MERIT BADGE SERIES

WELDING

BOY SCOUTS OF AMERICA®

How to Use This Pamphlet

The secret to successfully earning a merit badge is for you to use both the pamphlet and the suggestions of your counselor.

Your counselor can be as important to you as a coach is to an athlete. Use all of the resources your counselor can make available to you. This may be the best chance you will have to learn about this particular subject. Make it count.

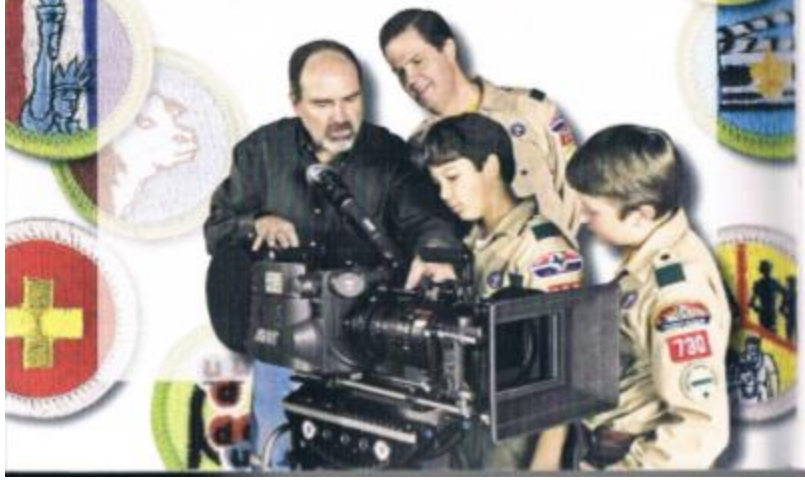
If you or your counselor feels that any information in this pamphlet is incorrect, please let us know. Please state your source of information.

Merit badge pamphlets are reprinted annually and requirements updated regularly. Your suggestions for improvement are welcome.

Send comments along with a brief statement about yourself to Youth Development, S209 • Boy Scouts of America • 1325 West Walnut Hill Lane • P.O. Box 152079 • Irving, TX 75015-2079.

Who Pays for This Pamphlet?

This merit badge pamphlet is one in a series of more than 100 covering all kinds of hobby and career subjects. It is made available for you to buy as a service of the national and local councils, Boy Scouts of America. The costs of the development, writing, and editing of the merit badge pamphlets are paid for by the Boy Scouts of America in order to bring you the best book at a reasonable price.



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Note to the Counselor

The Welding merit badge must be taught by a qualified person who is highly experienced in welding and is knowledgeable about various types of welding processes, specifically oxyacetylene welding, shielded metal arc welding, gas metal arc welding, and flux-cored arc welding.

The Welding merit badge offers Scouts an opportunity to learn four welding processes commonly used in industrial workshops and in home "garage" shops. Home versions of the equipment your Scouts will need can usually be found without a great investment. Portable versions for field use during Scout outings can sometimes be found, as well. During summer camp, compact electrical welding equipment can be powered from a simple 120-volt circuit or from a portable generator or self-contained power supply. If you are using oxy-fuel welding equipment, be aware that it is not powered by electricity.

You are encouraged to enrich each Scout's experience by drawing upon your professional knowledge and expertise. However, only the methods, techniques, and materials discussed in this book as appropriate for the Welding merit badge should be attempted. Keep in mind that as a merit badge counselor, you may not add or delete requirements, or change them to make them simpler or more difficult. If a Scout develops an enhanced interest in welding and wants to further his skills beyond the level of this booklet, encourage him to pursue additional training. Many high schools, community colleges, technical schools, and union halls offer training opportunities in welding to students who are of appropriate age and ability level.

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Scouts who are pursuing the Welding merit badge will require direct adult supervision. They will be working with molten metals, electric arcs, welding fumes, and power tools that, if misused, can cause serious injury. Personal protective equipment including eye protection, hearing protection, heavy gloves, and sturdy footwear must be in use at all times when Scouts are welding. There are no exceptions.

See the *First Aid, Composite Materials, Home Repairs, Woodwork, Emergency Preparedness,* and *Safety* merit badge pamphlets and the BSA Scouting Safely web page for more information about safety, first aid, and managing risks. The "Health and Safety" chapter includes a useful checklist for a welder's first-aid kit.

Requirements

1. Do the following:
   a. Explain to your counselor the hazards you are most likely to encounter while welding, and what you should do to anticipate, help prevent, mitigate, or lessen these hazards.
   b. Show that you know first aid for, and the prevention of, injuries or illnesses that could occur while welding, including electrical shock, eye injuries, burns, fume inhalation, dizziness, skin irritation, and exposure to hazardous chemicals, including filler metals and welding gases.
2. Do the following:
   a. With your counselor, discuss general safety precautions and Material Safety Data Sheets related to welding. Explain the importance of the MSDS.
   b. Describe the appropriate safety gear and clothing that must be worn when welding. Then, present yourself properly dressed for welding—in protective equipment, clothing, and footwear.
   c. Explain and demonstrate the proper care and storage of welding equipment, tools, and protective clothing and footwear.
3. Explain the terms *welding*, *electrode*, *slag*, and *oxidation*. Describe the welding process, how heat is generated, what kind of filler metal is added (if any), and what protects the molten metal from the atmosphere.
4. Name the different mechanical and thermal cutting methods. Choose one method and describe how to use the process. Discuss one advantage and one limitation of this process.
5. Do the following:
   a. Select two welding processes, and make a list of the different components of the equipment required for each process. Discuss one advantage and one limitation for each process.
   b. Choose one welding process. Set up the process you have chosen, including gas regulators, work clamps, cables, filler materials, and equipment settings. Have your counselor inspect and approve the area for the welding process you have chosen.
6. After successfully completing requirements 1 through 5, use the equipment you prepared for the welding process in 5b to do the following:
   a. Using a metal scribe or soapstone, sketch your initial onto a metal plate, and weld a bead on the plate following the pattern of your initial.
   b. Cover a small plate (approximately 3" x 3" x ¼") with weld beads side by side.
   c. Tack two plates together in a square groove butt joint.
   d. Weld the two plates together from 6c on both sides.
   e. Tack two plates together in a T joint, have your counselor inspect it, then weld a T joint with fillet weld on both sides.
   f. Tack two plates together in a lap joint, have your counselor inspect it, then weld a lap joint with fillet weld on both sides.
7. Do the following:
   a. Find out about three career opportunities in the welding industry. Pick one and find out the education, training, and experience required for this profession. Discuss this with your counselor, and explain why the profession might interest you.
   b. Discuss the role of the American Welding Society in the welding profession.

