. Explain the FCAW process.
3. List where these machines are used.
4. Describe the types of machines.
5. List the uses of shielding gas.
6. Identify the welding variables.

1 Flux Cored Arc Welding Safety

As with most welding processes, flux cored arc welding (FCAW) produces *non-ionizing radiation*, sparks, and fumes. FCAW also involves electricity, which means there is an opportunity for shock. There are several safety precautions that should be taken before beginning to weld.

Personal Protective Equipment

To prevent contact with sparks and flying particles, welders should wear the following personal protective equipment (PPE).

- Wear dry, insulated gloves that have no tears or holes
- Wear protective well-fitting garments such as leather gloves, a heavy shirt, cuffless pants, high shoes or pull-on boots or boots with leather laces, and a cap.
- Wear approved safety goggles with side shields underneath helmets
- Use approved helmets or head shields that protect the face, neck, and ears.
- Wear leggings, aprons, sleeves, shoulder covers, and bibs.
- Wear flame-resistant earplugs, protective earmuffs, or both.

SAFETY TIP

Never carry matches or butane lighters and never wear polyester when welding.

Fumes and Gases

FCAW produces metal fumes and a number of gas by-products. The metal fumes can be controlled through natural ventilation, local exhaust, or by the welder wearing respiratory protective equipment.

The gases that are a by-product of FCAW include ozone, nitrogen dioxide, and carbon monoxide. These gases are hazardous when breathed in high enough concentrations. It is important to observe all ventilation safety rules when welding.

Welding coated metals presents a greater health hazard than noncoated materials. Always ask supervisor for specific safety related issues or consult a Safety Data Sheet (SDS) if applicable, before starting. It is important for the welder to stay out of the smoke plume and to keep it as far away as possible from his or her face.

Ozone The ultraviolet light emitted from the arc interacting with the surrounding oxygen produces *ozone*. The amount of ozone produced depends upon the amount of ultraviolet light and the humidity, among other things. The ozone concentration will also increase when using argon as the shielding gas and when welding highly reflective metals. Natural ventilation should reduce the concentration of ozone to safe levels. However, if natural ventilation is not sufficient, make sure that the area receives a fresh air supply or that the welder wears the proper respirator.

Nitrogen Dioxide High concentrations of *nitrogen dioxide* are found only within 6″ of the arc. This gas quickly dissipates with normal ventilation and should not prove hazardous to the welder. However, it is important for the welder to stay away from the fumes.

Carbon Monoxide If carbon dioxide is used as the shielding gas for FCAW, the heat of the arc will produce a small amount of *carbon monoxide* in high concentrations 3″ to 4″ from the welding plume. With good ventilation, this gas will dissipate quickly enough to not cause harm to the welder. In whatever welding circumstances, good ventilation is essential. Welders should always avoid the plume.

Sparks

Sparks are a by-product of the FCAW process. The sparks can travel up to 35′-0″ away. Any combustible material within the 35′-0″ range should be removed. If that is not possible, metal screens or welding curtains should be placed to contain the sparks.

Arc

Flux cored arc welding produces high radiant energy due to the high arc energy. It also produces more welding fumes than GMAW as well as a longer and seemingly more violent arc.

Ultraviolet light from FCAW can cause a flash burn up to 50′-0″ away from the arc. If it is not possible to keep nonessential personnel out of the area, protective screens or curtains should be set up around the work area. Anyone directly involved with the welding process must use safety glasses in addition to an approved welding hood with a shaded lens no lighter than a 10.

Electrical Safety

Flux cored metal arc welding uses voltages ranging from 12 to 80 volts and amperages up to 575 amps. As with any electrical welding process, care should be taken not to come into contact with the electrical current. To avoid electric shock, the safety precautions below should be followed.

- Keep all electrical circuits dry.
- Keep all electrical ground connections mechanically tight.
- Use high-voltage cable; make sure the cable is in good repair.
- Do not touch live circuits.
- When replacing torch parts, make sure that all power to control circuitry is disconnected
- Always practice safe welding techniques.

In addition to the rules listed above, it is especially important to always use the ground cable properly. Place the ground cable as near to the work as possible. Placing the ground cable on the work itself is the best practice, if this is possible. Make sure the clamp is firmly attached to the ground surface. Electrocution could occur if the ground clamp slips off while cutting is being performed. Remember, the ground cable is there to protect the welder from being electrocuted.

4 Shielding Gases in FCAW-G

In the gas-shielded FCAW process (FCAW-G), an additional external shielding gas is used to protect the molten weld metal from the air. This is required for certain flux cored electrodes. The FCAW with sheilding gases is less voltage sensitive than FCAW without shielding gas.

The most common shielding gases used in FCAW-G are carbon dioxide and argon. These can also be mixed to provide the best shielding based on the nature and requirements of the work.

5 Equipment

The FCAW offers a range of equipment accessories. Depending on the volume of work and the work itself, the welder might be using any one of the equipment mentioned below.

FCAW Gun

The gun is what is used to guide the arc, release the shielding gas, if welding FCAW-G, and feed the electrode on the weld. Guns are manufactured in many different sizes. The gun/whip line size chosen must meet the requirements of the welding wire to be used. This determination is based on the rated amperage capacity and by the maximum and minimum wire diameters capable of traveling through the gun/whip line. Another factor that determines the right FCAW gun is the type and amount of welding to be done.

Figure 4A illustrates the different parts of an FCAW-S gun. Figure 4B illustrates the parts of an FCAW-G gun.

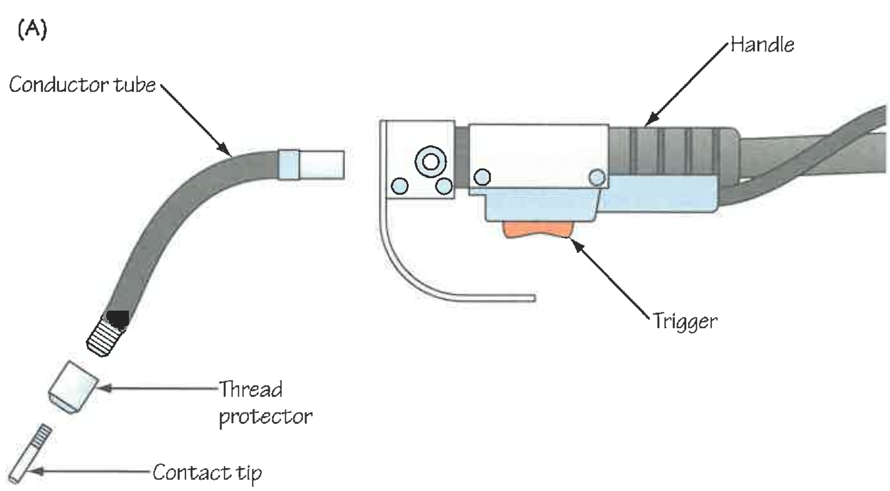


FIGURE 4
(A) Gun for FCAW-S
(continued on next page)

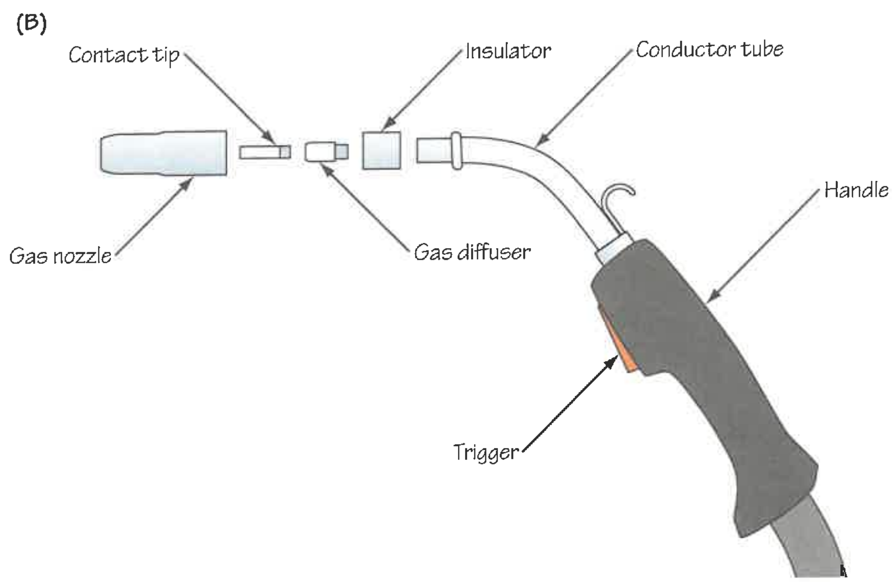


FIGURE 4 (CONTINUED)
(B) Gun for FCAW-G

Nozzles Nozzles for FCAW-G are usually made of copper or copper alloys. They are available in various diameters and lengths. The size chosen should be large enough to allow for gas shielding but small enough to access joints.

SELF CHECK

1. Why would FCAW-G be needed?
2. What is a large disadvantage of FCAW over other wire feed methods?

Wire Feeder

The most common and efficient way to get wire to the gun is through an automated **wire feeder** unit. This unit drives the wire from the roll through the gun/whip line. The wire feeder's speed is adjustable based on the voltage and current requirements. Wire feeders are rated based on the amount of wire they can hold. Some wire feeders are attached externally to the welder. Others are found inside the welder. Still other units are completely separate and attached a great distance from the power source through welding leads for maximum portability and reach.

One of the most common wire feeder designs, a voltage-sensing semiautomatic wire feeder, is shown in Figure 5.

Semiautomatic wire feeders allow the welder to choose a variety of electrode wire. To accommodate the different wire styles, the semiautomatic feeders need to have the wire roll switched.

The wire drive rolls are shaped differently to work best with the electrode needed for a particular welding job. Figure 6 illustrates the various types of drive rolls available and their uses.