Contents

During World War II, the country depended heavily on women to fill roles traditionally held by men. These women arc welders worked at a plant that produced B-25 "Billy Mitchell" bombers and P-51 "Mustang" fighter planes.

What Is Welding?

You may wonder what it means to weld. **Welding** is the process of joining with a weld—joining or combining similar pieces of **metal** by heating them with a flame torch or an **electric current**, then hammering or pressing them together while they are soft. Welding can also be done by melting plastic or metal into the **joint** of a similar material. The temperature range for welding is 3,000 to 10,000 degrees Fahrenheit.

Welding plays a major role in our modern world, and mastery of the skill can lead to exciting career opportunities. Someday, you may have an opportunity to experience exciting new career paths in welding. There are more than 80 welding, cutting, and welding-related processes, only a few of which will be covered in this booklet.

Terms in boldface, like **welding**, can be found in the glossary at the back of this pamphlet.

The American Welding Society was formed in 1919 by 20 members of the Wartime Welding Committee of the Emergency Fleet Corporation under the leadership of Comfort Avery Adams. This nonprofit organization is dedicated to the advancement of welding and allied processes. It is also closely involved with setting safety standards within the industry.

Astronaut Buzz Aldrin, who was a Scout, gives credit to welders for helping him become one of the first humans to walk on the moon.

Health and Safety

On the following pages, you will learn safety procedures to follow when **arc welding**.

Staying Safe While Welding

Arc welding uses an electric current that generates intense heat and emits intense light, both extremely dangerous. It is essential that you thoroughly understand all safety precautions before you begin. Carelessness or ignoring safety practices can be damaging or even fatal to you and to anyone who is nearby.

Always read the warning labels for every piece of equipment or component and **filler metals** you use. If you are ever in doubt about a safety issue, ask your merit badge counselor. Let's take a look at some of the risks.

Safety Basics

Arc welding, **oxy-fuel welding,** and **oxy-fuel cutting** all share one characteristic: The harmful and intense **infrared** and **ultraviolet rays** that are emitted by the welding process will damage unprotected eyes and exposed skin, kind of like getting a sunburn—only worse. When you are welding, you must *always* protect yourself. The information presented here will help you stay safe during welding activities.

Always have a fire extinguisher nearby. When welding, you must always be conscious of fire protection and keep a class ABC fire extinguisher within easy reach, mounted at shoulder level. Fire extinguishers should be checked monthly to ensure the tank is full and the pressure is normal. If anything appears out of the ordinary, replace the extinguisher or have it professionally serviced.

Welder's First-Aid Kit

These items are typically found in a welder's first-aid kit, which is extensive and geared to treat burns, eye irritations, cuts, sprains, and common welder injuries.

- 32 adhesive bandages (1" x 3")
- 6 extra-large adhesive bandages
- 10 PVP iodine wipes
- 12 BZK antiseptic wipes
- 10 triple antibiotic individual packets
- 5 burn gel packets (⅛ oz.)
- 1 Foille® burn ointment (½-oz. tube)
- 1 burn dressing
- 10 sterile dressing pads (3" x 3")
- 4 sterile oval eye pads
- Eye wash solution (three ½-oz. bottles)
- 2 sterile combine pads (5" x 9")
- 1 triangular bandage with pins (40" x 40" x 56")
- 1 sterile conforming gauze bandage (3")
- 1 instant cold pack
- 1 spool of adhesive tape (½" x 5 yards)
- 1 pair of bandage scissors (steel, 5 ½")
- 8 nonlatex vinyl gloves (large)
- 1 pair of forceps
- First-aid manual (such as one from the American Red Cross)

A class ABC fire extinguisher is a multipurpose, dry-chemical extinguisher useful for a welding environment. If you ever need to use an extinguisher, make sure you are between the fire and an exit. If the fire can't be controlled, you need a quick way out. For more information about fire extinguishers, see the *Fire Safety* merit badge pamphlet.

Button up and wear the proper clothing for protection from UV and infrared rays. Long-sleeved shirts of tightly woven, 100 percent wool (never synthetic fabrics) with buttoned cuffs and a collar (no pockets) provide the best protection from UV and infrared radiation, flying sparks, hot or melted metal, and flames. Wear pants with no cuffs (which can collect sparks and hot metal), and do not tuck pants into boots or shoes. It is best to wear dark colors, which will not reflect as much light as light-colored clothing. Wear a cap to help protect your head.

A fully protected welder wears the proper clothing along with a welding helmet and leather sleeves, gloves, and shoes or boots. Wearing protective leather clothing minimizes the risk of fire and burns from spatter. Store leather garments in a well-ventilated area.

It takes only one spark to start a fire. Be aware of the location of fire alarms and evacuation routes. Thoroughly inspect your entire area before beginning a weld.

Spatter (liquid metal droplets) can spray up to 35 feet from the work area. These sparks can quickly start a fire if they touch **flammable material**. That is why welders must wear only certain types of clothing. Wearing proper clothing will also help prevent most welding-related burns. Clothing and shoes made from synthetic fabrics like polyester or rayon can melt from the arc's extreme heat, causing severe burns.

Clean clothing, free of grease and other contaminants, is less likely to catch fire than dirty, greasy clothing.

Wear close-fitting clothing. Loose or baggy clothes can easily get caught in machinery.

Dark clothing helps protect a welder from the arc's harmful rays. Wool offers the best protection, but heavy cotton will do. For added safety, wear another layer of any of these: leather welding jacket, trousers, aprons, sleeves, or bibs.

During arc welding, *never* roll up your sleeves or cuff your pants. All clothing should be completely buttoned with no frays or tatters. It's best to wear a shirt that has no pockets. If your shirt has pockets, close, button, or tape them shut to prevent sparks from falling into them.

During welding, any exposed skin may get burned from spatter and UV rays. Always protect yourself.

Wear flame-resistant leather gloves. Keep your welding gloves dry, and check them for tears and rips. Take care of your gloves. If leather welding gloves get too close to excessive heat, they will shrink and distort, making them uncomfortable and eventually unusable.

Wear the proper footwear. Fully laced high-top boots provide the best protection. Keep them dry. Because sparks can fall into low-top shoes, wear smooth-top leather work boots, preferably with steel toes. Wear pants outside your work boots to prevent sparks from falling into your boots. Store boots in a clean, dry area.

Never handle hot metal!

Never handle hot metal! Welding gloves are not intended for handling hot metal. Use pliers or vise grips when handling parts that have just been welded.

Do not leave any skin exposed. A **welding helmet** or welding shield is designed to protect your eyes and face from the arc's harmful rays and intense light. You must wear face and eye protection during any welding process. Tinted glasses with proper shade, or goggles must be used with gas welding and cutting.

Safe welding starts with the proper attire.

Protecting yourself is the first step in safe welding.

When welding, always wear a face shield and protective clothing.

Always wear eye protection when you are welding or when you are near anyone else who is welding. Welder's flash, also described as sunburn on the eye, is known to doctors as photokeratitis. It is caused by exposure to the ultraviolet radiation given off by the welding arc. This affliction can cause extreme pain, swelling, fluid secretion, and temporary blindness. Usually, symptoms will begin to be felt several hours after exposure. Do not let this happen to you. Prevent injury from welder's flash by always wearing eye protection when you are welding or when you are near any welding activity.

If you have been welding and your eyes feel sunburned or you are having difficulty seeing, seek a doctor's care immediately. Welder's flash is usually a temporary condition, but repeated exposure can lead to permanent injury. Protect yourself from the arc's harmful rays by always wearing proper protective equipment for welding and cutting.

Remove all jewelry (watches, rings, etc.) before welding. Since you will be working around electricity and very high temperatures, wearing jewelry and watches is out of the question.

Keep the welding area neat and clean. With flying sparks, anything flammable will pose a fire hazard. Remove all flammable materials, trash, and any potential fire hazard.

Always be aware of others in the welding area. Onlookers must be protected, either with a **welding screen** or handheld **face shield,** depending on how near they are to the welding activity. They should maintain a proper distance from the arc and have adequate protection.

Even after you have finished welding, if you and others remain in the work area, you must continue to wear eye protection with side shields because of the risk of flying sparks or debris, especially while chipping **slag** (the solidified **flux** that forms on the weld bead) from a **workpiece.**

Protect Your Eyes

Something in the eye is not just painful—it could endanger your eyesight. For protection, always wear safety goggles and additional protective equipment as needed when welding or in an area where others are welding. Protective eyewear will also keep harmful **fumes** and vapors from hurting your eyes.

If a foreign object gets in your eye, do not rub the eye; rubbing might scratch the cornea (the clear covering of the colored part of the eye). Blink your eyes; tears might flush out the object. If that doesn't work, wash your hands with soap and water, then try to flush out the particles with clean running water or clean water poured from a glass or bottle.

Foreign matter that is embedded in the eye or that will not wash out must be treated by a physician. Stabilize the object if possible and cover the injured eye with a dry, sterile gauze pad. Seek immediate medical attention.

Handheld face shield commonly used by onlookers

Always wear a welding helmet for protection from the arc's dangerously bright light and harmful rays. Be sure your helmet has no cracks or breaks that could let light inside. Always use a plastic cover inside and outside of the lens to protect the filter lens. If the plastic cover lens becomes excessively scratched or dirty, remove and/or replace it.

Guide for Shade Numbers				
Operation	Electrode Size 1/32 inch (mm)	Arc Current (A)	Minimum Protective Shade	Suggested Shade No. (Comfort)
Shielded metal arc welding	<3 (2.5) 3–5 (2.5–4) 5–8 (4–6.4) >8 (6.4)	<60 60–160 160–250 250–500	7 8 10 11	– 10 12 14
Gas Metal Arc Welding and Flux Cored Arc Welding		<60 60–160 160–250 250–500	7 10 10 10	– 11 12 14
Gas tungsten arc welding and plasma arc cutting		<50 50–150 150–500	8 8 10	10 12 14
Oxy-fuel gas welding	Plate thickness <⅛" ⅛"–½" >½"	Plate thickness <3mm 3–13mm >13mm		 4 or 5 5 or 6 6 or 8
Oxy-fuel gas cutting	Plate thickness <1"	Plate thickness <25mm		3 or 4

Proper filter lens shading for arc welding

The chart shows the appropriate shading for arc welding processes. Begin with the darkest shade recommended for the process you are using; then move one shade lighter at a time until you find the most comfortable one while still adhering to the standard. Auto-darkening **welding shields** that automatically darken when the arc is struck are also available.

Always wear an approved welding helmet while welding. Wearing a welding helmet allows you to safely view the arc through a window with a **filter plate** that removes damaging rays and light. The filter plate is protected from spatter and debris by a clear lens made of plastic or glass. Filter plates are available in various shades, ranging from darker to lighter. The higher the shade's number, the more shading it provides.

The American Welding Society sets the safety standards for the amount of shading needed for any welding process. The shade you use is specific to the welding process, the amount of **amperage**, and the size of **electrode** you use.

Always read all warning labels on arc welding components and filler metals container.

Prevention goes hand in hand with mitigation, which means "to lessen in force or intensity" and "to make less severe." By taking precautions to manage risk and the possibility of injury, you can be prepared to anticipate, help prevent, mitigate, and respond to just about any incident that might happen while welding.

Risk of Burns and Fire

The electric arc is extremely hot. Temperatures can reach 10,000 degrees Fahrenheit or higher. Exposure to this intense heat poses an extreme risk of burns or of starting a fire from the spatter.