FIGURE 5
LN 25 semiautomatic wire feeder

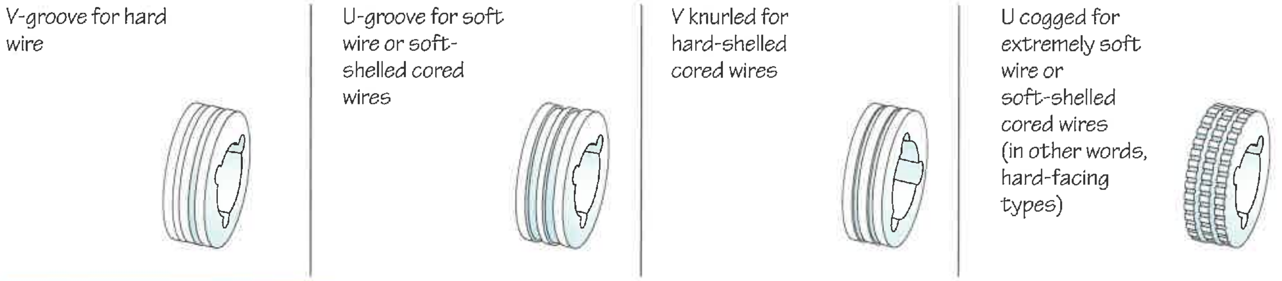


FIGURE 6
Drive rolls

Starting the Arc

To start the arc, use either a running start or a scratch start. A running start is when the arc is started at the beginning of the weld. The welder touches the electrode to the base metal and presses the gun trigger. This starting method often does not allow the electrode to heat up enough before starting and poor bead formation results at the beginning of the weld.

The scratch start is usually preferred. In this method, the arc may be struck on a starting tab or approximately 1″ ahead of where the weld needs to begin. The electrode is then moved back to the starting point.

Equipment Maintenance

It is important to maintain FCAW equipment in good condition in order to work efficiently and well.

- Keep the gun nozzle clean and free of slag and other welding particles.
- Keep the whip lines in good working order.
- Keep power cables (leads) in good shape.
- When a jam occurs in the gun/whip line, learn to quickly shut off the machine to avoid jamming the electrode wire so tight that it cannot be removed.
- Keep the cooling fan clean and clear of debris so it can run at maximum efficiency.
- Always keep an extra spool of electrode wire so that welding can continue when one roll runs out.
- Keep in mind the duty cycle of the welding machine.

6 Flux Cored Wire Electrodes

The flux cored wire electrode contains its own flux in a tubular insert. The internally contained flux serves the same purpose as the shielding gas does. It protects the weld from atmospheric contamination while the weld sets. This type of electrode can be used in the FCAW gun.

In order to work properly, the electrode **stick out** (extension) must be at the manufacturer's minimum for that electrode so that the flux is able to produce enough vapor to shield the weld. If the electrode stick out is too short, the electrode will fail to heat enough to produce the vapor needed to protect the weld. If it is too long, the wire will stick to the metal. It is important that the voltage to amperage ratio be kept as constant as possible to achieve a consistent weld.

There are many varieties of flux cored **filler wire** available on the market. The chemical compositions of continuous flux cored wire electrodes are given in Table 1.

TABLE 1

Chemical compositions of flux cored wire electrode[1]

AWS classification	UNS number	C	Mn	Si	S	P	Cr[2]	Ni[2]	Mo[2]	V[2]	Al[2]	Cu[2]
E7XT-1 E7XT-5 E7XT-9	W07601 W07605 W07609	0.18	1.75	0.90	0.03	0.03	0.20	0.50	0.30	0.08	—	0.35
E7XT-4 E7XT-6 E7XT-7 E7XT-8 E7XT-11	W07604 W07606 W07607 W07608 W076011	n.s but d&r[3]	1.75	0.60	0.03	0.03	0.20	0.50	0.30	0.08	1.8	0.35
E7XT-G	—	n.s but d&r[3]	1.75	0.90	0.03	0.03	0.20	0.50	0.30	0.08	1.8	0.35
E7XT-12	W07612	0.15	1.60	0.90	0.03	0.03	0.20	0.50	0.30	0.08	—	0.35
E7XT-13 E7XT-2 E7XT-31 E7XT-10 E7XT-14 E7XT-GS	W06613 W07602 W07603 W07610 W07613 W07614	n.s.[4]	n.s.[4]	n.s.[4]	n.s.[4]	n.s.[4]	n.s.[4]	n.s.[4]	n.s.[4]	n.s.[4]	n.s.[4]	n.s.[4]

[1] Weight in percentage. Single values are maximums.

[2] Reported only if intentionally added. Aluminum only for self-shielded electrodes; gas-shielded electrodes need not have significant additions.

[3] Not specified, but determined and reported.

[4] Not specified.

Figure 7 shows how the classification system works for tubular flux cored electrodes.

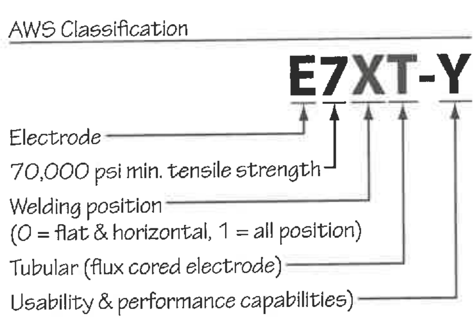


FIGURE 7
FCAW flux cored wire

SELF CHECK

1. In what different ways can wire be fed for FCAW-S?
2. How do welders distinguish different kinds of electrode wire?
3. Why is it important to extend the electrode stick out the proper distance from the nozzle/contact tip?

7 Welding Basics

Several factors will influence the quality of a weld. These factors need to be adjusted based on the type of metal being welded, its thickness, the position of the welding that is being done, the required deposition rate and the welding specifications.

Welding Variables

Each of the factors below influences the others. Therefore, when changing one, another is affected as well. Knowing how these variables interact and establishing the correct combination of the variables will result in a good, solid weld.

Welding Amperage (Electrode Feed Speed) The manufacturer of the electrode sets parameters that the electrode is capable of being properly operated within, such as in between 150 inches per minute (ipm) and 375 ipm. This has to be balanced to the proper amount of voltage.

Polarity The electrode manufacturer determines which polarity should be used with which electrode. The most common with FCAW electrodes is electrode negative, but with some few FCAW electrodes, electrode positive is needed.

Arc Voltage (Arc Force) The manufacturer of the electrode sets parameters of voltage for proper operation of the electrode, such as between 18 volts and 32 volts. The welder controls the voltage within the manufacturer's range to best balance the voltage-to-amperage ratio, which is determined by the electrode feed speed.

Travel Speed The amount of weld bead that can be applied over a given period of time is the **travel speed**. It is measured in inches per minute (ipm). It is determined by the electrode feed speed balance to the voltage. For example: if the electrode feed speed is set at 275 ipm and the voltage is set at 22 volts, the travel speed is 14″ of 5⁄16″ bead per minute (ipm).

Electrode Extension The electrode extension, commonly referred to as stick out, is the distance between the end of the contact tip and the metal to be welded. It is set by the manufacturer. For example: the electrode stick out range is between ½″ and 1″ and the optimum stick out is ¾″, providing that the electrode feed speed is balanced with the proper amount of voltage. Fluctuations in stick out length affect the ratio of voltage to amperage, which affects the quality of the welding bead.

Electrode Orientation (Trail or Lead Angle) The orientation of the electrode refers to its position in relationship to the weld puddle and whether the weld is being pushed or pulled. This depends on the electrode being used; some create a better weld bead when pushed, other when pulled.

Electrode Diameter The diameter of the tubular electrode is measured in millimeters or inches. Common sizes are .030mm, .035mm, .045mm, .068mm, .072mm, 1⁄16″, 5⁄64″, and 3⁄32″.

Electrode Composition The chemical makeup of the inner flux and the tubular wire that together make up the FCAW electrode affects the strength and quality of the weld. Choice of electrode will depend on the parent metal.

Weld Joint Design A welder who is not qualified on the particular design of the joint being welded may produce an inadequate weld.

Shielding Gas In FCAW-G, the strength and quality of the weld will depend on the shielding gas used, as will the travel speed.

Flow Rate The volume of shielding gas needed in FCAW-G to protect the welded bead as it cools is an important variable. If not enough shielding gas is used, the quality of the weld may not be as good; if too much is used, the welding bead will cool too quickly and the weld may crack.

Gun Angle

There are two angles to be aware of when holding a FCAW gun: the travel angle of the gun and the work angle. Guns may be moved via a drag or a push angle. See Figure 8 for an illustration of gun angle and movement.

When welding in the flat position, it is usually best to hold the gun between a 5° angle and a 15° angle. Be careful not to change the angle as the end of the weld approaches.

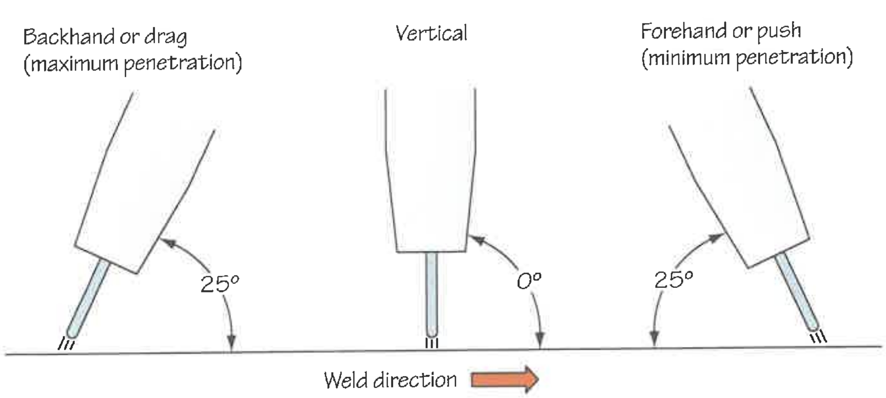


FIGURE 8
Push and drag angle

Summary

Flux cored arc welding is useful on both ferrous and nonferrous metals. It involves an electric arc and a consumable electrode that contains a flux. In one form of this process (FCAW-S), no external shielding gas is required because the flux inside the electrode changes to a gas when heated. Another version of flux cored arc welding (FCAW-G) does utilize a shielding gas.

Flux Cored Arc Welding (FCAW) QUESTIONS

Show your understanding of the information in this chapter by answering the questions and filling in the blanks below.