Be sure your work area is free of **combustible** and flammable materials, including gas, oil, and grease, and that these materials are at least 35 feet from any welding activity. Commonly ignited substances are trash, wood, fabric, boxes, papers, rags, plastics, and chemicals. If you are welding in a

For more information about burns, see the *First Aid* merit badge pamphlet.

Leather high-top work boots will help protect your ankles and feet.

questionable area, place **fire shields** or flame-resistant blankets around the welding area, and have a responsible **fire watcher** keep watch for you. Continue inspecting for fire for 30 minutes after welding.

First Aid for Thermal Burns. *Superficial burns* are mild burns that affect only the outer layer of skin. Treat them by holding the burn under cold water or applying cool, wet compresses until the pain eases. *Partial-thickness burns* are more serious than superficial burns and affect the outer layer of skin and part of the layer of skin below it. They typically include a reddening and blistering of the skin. To treat such burns, first remove the person from the source of the burn. Cool the burned area with cold, running water until the pain is relieved. Let the burn dry, then protect it with a loosely applied, sterile gauze pad and bandage.

Full-thickness burns are very serious. They destroy the outer layer of skin and the layer below it. A victim who has been exposed to open flames, electricity, or chemicals may sustain full-thickness burns. The skin may be burned away and the flesh charred. If nerves are damaged, the victim may feel no pain. Such burns constitute a medical emergency. Do not try to remove any clothing, as it may be sticking to the victim's flesh. After cooling the burn, cover the burned area with dry, sterile dressings. **Seek immediate medical attention.**

Risk of Electrical Shock

One of the most serious risks to the welder is **electrical shock.** An electrical shock of more than 30 volts can be fatal. Arc welding presents the risk of both **primary voltage shock** and **secondary voltage shock.** Primary voltage shock occurs when the power is on and someone simultaneously touches a **lead** inside the welding machine and either the welding machine or other grounded metal. The shock can be between 120 and 480 volts.

Secondary voltage shock will occur if you touch the electrode while another part of your body touches the workpiece. If you touch both of these components at the same time, you will receive an electrical shock ranging from 60 to 100 volts. The higher the voltage in an electrical circuit, the more serious the electrical shock will be.

Always remember that electricity easily flows through water. Therefore, when you are arc welding, you must stay dry. Never weld with wet gloves. *Even wetness from perspiration is dangerous.* Wear proper welding clothing to maintain **insulation** between yourself and your work.

Before you begin welding, be sure your work area is clean and dry. Inspect all of the equipment you will be using. Cables, electrodes, and **electrode holders** must be dry and in good condition. Ask your counselor to make a visual inspection and to replace any damaged components. Do not attempt to repair a welding machine yourself.

Be aware of risks at every stage of the welding process.

The shielded metal arc welding electrode holder must be dry.

Always keep your welding work area clean and dry.

When welding, stay safe and stay dry—never stand on a wet floor and never wear jewelry.

Never touch the electrode or metal parts of the electrode holder with skin or wet clothing. Never rest your body on the workpiece. Welding in or on the workpiece in damp or wet conditions will increase the risk of electrical shock.

Always remember that even though the welder is in the "off" position, a charge still exists inside the machine. Never open the housing of a welder without supervision by a trained technician.

First Aid for Electrical Shock. If electricity travels through a part of your body, you can get an electrical burn. Besides a burn, too much electricity can even stop the heart from beating correctly or damage other internal organs. Superficial and partial-thickness burns from electricity look like burns from too much heat; the skin may look charred. Full-thickness electrical burns may not leave charred skin. Instead, the skin can look leathery and white and be hard to the touch. Call 911 or the local emergency-response number if someone has an electrical burn.

Never touch a person who is in contact with a live electrical power source. If you encounter a victim of an electrical burn, shut off the power at its source and call an ambulance immediately.

Risks of Harmful Fume Inhalation

The welding process can emit dangerous fumes. A visible, smokelike cloud, known as the **fume plume,** arises directly from the point of welding. The fume plume is never safe to breathe. Long-term and short-term exposure may lead to severe respiratory and skin problems. The fume plume contains metallic vapors that have condensed into tiny particles of solid metal. These particles are suspended in the air and can settle on the walls and floor of the work area. Always protect yourself from the fume plume by wearing protective clothing and headgear. **Do not ever place your head directly into the fume plume.**

When welding with most mild steel electrodes with clean materials, if you are comfortable and can breathe easily, and the air is visibly clear, you probably have adequate ventilation. However, if you have a headache, chest pains, feel dizzy or nauseous, or have trouble breathing, turn off your welder, seek fresh air immediately, and notify your merit badge counselor. Also take note if you are pale, your eyes are tearing, or you feel a burning sensation around the lips, tongue, or on the skin. Seek medical attention.

Never inhale the gases of the fume plume.

All welding areas must have good **ventilation.** Air must be allowed to circulate without blockages such as dividing walls or equipment. Good ventilation can be supplemented with fans or **exhausts** that will direct fumes away from your face. Always keep your head away from the fume plume.

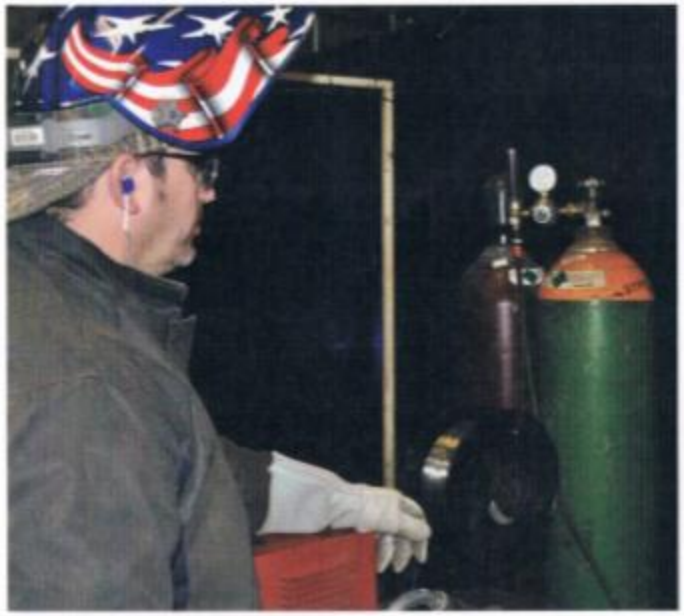
Some filler metals can produce toxic fumes when used in welding, which is why it is important to keep the area well ventilated. Anyone who becomes overwhelmed by fumes should seek fresh air and loosen tight clothing at the neck and waist for easier breathing. Seek immediate medical attention. It is important to let medical personnel know the contaminants that might have been released at the workplace.

Good ventilation and a safety-approved welding helmet are essentials in protecting yourself from the fume plume.

Risk of Explosion

The **shielding** gases used in arc welding are commonly **inert** or only slightly reactive. However, the cylinders that contain these gases are under intense pressure. Always handle cylinders with care. Do not heat or weld on a cylinder.

Above all, learn about the materials you are welding and know the risks involved when working with them. Make sure you have the correct **base metals,** electrode, and shielding gases. This information can be found in the chapter "Welding and Cutting Methods." Never weld near flammable or combustible materials. Notify your merit badge counselor if you detect any damage to your welding equipment.



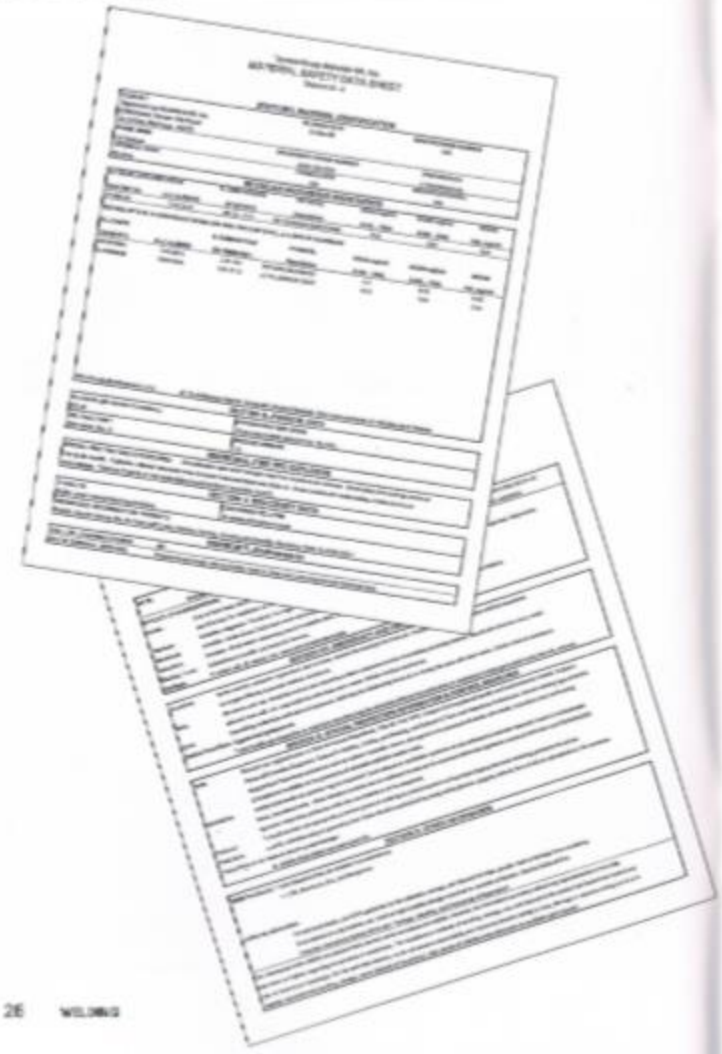
When using shielding gas, always observe safety precautions.

Exercise great caution when attaching a regulator to a cylinder.

Material Safety Data Sheets

Material Safety Data Sheets are available for the filler materials you may be using. The MSDS gives the proper procedures for working with, handling, storing, and disposing of materials. The MSDS will also alert the user to any hazardous substances the product may contain, such as a hazardous material in a particular welding rod or that could evolve during welding with a particular welding rod.

Information about health and safety procedures is available from the American Welding Society, OSHA, and the National Institute for Occupational Safety and Health. Guidelines, definitions, and facts that will help you learn how to remain safe while welding can be downloaded free of charge from the AWS at www.aws.org/technical/facts. Also check out "Safety in Welding, Cutting, and Allied Processes," No. ANSIZ49.1, which can be found at www.aws.org/safety.



The format of the MSDS may vary, but by U.S. law, all must include certain information presented in eight specific sections. Some internationally formatted sheets will have up to 16 sections. Here are the eight required sections, although many manufacturers include additional information, such as emergency and first-aid procedures.

Manufacturer Information. Identifies the material and lists the manufacturer's name, address, and emergency telephone number.

Hazardous Ingredients. Lists the hazardous ingredients in the material and some of the exposure limits (such as the permissible exposure limit, or *PEL*).

Physical and Chemical Characteristics. Tells what the material will look and smell like, whether it is a liquid or solid, the melting point (if it is a solid), and what will cause it to react.

Fire and Explosion Hazards. Tells whether the material is flammable and lists the flash point, firefighting materials and methods, and any unusual burning characteristics.