1. There is only one type of flux cored metal arc welding process. (True; False)
2. The electrodes in FCAW provide the ______________ gas to protect the weld.
3. ______________ ______________ and ______________ are the most common shielding gases used in the gas-shielded flux cored arc welding (FCAW-G) process.
4. Most FCAW welding uses DCEN. (True; False)
5. FCAW will work on ______________ and ______________ metals.
6. Deposition rate is very high in flux cored arc welding. (True; False)
7. How are wire feeders rated?

   ____

   ____
8. The electrodes used in FCAW have a tubular insert that contains a(n) ______________ which becomes a gas when heated by the arc.
9. As the wire feed speed increases, the ______________ increases.
10. The voltage to amperage ratio is not very important in FCAW. (True; False)

1 Gas Tungsten Arc Welding Safety

As with most welding processes, gas tungsten arc welding (GTAW), also called TIG welding, produces radiation, sparks, and fumes. GTAW also involves electricity, which means there is an opportunity for shock. There are several safety precautions that should be taken before beginning to weld.

Personal Protection Gear

To prevent contact with sparks and flying particles, welders should wear the following personal protective equipment (PPE):

- Wear dry, insulated gloves that have no tears or holes.
- Wear protective well-fitting garments such as leather gloves, a heavy shirt, cuffless pants, leggings, high shoes or pull-on boots or boots with leather laces, and a cap.
- Wear approved safety goggles with side shields in addition to wearing a welding hood or helmet with a shade rating no less than recommended for the process.
- Use approved helmets or hoods that protect the face, neck, and ears.
- Wear leggings, aprons, sleeves, shoulder covers, and bibs.
- Wear flame-resistant earplugs, protective earmuffs, or both.

SAFETY TIP

Never carry matches or butane lighters and never wear polyester when welding.

Fumes and Gases

Gas tungsten arc welding produces metal fumes and a number of gas by-products. The metal fumes can be controlled through natural ventilation, local exhaust, or by the welder wearing respiratory protective equipment.

Welding coated metals presents a greater health hazard than welding non-coated materials. Always ask a supervisor for specific safety-related issues or consult a Safety Data Sheet (SDS) if applicable, before starting. It is important for the welder to stay out of the smoke plume and to keep it as far away as possible from his or her face.

The gases that are a by-product of gas tungsten arc welding include ozone and nitrogen dioxide. These are both hazardous gases when breathed in high enough concentrations. It is important to observe all ventilation safety rules when welding.

Ozone The ultraviolet light emitted from the arc interacting with the surrounding oxygen produces *ozone*. The amount of ozone produced depends upon the amount of ultraviolet light and the humidity, among others things. The ozone concentration will also increase when using argon as the shielding gas and when welding highly reflective metals. Natural ventilation should reduce the concentration of ozone to safe levels. However, if natural ventilation is not sufficient, make sure that the area receives a fresh air supply or the welder wears a respirator.

Nitrogen Dioxide High concentrations of *nitrogen dioxide* are found only within 6" of the arc. This gas quickly dissipates with normal ventilation and should not be hazardous to the welder. However, it is important for the welder to stay away from the welding fumes.

Inert Shield Gases *Inert* shield gases, such as argon and helium, while not normally harmful, can become a danger if too much builds up in an enclosed area. This is yet another reason to make sure the welding area is adequately ventilated.

Radiation

Intense bright flashes of light at a construction site are a sure sign that welding is taking place. That bright light is one of the radiation hazards of welding. There are two types of radiation.

- ionizing radiation
- non-ionizing radiation

The first kind of radiation, ionizing radiation, is present in the dust created during the grinding of thoriated tungsten electrodes for gas tungsten arc welding. Ionizing radiation is capable of displacing electrons from atoms, creating charged atoms or ions. Ionizing radiation is extremely harmful to all living beings. Excessive exposure to ionizing radiation poses a health risk.

The other kind of radiation, non-ionizing radiation, occurs in just about every other kind of welding except resistance, or spot, welding and cold-pressure welding. There are three types of non-ionizing radiation: visible, infrared, and ultraviolet.

The welder can see the visible radiation in the form of light but infrared and ultraviolet cannot be seen. Infrared and ultraviolet light, along with visible light, are present when most welding processes are conducted. Non-ionizing radiation can cause eye damage and skin burns. When arc welding or observing arc welding, it is necessary to observe the following safeguards.

- Wear proper eye and skin protection, even if the work is of very short duration.
- Wear appropriately shaded helmets or shields and goggles.
- Avoid wearing contact lenses.
- Wear appropriate gloves to protect hands and upper arms and to keep hands dry.
- Wear clothing to protect the neck area, such as cap sleeves, shoulder covers, and bibs.

Gas tungsten arc welding produces higher radiant energy than shielded metal arc welding. This is due to higher arc energy; fewer welding fumes, and a longer arc. Ultraviolet light from GTAW can cause a *flash burn* up to 50'-0" away from the arc. Move combustible materials away from the area

SAFETY TIP

Gas tungsten arc welding requires a higher shade of lens and heavier clothing to protect skin from being burned than other kinds of welding.

where welding is occurring. If that is not possible, set up protective screens around the work area.

Electrical Hazards

Gas tungsten arc welding uses voltages ranging up to 85. As with any electrical welding process, take care not to come into contact with the voltages. The tungsten electrode is electrically charged. To avoid electric shock, never touch the electrode, and follow these general precautions.

- Keep all electrical circuits dry.
- Keep all electrical ground connections mechanically tight.
- Only use cables that are designed to carry the amount of voltage that will be used.
- Make sure the cable is in good repair.
- Do not touch live circuits.
- When replacing torch parts, make sure that all power to control circuitry is disconnected.
- Always practice safe welding techniques.

SAFETY TIP

Always attach the ground cable securely to the workpiece.

In addition to the rules listed above, always use the ground cable properly. Place the ground cable as near to the work as possible. Placing the ground cable on the workpiece itself is the best practice, if this is possible. Make sure the clamp is firmly attached to the ground surface.

SELF CHECK

1. What are some specific dangers associated with gas tungsten arc welding?
2. How can an inert gas be harmful?

2 What Is Gas Tungsten Arc Welding?

By combining a nonconsumable tungsten or tungsten alloy electrode with an electric arc and a shielding gas in **gas tungsten arc welding** (**GTAW**), also called **TIG welding**, superior quality welds can be made on almost all metals, both *ferrous* and *nonferrous*.

Gas tungsten arc welding process uses a nonconsumable tungsten electrode to create the arc. The welding arc is formed between the nonconsumable tungsten and the base metal. The heat generated by the arc melts the parent metal. Once the weld pool is created, the torch moves along the joint and the arc continues to melt the surface. Filler metal, if used, is added to the weld separately, making the process very flexible. TIG welds can be excellent in quality because a wide variety of filler metals are available and may be matched to the parent metal.

Figure 1 illustrates how the gas tungsten arc welding process is performed.

Starting an Arc

There are several options to starting the GTAW unit. One method is the high-frequency start. Another is the scratch or touch start.

High-Frequency Starts The *high-frequency start* can be used in both AC and DC power sources. A spark-gap oscillator pulses a series of high frequency bursts in line with the welding circuit. The high voltage ionizes the gas between the electrode and the work. The ionized gas is then able to conduct a welding current that initiates the welding arc.

Because high-frequency radio waves are generated using this method, any nearby computers or radios might malfunction. The Federal Communications Commission regulates this type of starting and the user should follow the manufacturer's instructions for proper starting technique.

Scratch Start The *scratch start* begins with the power supply energized and the shielding gas flowing. The torch should be lowered enough to just make contact with the work then quickly withdrawn. It is similar to striking a match. The act of withdrawing the torch will initiate the arc. While this method is simple, the electrode has a tendency to stick to the work. This results in contamination of the electrode as well as tungsten contamination of the work.

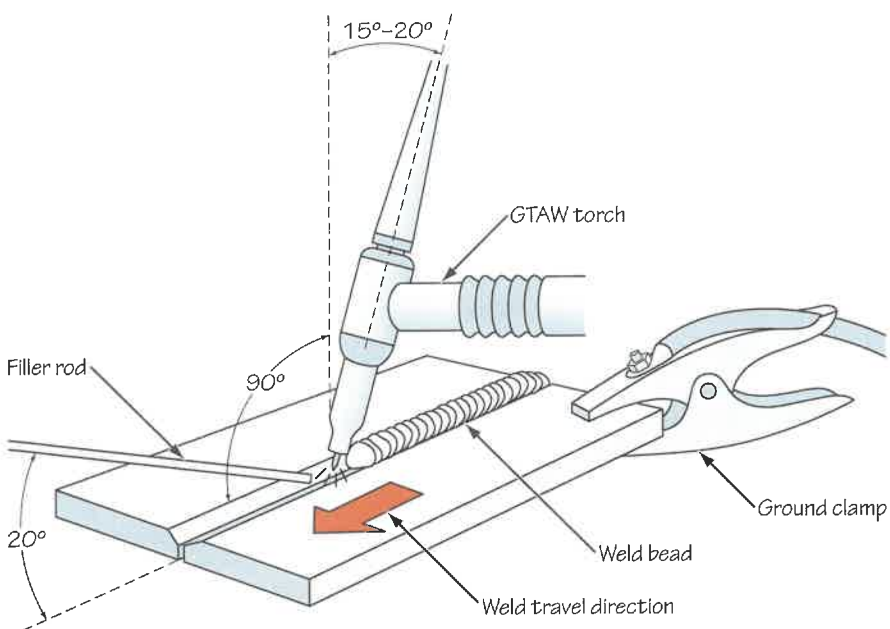


FIGURE 1
Gas tungsten arc welding

Current GTAW is available in **direct current** (**DC**) or **alternating current** (**AC**). Direct current is usually used with electrode negative. **DCEN** (**direct current electrode negative**), also called **straight polarity**, is most frequently used in GTAW. It provides the greatest amount of heat and the deepest weld penetration. The shield gases most commonly used with DCEN are argon, helium, or a mixture of the two. Use of DCEN requires special attention before welding due in part to poor oxide cleaning action.

Much less frequently used, **DCEP** (**direct current electrode positive**), also called **reverse polarity**, creates a cleaning action on the work, especially aluminum. DCEP requires a larger-diameter electrode. This polarity is mainly used to weld sheet metal. DCEP is not recommended because of the high heat generated on the tungsten.

AC welding combines the deep penetrating weld of DCEN with the cleaning action of DCEP. When balanced, AC welding also provides better oxide removal. If the base metal allows, TIG welders prefer using alternating current (AC) because of the cleaning action rather than direct current (DC).

SELF CHECK

1. Why is a scratch start often better than a high-frequency start?
2. Is filler wire required with GTAW?

3 Tungsten Electrodes

The element **tungsten** is a hard, brittle, corrosion-resistant, gray to white metal. It has the second highest melting point of all metals, 6,170° Fahrenheit (F). Only carbon has a higher melting point (6,740° F). Tungsten electrodes are not consumed during welding, but as the point of a tungsten electrode dulls, it must be reground, causing tungsten loss.

There are many varieties of tungsten. Plain tungsten is used for AC welding. Tungsten with 1 percent zirconium is also good for AC welding. Thoriated tungsten electrodes are used with DCEN, also called straight polarity, welding. These electrodes run cooler and the tips do not become molten, unlike pure tungsten electrodes.

Tungsten electrodes come in different mixtures: pure, or plain, tungsten, 1 or 2 percent thoriated, mixed with 1 or 2 percent thorium respectively, or zirconiated, mixed with zirconium.

Tungsten Electrode Color Identification

Each piece of tungsten is color coded on one end. Color coding is added for electrode identification and safety concerns. It also serves as a method to attain a sound efficient weld by selecting the correct electrode. The color coding for tungsten electrodes is shown below.

- Green band = pure tungsten for general purpose use for a variety of metals; usually reserved for alternating current on aluminum, etc. because it is more expensive
- Yellow band = 1 percent thoriated tungsten, providing easy starts, good arc stability, and resistance to weld puddle contamination.
- Red band = 2 percent thoriated tungsten, providing very easy starting, great arc stability, high current capacity, long life, and even better resistance to weld puddle contamination.
- Brown band = A zirconium tungsten electrode, which has a long life when performing certain AC welding tasks, but is very expensive.

It is important not to accidentally remove this identifying information by grinding the tungsten electrode at the color-coded end.

TRADE TIP

Do not grind or ball the colored end of the tungsten electrode. That end contains the electrode identification information.

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Electrode Sizes and Current Capacities

Choosing the correct size tungsten or thoriated tungsten electrode is important for creating good welds. At the correct current levels, the tungsten electrode cannot be consumed. However, if the correct levels of current are exceeded, the tungsten will erode or melt. Also, pieces of the tungsten electrode may fall into the weld pool and cause defects in the weld. If the current levels are below those recommended for a certain size electrode, arc instability may result.

Table 1 shows the recommended tungsten electrodes for specified currents.

How much current a tungsten electrode can take depends on the following variables.

- type of shielding gas
- electrode length beyond holder, also called stick out
- post flow for electrode cooling
- current type

TRADE TIP

For every .001″ of material, 1 amp of current is required.

A general rule is to select an electrode with the smallest diameter possible that will not result in melting the tungsten at the chosen current. See Table 1.

Tungsten Electrode Preparation

Although tungsten electrodes are considered nonconsumable, they can erode or melt if used improperly. Preparing a tungsten electrode involves grinding the end into either a pencil or into a rounded, balled point.

Creating a Tapered Tip Grinding should take place on a grinding wheel devoted only to grinding tungsten electrodes. The tungsten must not be contaminated with other materials that might come into contact with a general-purpose grinder.

TRADE TIP

Select one bench grinder and mark it "Tungsten Only!" Use it only for sharpening tungsten electrodes.

TABLE 1

Guide for nozzle selection, current setting, and shield gas flow

Electrode diameter in inches (mm)	Cup size	Welding current (Amps) tungsten type				Argon flows ferrous metals		Argon flow aluminum	
		AC pure	AC thori-ated	DCEN pure	DCEN thori-ated	Standard body CFH (L/MN)	Gas lens body CFH (L/MN)	Standard body CFH (L/MN)	Gas lens body CFH (L/MN)
.020 (0.50)	3, 4 or 5	5–15	5–20	5–15	5–20	5–8 (3–4)	5–8 (3–4)	5–8 (3–4)	5–8 (3–4)
.040 (1.00)	4 or 5	10–60	15–80	15–70	20–80	5–10 (3–5)	5–8 (3–4)	5–12 (3–6)	5–10 (3–5)
1/16 (1.60)	4, 5 or 6	50–100	70–150	70–130	80–150	7–12 (4–6)	5–10 (3–5)	8–15 (4–7)	7–12 (4–6)
3/32 (2.40)	6, 7 or 8	100–160	140–235	150–220	150–250	10–15 (5–7)	8–10 (4–5)	10–20 (5–10)	10–15 (5–7)
1/8 (3.20)	7, 8 or 10	150–210	220–325	220–330	240–350	10–18 (5–9)	8–12 (4–6)	12–25 (6–12)	10–20 (5–10)
5/32 (4.00)	8 or 10	200–275	300–425	375–475	400–500	15–25 (7–12)	10–15 (5–7)	15–30 (7–14)	12–25 (6–12)
3/16 (4.80)	8 or 10	250–350	400–525	475–800	475–800	20–35 (10–17)	12–25 (6–12)	25–40 (12–19)	15–30 (7–14)
1/4 (6.40)	10	325–700	500–700	750–1000	700–1100	25–50 (12–24)	20–35 (10–17)	30–55 (14–26)	25–45 (12–21)

TRADE TIP

After grinding a taper, flatten the tip slightly by touching it to the diamond wheel.

One of the most important aspects of electrode preparation when welding with direct current is grinding the correct **taper**. Tungsten electrodes are manufactured with the grain running longitudinally (lengthwise). This allows the electrons flowing on the outer edges of the electrode to travel with more density. Knowing this makes it easier to understand why it is important to grind the taper lengthwise and concentric to the electrode. Grinding the taper lengthwise allows the electrons to flow steadily and directly to the point of the electrode. It allows for good starts and keeps the heat concentrated at the point of the electrode. See Figure 2.

If the taper is ground crosswise to the electrode, the electrons are forced to jump across the grinding ridges, causing the electrons to wander and spread out before reaching the tip creating a wide gap. This is also shown in Figure 2.

The angle of the tip selected is another factor that impacts weld penetration and arc shape. Generally, as the angle is increased the weld penetration increases and bead width narrows. Guidelines for proper tungsten selection, diameters and tapers are published in welding manuals, charts, and AWS. As a rule, a larger-diameter tungsten runs cooler and will last longer even with higher amperages. A tradeoff to a larger-diameter electrode is a less stable, hard to control arc at lower amperages.

Creating a Balled Tip Pure tungsten, plain end, or zirconiated tungsten, brown stripe, is used with alternating current to weld aluminum. This requires the tungsten tip to be shaped like a ball or rounded on the tip instead of pointed. This is usually accomplished by striking the arc on a piece of copper, holding the arc until it stabilizes or becomes incandescent. A ball is formed on the tip.

The ball must not be over 1.5 times the diameter of the electrode. If the ball is larger than this then the current setting is too high and should be lowered. The balled-point electrode is used on aluminum or aluminum alloys. Figure 3 shows a correctly shaped balled electrode.

Cutting Tungsten One safe method to cut tungsten is with a diamond wheel. Estimate the required length, then cut straight through the tungsten.

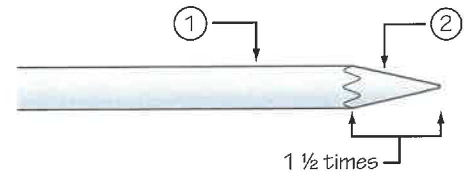
Many times a tungsten electrode is ruined because improper techniques are used to shorten it, for example to remove a contaminated end. The most common mistakes made to shorten the electrode include the following.

- using wire cutters to snip the tungsten
- breaking it off with the hands
- snapping the tungsten between two pairs of pliers
- grinding a notch on the side and snapping the tungsten
- striking the tungsten with a hammer on a sharp corner

Remember, tungsten is very brittle and, if handled improperly, it may shatter. This can cause serious eye injury or cuts.

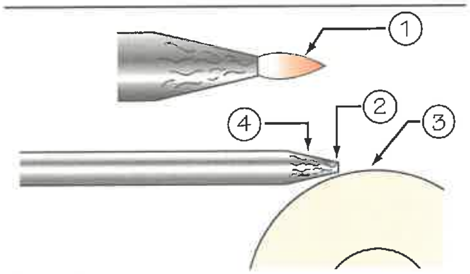
If cared for, the tungsten electrode will have a long useful life. However, there are certain factors that can shorten the useful lifespan of a tungsten electrode.

- welding at too high a current for the size or type (see chart)
- oxidation formed when shielding gas is cut off too soon in the cooling-off process
- contamination by other metal caused by touching the electrode to the filler rod or parent metal
- contamination from low shielding gas flow
- contamination from turbulence caused by high shielding gas flow



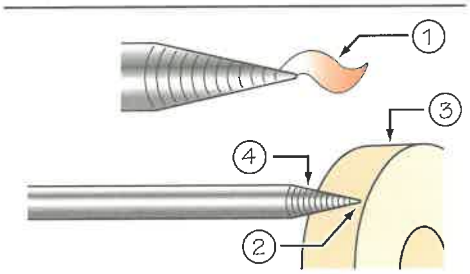
1 Tungsten electrode
2 Tapered end

Grind end of tungsten on fine-grit, hard, abrasive wheel before welding. Do not use wheel for other jobs or tungsten can become contaminated causing lower weld quality.



Ideal tungsten Preparation—stable arc

1 Stable arc
2 Flat
3 Grinding wheel
4 Straight ground



Wrong tungsten Preparation—wandering arc

1 Arc wander
2 Point
3 Grinding wheel
4 Radial ground

FIGURE 2
Tungsten electrode preparation

SAFETY TIP

The only safe way to cut tungsten is on a diamond wheel.