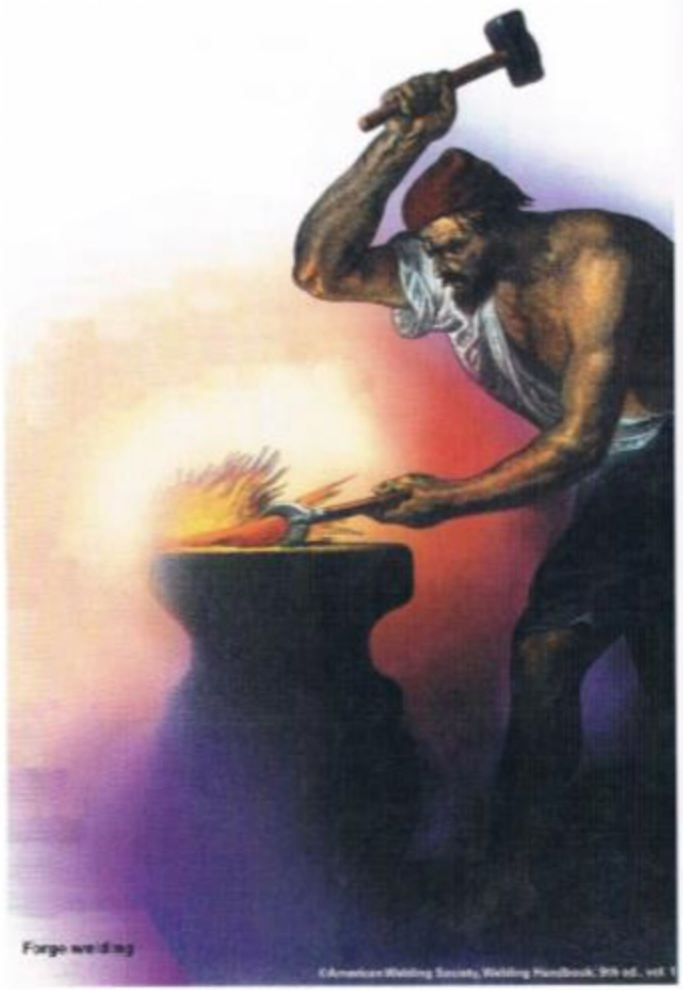
Reactivity. Tells how other chemicals will react with the material.

Health Hazards. Lists known routes of entry into the human body and the health risks from each, and lists any cancer research that might have been done on the material. Describes how to recognize and treat overexposure.

Precautions for Safe Handling and Use. Lists procedures to use in case of accidental spills and gives information about proper disposal.

Control Measures. Lists ways to avoid making contact with the material, such as using respirators, wearing gloves, and working in a well-ventilated area.

Most materials necessary for welding, such as tubing, bars, and sheets of metal, are safe in their solid form. However, welding does create some waste that can be toxic and should be disposed of properly and according to the manufacturer. The industry has been going green in recent years, though, and some welders have seen the environmental and economical benefits of recycling slag from submerged arc welding. Processing recycled slag into flux can be a significant savings over purchasing new flux.



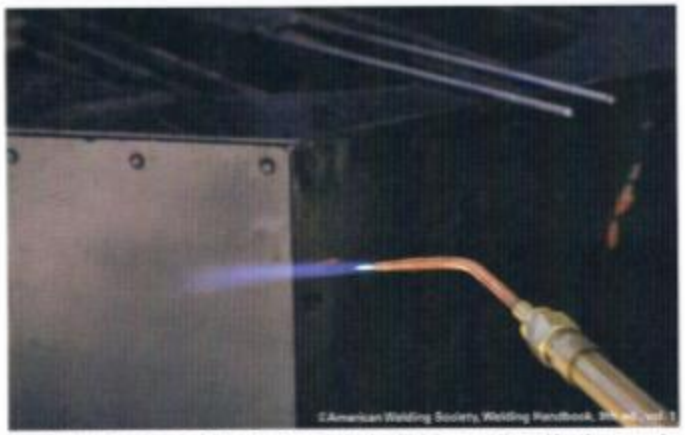
Forge welding

©American Welding Society, Welding Handbook, 9th ed., vol. 1

Welding and Cutting Methods

Welding has come a long way since its early Bronze Age beginning. **Forge welding** is one of the oldest and simplest methods of joining metals to create one "new" piece. The forge welder heats two or more pieces of metal and hammers them together. Today, forge welding has been largely replaced by gas and electric welding, advances made during the Industrial Revolution.

This manual describes a number of conventional welding and cutting methods. Each offers an opportunity for you to learn new skills as you create, build, and alter objects or make artworks. Welding and cutting are great skills to master.



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Oxy-fuel welding is one of the simplest methods of joining metals and has been used for more than a century.

Welder using shielded metal arc welding

Common Welding and Cutting Processes

Here are some of the more common welding and cutting processes used in a garage or shop.

Oxy-Fuel Welding

Oxy-fuel welding (sometimes called oxyacetylene or gas welding) and oxy-fuel cutting use fuel gases and oxygen to weld and cut metals. This process involves *oxidation*, or the combination of a substance with oxygen.

Oxy-fuel welding relies on the chemical reaction between the oxyacetylene flame and the base metal. This provides the heat to melt the base and usually a filler metal. Welders use this process to weld sheet and thin plate, tubes, and small-diameter pipes.

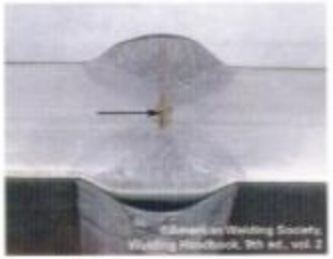
ADVANTAGES AND DISADVANTAGES OF OXY-FUEL WELDING

The primary advantage of oxy-fuel welding is that it allows good control of the heat input. You can learn how to handle a torch and control your weld at a slow speed. Skilled operators with gentle movements can control the weld-bead size, shape, and weld puddle. This method is also inexpensive and portable when compared with other methods, and can even be set up in a garage shop.

Oxy-fuel welding has its disadvantages:

- It requires a high skill level to minimize **discontinuities.**
- The OAW flame is not as concentrated as an electric arc.
- It is not economical for thick section welding (more than ¼ inch thick).
- The welding speed is slower than arc welding speed.
- Weld-metal properties are difficult to control.

Undercut at the toe of an oxy-fuel arc weld



Incomplete joint penetration

Oxy-fuel welding

Porosity

Englishman Edmund Davy discovered acetylene in 1836, and the process of welding with an oxy-fuel torch (oxyacetylene torch) was developed by French chemist Henry-Louis Le Chatelier in 1895. Oxy-fuel welding was one of the first modern fusion-welding processes. It has become less popular for industrial applications but is still widely used for welding pipes and tubes, repairing objects, and fabricating certain types of metal-based artwork.