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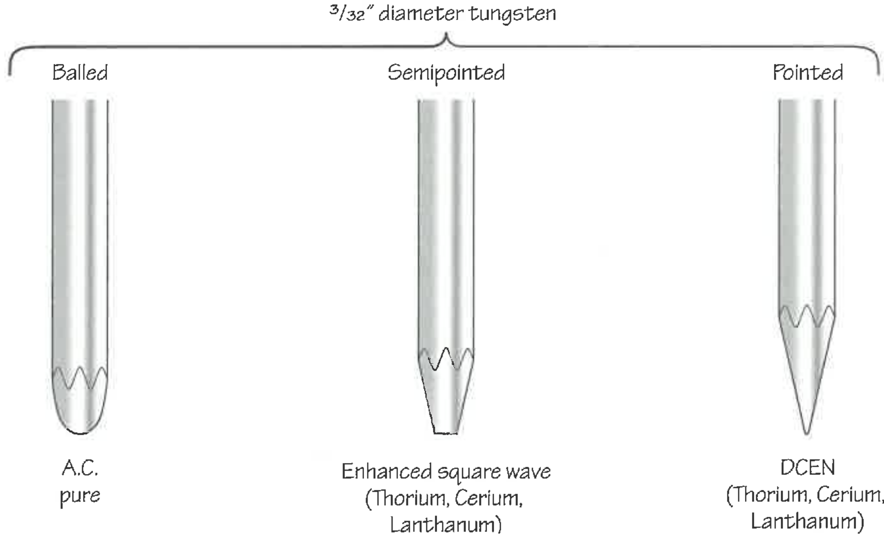
FIGURE 3
Balled electrode



SELF CHECK

1. What quality of tungsten makes it a good electrode for GTAW?
2. How can a tungsten electrode be damaged?

4 Shielding Gases

Shielding gases in gas metal arc welding function by protecting the weld from oxygen, nitrogen, and hydrogen contamination during the critical cooling period. Several inert gases are used as a shield gas in the GTAW, but certain gases work better on certain metals.

Argon and helium and mixtures of the two are good overall shielding gases for most jobs. These gases do not react with the tungsten electrode because they are chemically inert. Hydrogen and nitrogen are also used as shield gases. Special gas mixtures are available which work better with certain metals.

Flow Rate

An important consideration when TIG welding is setting the correct shielding gas flow rate, for **preflow** welding, and post flow. It is very important to know if the ball in the flow meter is read from the center of the ball or from the top of the ball. Many newer gauges use the top of the ball for setting the correct flow. On multigas meters check that the proper scale is being used.

Setting the Flow When Welding Charts are available to show what gas and flow rate is needed for various metals and electrodes. Use a chart to find the correct flow for the diameter of the tungsten electrode and base metal being welded. The GTAW torch must be purged before the flow rate is set.

Pre-Flow The time interval between the start of shielding gas flow and the arc starting. It purges atmosphere from welding area before arc starts.

Setting Post Flow The post flow is the flow of shielding gas after welding has ceased. The flow of protective shielding gas must be maintained until the base metal has had a chance to cool. It allows the weld to solidify without contamination from the atmosphere. The post flow allows the tungsten electrode to cool in the shielding gas as well, protecting it from atmospheric oxidation.

One way to set the post flow duration, when welding aluminum for example, is to strike an arc on a piece of copper and let the arc stabilize—the tungsten end should ball and look incandescent. Break the arc and watch the gauge on the flow meter. Correct the setting as necessary.

With this procedure the welder not only sets the post flow, he or she performs a second important task: cleaning the tungsten electrode itself. The extreme heat created by the arc on the copper plate vaporizes any oxidation on the tungsten.

As a rule of thumb, the post flow time limit should equal the decimal equivalent of the electrode diameter in seconds. For example, a ⅛″ electrode is .125″. Using this rule of thumb, the post flow rate should continue 12.5 seconds after the arc is broken. If the post flow is not set long enough, the tungsten electrode will cool in the atmosphere. This will allow it to oxidize and turn blue or black. Charts are also available that give post flow durations for different diameter electrodes.

5 The GTAW Torch

The GTAW torch supplies the current, the electrode, and the shielding gas to the welding zone. The working parts of a torch are the body, a *collet* or clamp, a collet nut, a nozzle, and the electrode. See Figure 4 for a cross-sectional drawing of the torch.

Torches are rated in size by the amount of current they can safely handle.

TRADE TIP

Keep the torch tip where the welding stopped during the post flow.

Torch Cooling Systems

Torches can be either gas-cooled, sometimes called air-cooled, or water-cooled. In gas-cooled torches, the cooling is provided by the inert shielding gas flowing through the torch. Gas-cooled torches are limited to a maximum current of 200 amps.

Water-cooled torches are fitted with hoses that allow water to circulate throughout the torch. The water is common tap water that is either connected to a constant source or a closed system. The closed system contains a reservoir, pump, and a radiator or water chiller. Water-cooled torches are more efficient at shedding heat than gas-cooled ones. They can typically handle 300 to 500 amps. There are some water-cooled torches that can handle up to 1,000 amps.

Most machine or automatic welding applications use a water-cooled torch.

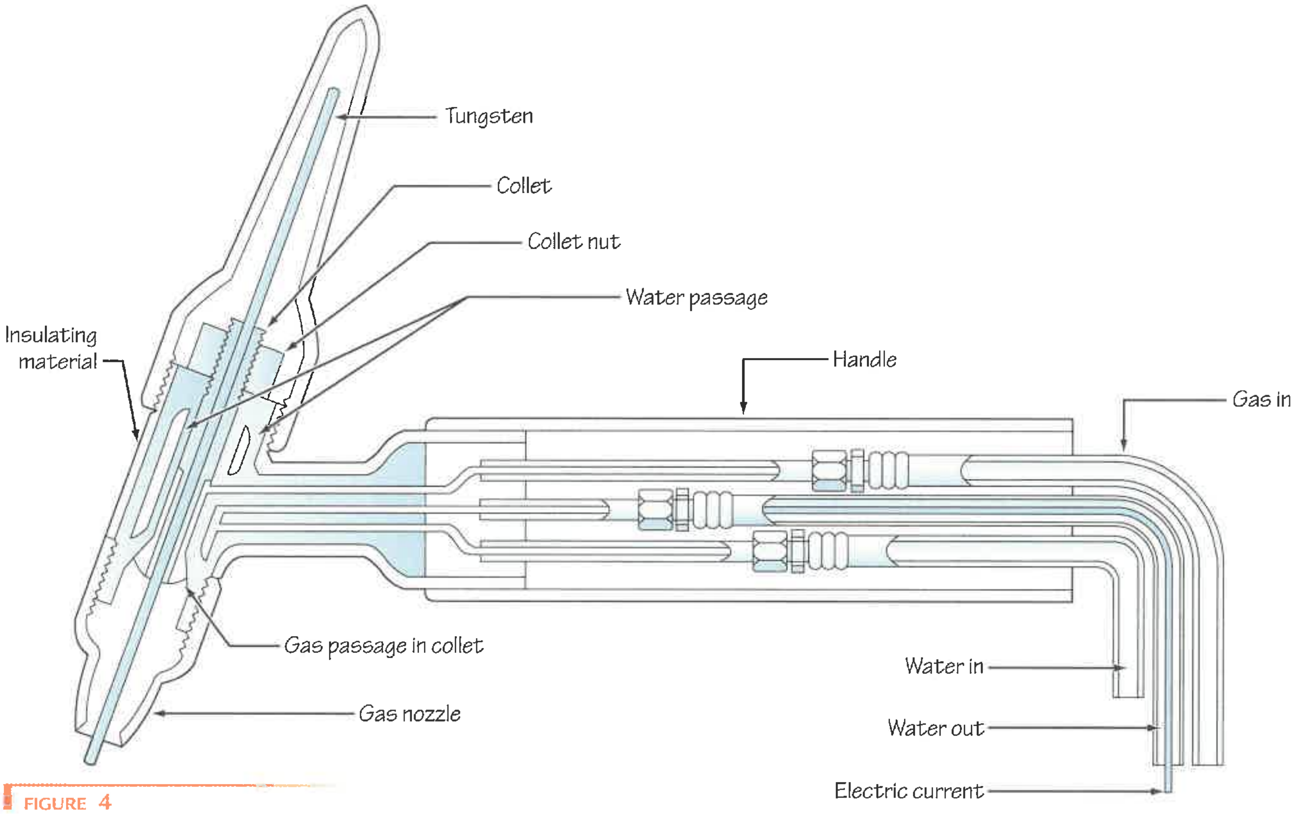


FIGURE 4
GTAW welding torch

Nozzles

Nozzles are made from metal or, most commonly, ceramic. Ceramic nozzles are air-cooled and very brittle. Use common sense when handling the TIG torch so as not to break the nozzle.

Nozzle selection depends on electrode size and amperage. A general rule of thumb for nozzle selection: inside diameter (i.d.) of the nozzle should be four to six times the electrode diameter. A nozzle that is too small will overheat, causing it to deteriorate and break. An overheated nozzle is also more susceptible to contamination.

Nozzles are generally classified with a numbering system such as 4, 5, 6, and so on. The numbers represent the nozzle size in sixteenths of an inch. For example, a #6 nozzle represents 6⁄16″ or 3⁄8″ i.d.

SELF CHECK

1. What is involved in preparing a tungsten electrode?
2. What two methods are used to cool GTAW torches?

6 GTAW Welding Basics

As with other welding techniques, there are five essentials for good TIG welds.

- correct electrode
- correct amperage
- correct welding gap
- correct travel speed
- correct electrode angle

The key to making good welds with the GTAW process is to use the lowest machine setting possible for the metal being welded. Applying just the right amount of heat at the right place for the right amount of time is the recipe for a good TIG weld.

The shape of the tungsten electrode is also important. If welding light-gauge carbon or stainless steel or if concentrating heat in a small area, an electrode sharpened to a point should be used. When welding aluminum or magnesium with sine wave AC, use an electrode with a balled end.

Maintain a short arc and direct the arc only to the spot that needs to be welded. Straying from this area will distort and deteriorate the metal.

Once the correct area is molten, do not linger too long there. If a filler rod is used, move the rod out with the arc and then carry the correct amount back to the weld zone to gain uniform distribution. Use a rod one size smaller than the thickness of the workpiece.

How far the tungsten electrode should be extended beyond the nozzle depends on the shape of the work and the type of joint. Remember, the farther the extension, the less effective the shielding gas.

DCEN is recommended for welding mild steel and stainless steel. A thoriated tungsten electrode gives the best results when welding on these metals. The nozzle should be held as close as possible to the work, allowing room for the welder to see the **root pass**, which is the first welding bead.

When cleaning the base metal, a stainless steel brush must always be used, or the weld will be ruined.

TRADE TIP

Never use anything but a stainless steel wire brush in TIG welding.

Fuse Weld

A fuse weld is a weld made without the use of a filler rod. This requires the two pieces of compatible metal to fit well together before welding starts. To weld, both pieces need to be heated simultaneously so that the molten metal pools together. A circular heating motion works well for fuse welding.

Filler Wires

A **filler wire**, also known as a **filler rod** or **filler metal**, is used to help bridge gaps in metal that need to be joined. Filler wire is also useful for joining dissimilar metals. Filler metals are chosen based on the following criteria.

- job requirements
- job metal type
- welding ease
- characteristics needed (strength, hardness, etc.)
- preheat and postheat requirements
- color match
- shielding gas used

7 Troubleshooting

Table 2 lists common problems and solutions for GTAW welding.

TABLE 2

GTAW troubleshooting guide

Problem	Cause	Remedy
Wasteful electrode consumption	1. Improper inert shielding (resulting in oxidation of electrode)	1. Clean nozzle; bring nozzle closer to work; step up gas flow, shorten tungsten extension from electrode holder.
	2. Operating on electrode positive	2. Employ larger electrode or change to electrode negative.
	3. Improper size electrode for current required	3. Use larger electrode.
	4. Excessive heating in holder	4. Use ground finish electrodes; change collet; check for improper collet contact.
	5. Contaminated electrode	5. Remove contaminated portion—erratic results will continue as long as contamination exists.
	6. Electrode oxidation during cooling	6. Keep gas flowing after stoppage of arc for at least 10–15 seconds. Rule: 1 second for each 10 amps.
Erratic arc	1. Dirty, greasy base material	1. Use appropriate chemical cleaners, stainless steel wire brush, or abrasives.
	2. Joint too narrow	2. Open joint groove; bring electrode closer to work; decrease voltage.
	3. Contaminated electrode	3. Remove contaminated portion of electrode.
	4. Electrode diameter too large	4. Use smaller electrode—use smallest diameter needed to properly handle current.

(continued)

TABLE 2 *(continued)*

GTAW troubleshooting guide

Problem	Cause	Remedy
Porosity	1. Entrapped gas impurities (hydrogen, nitrogen, air, water vapor)	1. Purge air from all lines before starting arc; remove condensed moisture from lines; use welding grade (99.995%) inert gas.
	2. Possible use of old acetylene hoses	2. Use only new hoses. Acetylene impregnates hose.
	3. Gas and water hoses interchanged	3. Never interchange water and gas hoses. (Color coding helps.)
	4. Oil film on base material	4. Clean with chemical cleaner not prone to break-up in arc. Rule: do not weld while wet!
Tungsten contamination of workpiece	1. Scratch starting with electrode	1. Use high-frequency starter; lift arc.
	2. Electrode melting and becoming an inclusion in the weld base plate	2. Use less current or larger electrode; use cerium, lanthanum, thorium, or zirconium tungsten (these run cooler).
	3. Shattering of electrode by thermal shock	3. Make certain electrode ends are not slivered or cracked when using high current values; use embrittled tungsten to facilitate easy and clean breakage; properly grind tungsten.

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SELF CHECK

1. How far should the tungsten electrode extend from the torch?
2. When should a filler rod be used?

Summary

Gas tungsten arc welding (GTAW) is a versatile and very powerful welding process. GTAW works well on all commercial metals. It utilizes a nonconsumable tungsten electrode and a shielding gas, and sometimes a filler metal. This welding technique can be used with a variety of power sources and currents.

Gas Tungsten Arc Welding (GTAW) QUESTIONS

Show your understanding of the information in this chapter by answering the questions and filling in the blanks below.

1. ______________ and ______________ and mixtures of them are the two gases normally used as shielding gas in GTAW.
2. List three methods that can be used to avoid breathing in metal fumes while performing TIG welding.

   ____

   ____

   ____
3. GTAW can be used on all ______________ metals.
4. The tungsten electrode must be replaced after every use. (True; False)
5. Filler wires are used when two ______________ metals are welded.
6. What color code is pure tungsten? ______________
7. Torches are rated by the kind of tungsten they use. (True; False)
8. What size is a # 4 nozzle in sixteenths of an inch? ______________
9. What is the only kind of wire brush to be used to clean the welds in TIG welding?

   ____
10. Give three reasons for an erratic arc.

   ____

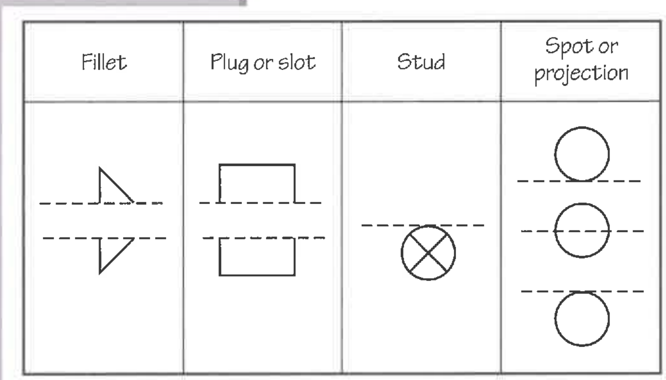
   ____

   ____

CHAPTER 13

Weld Symbols

CONTENTS



INTRODUCTION

Weld symbols are used to give instructions. These symbols appear on engineering drawings and tell a welder exactly what to weld, where to weld, what type of welds to make, and what welding process to use, among other things. Some symbols are required, that is, they are used on every drawing. Other symbols are optional and whether they appear or not is dependent upon the engineer or the project requirements. The weld symbols shown in this chapter are drawn in accordance with AWS standards.

Knowing what the symbols are and how to read them will result in better communication and welding quality.

KEY TERMS

Key Terms are in order of appearance.

weld symbols lines formed in a certain way that indicates welding actions that should take place

reference line information about the welding process is located on this line; a required weld symbol

arrow indicates the part of a reference line applying to the nearest joint while information on the other side of the arrow applies to the farthest joint; a required weld symbol

tail used only when there is additional information supplementing the required instructions found on the reference line

weld-all-around circle around the junction of the arrow and the reference line

field weld flag that juts away from the reference line, indicating that a weld should be made at the installation point or the place of construction, not at the shop

melt-through solid half circle attached to the reference line, indicating complete joint penetration with root reinforcement in welds made from one side

consumable insert empty box affixed to the reference line opposite a groove-weld symbol

backing box that sits on top of the reference line and indicates that a backing strip or bar should be used when making the weld

spacer rectangle that sits within the reference line and indicates that a joint spacer should be used

contour symbol line drawn above the reference line that indicates the shape of the finished weld

OBJECTIVES

Upon successful completion of this chapter, the participant should be able to:

1. Describe the basic weld symbols.
2. Describe the optional symbols.

1 Weld Symbols

When welding instructions need to be given on a drawing, engineers and foremen use **weld symbols** to communicate. There are two classes of symbols: required and optional.

Required symbols are those that must appear on the drawing. These symbols consist of the reference line and the arrow. Additional information that may be provided but is not required uses optional symbols. Optional information includes the dimensions and other data, finishing symbols, specification process or other references, and supplementary symbols.

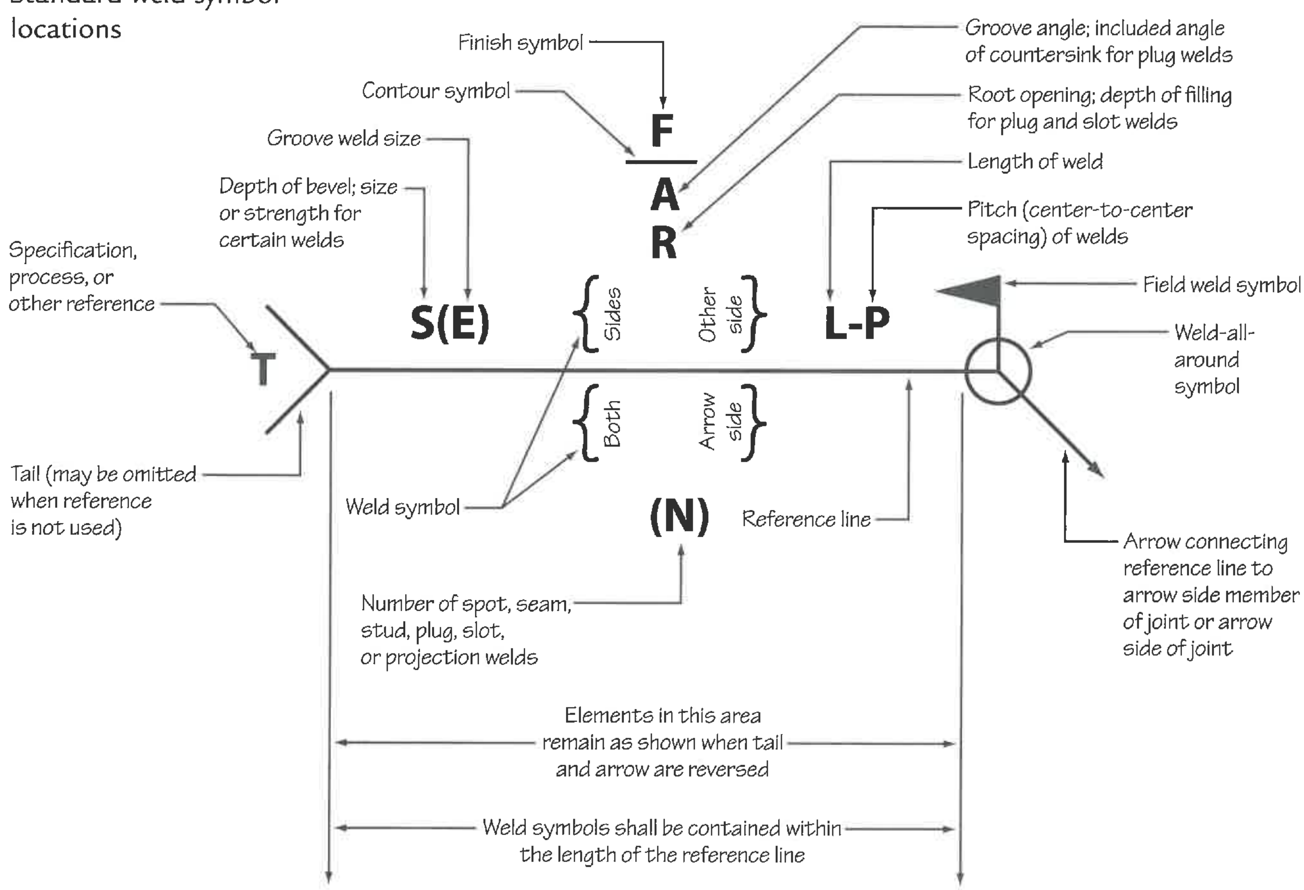
Symbols are placed in a standard order. Each element is represented in relation to the other symbols. Figure 1 shows the standard locations of various symbols.