When welding, always wear a face shield and protective clothing.

OXY-FUEL WELDING EQUIPMENT

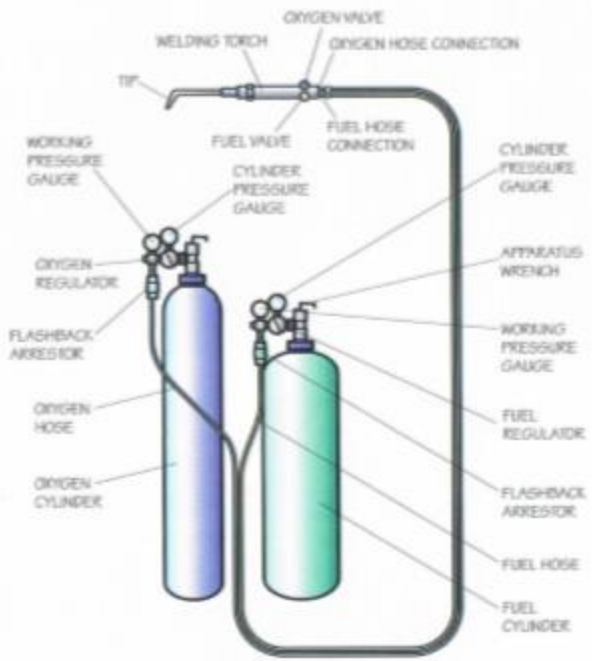
Oxy-fuel welding requires two cylinders of gas—one for oxygen and one for fuel gas. It also requires gas-flow regulators, hoses, check valves, flashback arrestors, and a welding torch-and-tip assembly. Oxy-fuel torches may be light or heavy duty. Nozzles and tips attach to the torch head. Gas flows through the welding tip just prior to ignition and burning. Manufacturers specify tips by orifice diameter or drill size. Recommended tip sizes are based on material thickness. The fuel-gas hose is red; the oxygen hose is green. The T-grade hose is for use with all fuel gases; R-grade is for acetylene only.

For safety, the oxygen fitting has right-hand threads; when you turn the fitting to the right, it will tighten. The fuel-gas fitting has left-hand threads with grooved nuts; when you turn it to the left, it will tighten. This prevents someone from accidentally connecting the fuel-gas to the oxygen receptacle, and vice versa.

In oxy-fuel welding, a welding torch is used to fuse the base metals by heating the two pieces to a temperature that produces a shared molten pool of metal. The molten pool is generally supplied with additional filler metal.

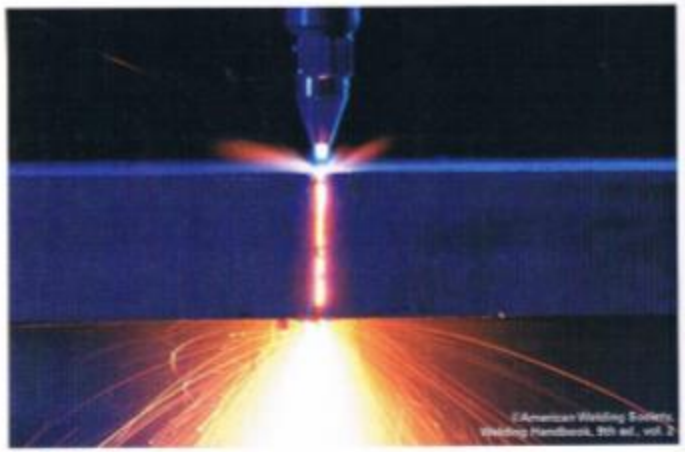
When you are finished using the welding torch, turn off the flame, coil the hoses, and store them on the appropriate brackets on the torch cart. If there are no brackets, store the torch and hoses away from any heat sources, out of the way to prevent a tripping hazard. Turn off the gas cylinders.

Store all hand tools safely in the appropriate place in a tool box or cabinet. If there is weld spatter on the welding table, grind off the table to remove the weld spatter. With a hand broom, sweep off the welding table. With a floor broom, sweep the floor. Always leave the area neat and clean, ready for the next welder and project.



Setup for oxy-fuel welding (secure cylinders)

A *valve* is a device that prevents the flow of gas from a cylinder when it is not in use.



Oxy-fuel cutting

Oxy-fuel equipment lends itself to applications such as iron or steel welding, brazing, metal heating (for bending and forming), and oxy-fuel cutting.

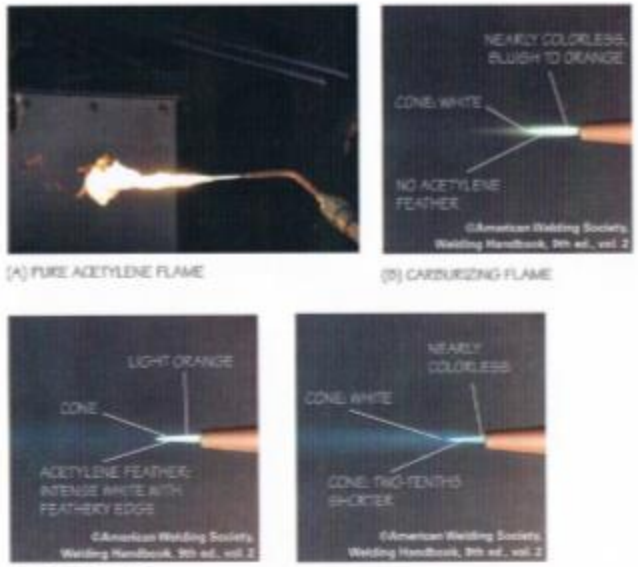
Oxy-Fuel Cutting

In oxy-fuel cutting, a cutting torch is used to heat metal to kindling temperature (generally red for iron **alloys**). A stream of oxygen is then trained on the metal to oxidize (burn) the metal. The slag, or burned metal, is removed from the cut *(kerf)*.

Cutting to Size

If you are working with **steel** plate, tubing, or **iron,** you may need to cut some materials to size before welding. Cuts can be made mechanically or thermally. Thermal cutting confines cuts to a narrow, well-defined zone of controlled width, or kerf. Oxy-fuel cutting and plasma arc cutting are two widely used thermal methods. Oxy-fuel cutting severs ferrous metals by oxidizing the iron in oxygen to form iron oxide slag.