2 Required Symbols

There are only two required weld symbols: the reference line and the arrow. From these, the basic welding instructions are given.

FIGURE 1

Standard weld symbol locations



Reference Line

Information about the welding job is located on the **reference line**. Any other symbols used in the welding instructions are located on or around this line. Multiple reference lines can be used with a single arrow to indicate a sequence of welding events. Reference lines are read starting with the closest line to the arrow tip then outward. They are read from the bottom up.

Reference lines may also be used to give supplemental weld information and inspection requirements. Figure 2 shows multiple reference lines and the order in which the instructions should be read and followed. Figure 3 shows how multiple reference lines are used in an actual weld application.

FIGURE 2
Multiple reference lines

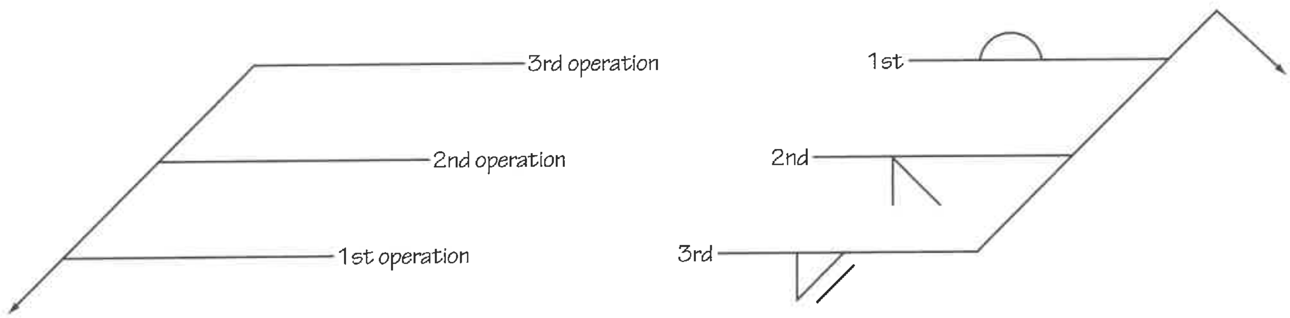
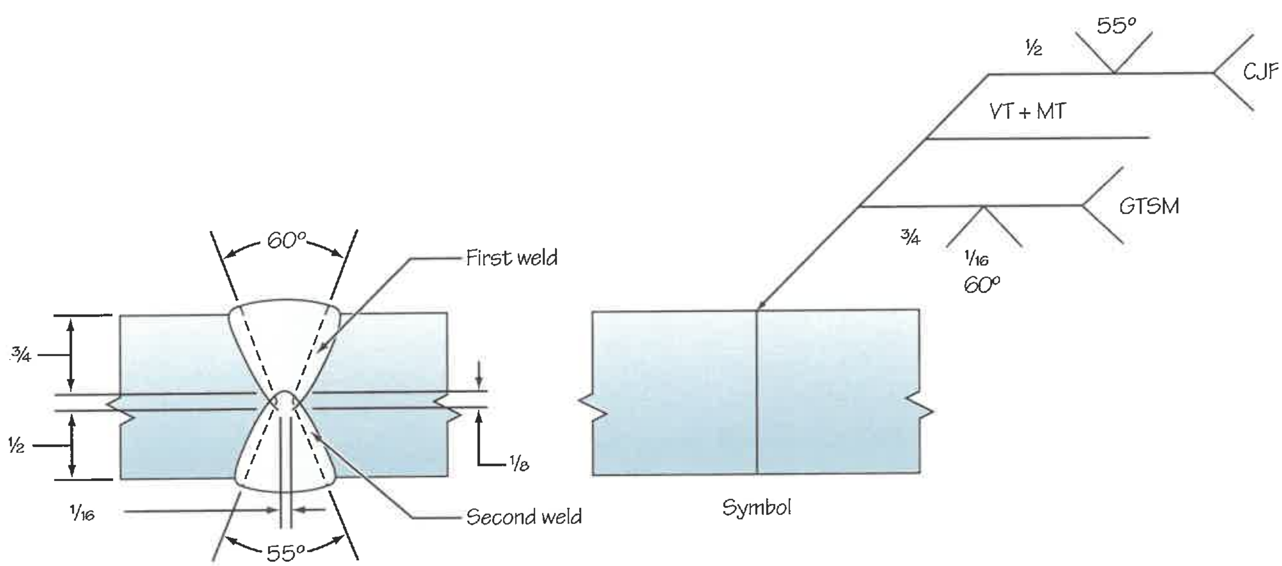


FIGURE 3
Using multiple reference lines



Depth of bevel (arrow side)–¾″
Depth of bevel (other side)–½″
Root opening–1/16″
Groove angle (arrow side)–60°
Groove angle (other side)–55°

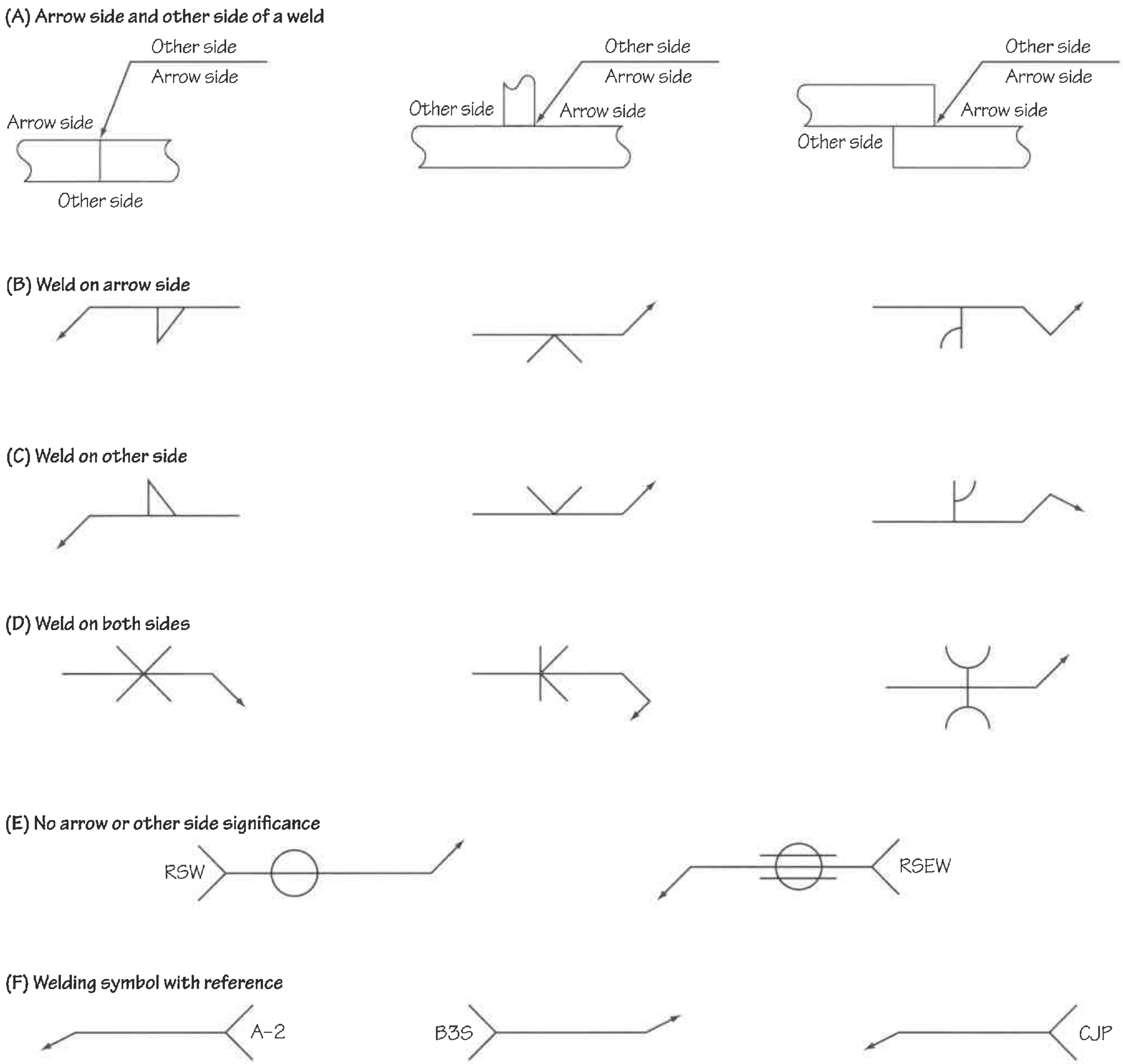
Notes:
GTSM –Gouge to sound metal
CJP –Complete joint penetration
VT+MT–Visual examination followed by magnetic particle examination from the other side of the joint

Arrow

There are only two required parts to a welding symbol: a reference line and an arrow. See Figure 4. The reference line contains information about the welding job. It is always drawn horizontally. Used to apply weld symbols and other data, it has a particular significance that stays the same regardless of any elements that are added to it. The lower side of the reference line is termed the arrow side and the upper side of the reference line is termed the other side.

FIGURE 4

Reading the arrow symbol



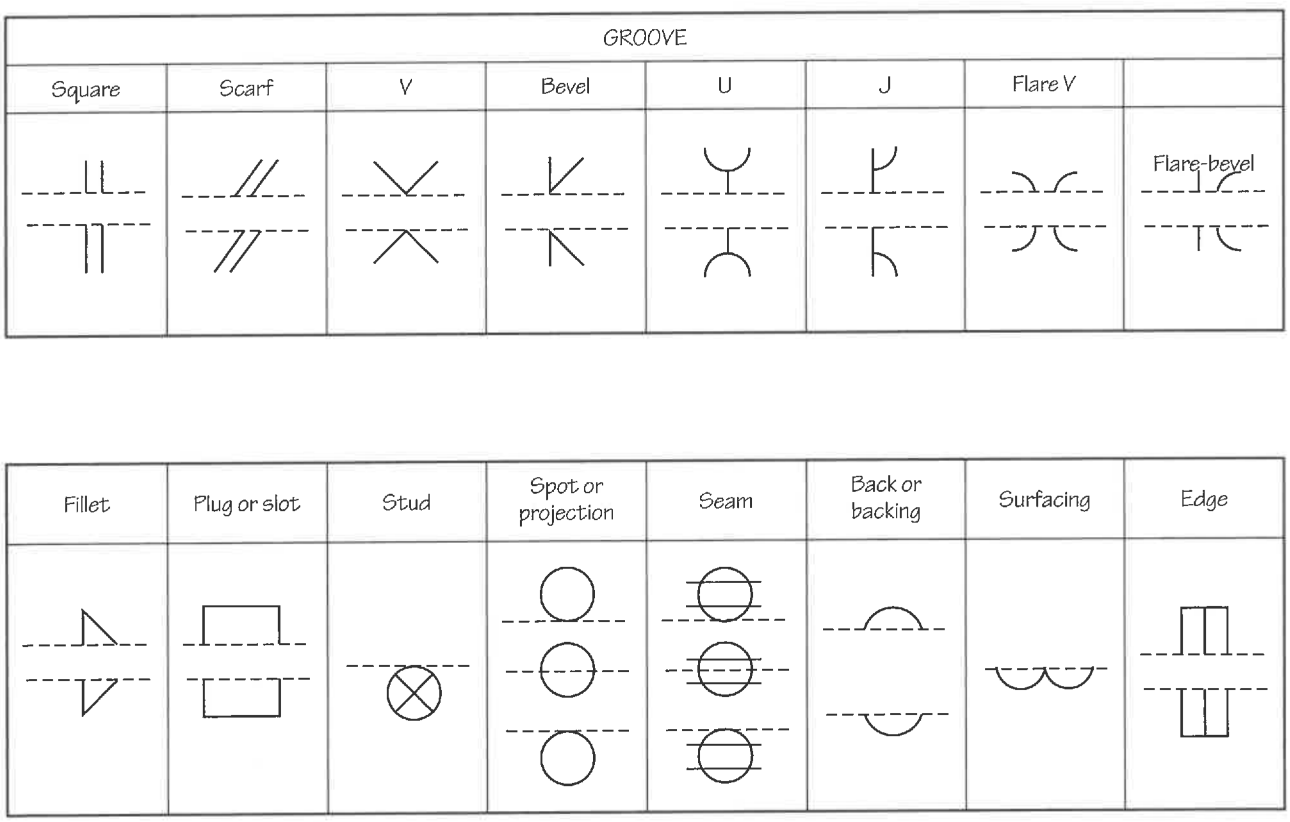
The **arrow** simply connects the reference line to the weld joint or the area to be welded. If the other side of the joint is to be welded, the weld symbol is placed above the reference line. If the arrow side of the joint is to be welded, the weld symbol is placed below the reference line. If both sides of the joint need to be welded, weld symbols are placed above and below the reference line.

Tail

When there are additional welding instructions or information that needs to be shown, that information is placed in the **tail**. The tail is only used if the information included is supplemental to the required instructions found on the reference line. Examples of what this information could be are the welding process, process variation, method of application and welding procedure number.

There are 16 basic weld symbols. Each of these symbols forms the building blocks of most welding projects. Figure 5 illustrates the symbols.

FIGURE 5
Weld symbols



SELF CHECK

1. Is one weld symbol more important than another?
2. Can very complicated instructions be simplified using weld symbols?

3 Optional Symbols

Optional, or additional, symbols are used to provide more information instructions or requirements. They are only used in addition to the required symbols. Figure 6 illustrates supplemental weld symbols. There are six supplemental symbols and each is explained below. However, there are a number of other optional weld symbols used for specific situations and techniques.

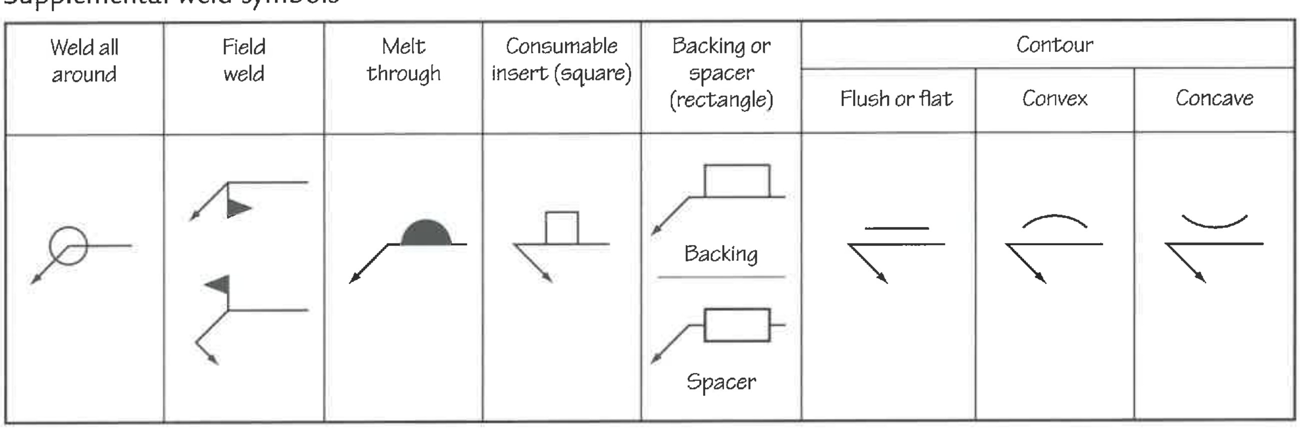
Weld-All-Around Symbol

The **weld-all-around** symbol is a circle around the junction of the arrow and the reference line. It always means to weld all around the area indicated by the arrow. If there are additional welding instructions, it may mean to weld all around different parts of the object to be welded.

Field Weld Symbol

The **field weld** symbol is a flag that juts away from the reference line in either direction. The field weld symbol indicates that a weld should be made at the installation point or the place of construction and not in a shop.

FIGURE 6
Supplemental weld symbols



Melt-Through Symbol

The **melt-through** symbol is a solid half circle attached to the reference line. It calls for complete joint penetration with root reinforcement in welds made from one side. It is usually placed on the other side of the reference line. The placement indicates where the reinforcement is requested.

Consumable Insert Symbol

The **consumable insert** symbol is an empty box affixed to the reference line. It is placed on the reference line opposite the *groove-weld symbol.* The specific information on the consumable is placed in the tail of the weld symbol.

Backing and Spacer Symbols

The backing and spacer symbols each are slight variations on an empty rectangle. The **backing** symbol is a box that sits on top of the reference line while the **spacer** symbol is a rectangle that sits within the reference line. The backing symbol is used to indicate that a backing strip or bar should be used to make the weld. The backing symbol is always used in combination with a groove-weld symbol so as to not confuse it with the *plug-* or *slot-weld* symbol. The tail of the weld symbol contains the backing type, material, and dimensions of the backing plate.

The spacer symbol is used to indicate a joint spacer should be used. The material and dimensions of the joint spaces are indicated in the weld symbol tail or elsewhere in the drawing.

Contour Symbol

The **contour symbol** is a line drawn above the reference line that indicates the shape of the finished weld. The line varies in shape from flush, or flat, to *convex* to *concave*. How the shape is to be achieved is often indicated above the symbol. The finishing methods are chipping (C), grinding (G), machining (M), or unspecified (U).

SELF CHECK

1. Are the optional symbols listed above the only other optional symbols used?
2. Would it be quicker and easier to write out welding instructions?

Summary

Weld symbols are used to communicate welding instructions. There are required basic symbols that must appear on engineering drawings, for instance, reference line, arrow, and sometimes a tail, and optional symbols that are used to convey additional information as necessary. Knowing the symbols and being able to understand the information and directions they convey will make it easier to work efficiently on the jobsite.

CHAPTER Review

Weld Symbols QUESTIONS

Show your understanding of the information in this chapter by answering the questions and filling in the blanks below.

1. There are ______________ required weld symbols.
2. There are ______________ basic weld symbols.
3. Weld symbols are used to give ______________ to the welder.
4. Reference lines are read from ______________ to ______________.
5. Additional information can be given in the ______________ that is attached to the reference line.
6. The field weld symbol is a ____.
   a. box
   b. circle
   c. line
   d. flag
7. The melt-through symbol is a ____.
   a. rectangle
   b. half-circle
   c. square
   d. flag
8. The weld-all-around symbol is a ____.
   a. box
   b. circle
   c. line
   d. flag
9. The consumable insert symbol is a(n) ____.
   a. empty box above the reference line
   b. circle above the reference line
   c. filled box above the reference line
   d. filled circle through the reference line
10. It is faster to use symbols than to write out instructions. (True; False)