The setup for manual oxy-fuel cutting is similar to oxy-fuel welding, although the torch attachment is different. The cutting torch attachment functions are designed to (1) control the flow and mixture of fuel gas and preheat the oxygen, (2) control the flow of cutting oxygen, and (3) discharge the gases through the cutting tip at the proper speed and volume for preheating and cutting.



(A) PURE ACETYLENE FLAME (B) CARBURIZING FLAME

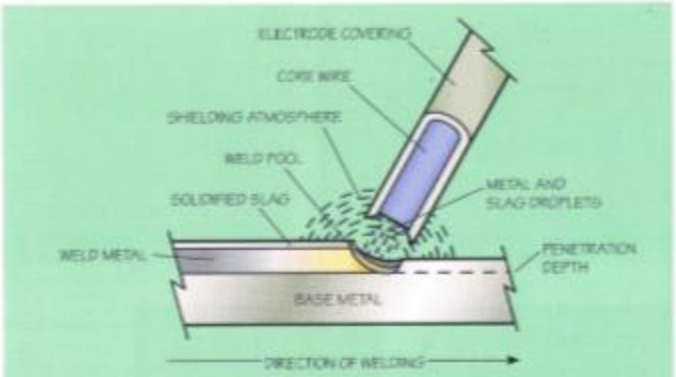
(C) NEUTRAL FLAME (D) OXIDIZING FLAME

Oxy-fuel flames

Ferrous metals contain iron. Nonferrous metals do not.

ADVANTAGES AND DISADVANTAGES OF OXY-FUEL CUTTING

The advantages to oxy-fuel cutting are its low cost, portability, and versatility of cutting direction and size. However, the disadvantages of oxy-fuel cutting are poorer tolerances compared with machine tools, potential fire, fume and burn hazards, and the requirements of adequate ventilation.



Shielded metal arc welding components

Shielded Metal Arc Welding

In 1890, C.L. Coffin of Detroit was awarded the first U.S. patent for an arc welding process using a metal electrode. This was the first record of the metal melted from the electrode carried across the arc to deposit filler metal in the joint to make a weld. By 1900, **shielded metal arc welding (SMAW)**—the process of using a coated metal electrode—had been developed in Great Britain. A thin coating of clay or lime was applied to the bare rod by dipping short lengths into a thick paste and allowing the coating to dry. This coating provided a more stable arc with the gas and flux shielding to protect the molten weld puddle.

ADVANTAGES AND DISADVANTAGES OF SHIELDED METAL ARC WELDING

Because of its versatility (a wide variety of metals can be used) and simplicity, shielded metal arc welding (often called "stick welding") remains one of the world's most popular and useful welding processes. It involves using the heat of an electric arc between a covered metal electrode and the work. SMAW equipment is also inexpensive and can be used in remote areas. Gasoline and diesel-powered generator/welding equipment make the process portable; small, lightweight inverter power sources are available. The process is less sensitive to wind and draft than gas-shielded arc processes, making it more suitable to the outdoors than other methods.

Compared with its advantages, shielded arc welding has few disadvantages. The fumes this process emits can make it undesirable to weld indoors, and the length of the electrodes can limit its productivity. If not cleaned properly, a weld can also contain slag inclusions, or pockets of material (most often slag or flux) that get trapped in and between the weld metal and the base metal, making the weld porous and weak.

Slag peeling off shielded metal arc welding workpiece

***Shielding* means protecting the weld metal from contamination. In shielded metal arc welding, as the weld is laid, the flux coating of the electrode disintegrates, giving off vapors that shield the weld area from atmospheric contamination.**

Gas metal arc fillet weld

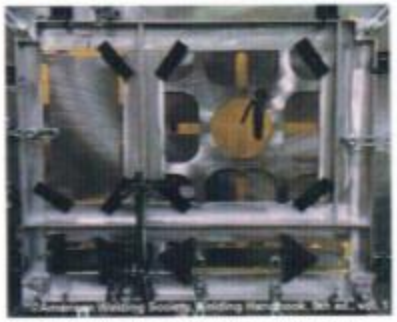
Gas Metal Arc Welding

In 1948, using the principle of shielding the welding arc with inert gas, **gas metal arc welding (GMAW)** was developed. In this method, a continuously fed wire electrode was used to create the electric arc and as a consumable filler metal. Improvements in welding power supplies and the use of smaller-diameter wires greatly improved the process. Because of the high cost of inert gases (helium and argon), this process was first developed to join nonferrous metals. Later developments allowed the use of less expensive CO_2 shielding gases with steel, which led to variations of the process, including spray-arc, short-circuiting arc, and pulsed-arc transfers.

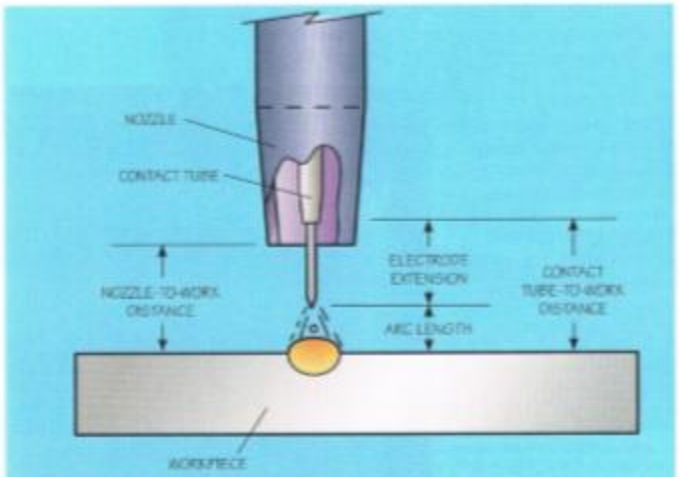
Gas metal arc welding uses the heat of an electric arc between a continuously fed bare wire filler-metal electrode and the work. Arc shielding comes from externally supplied gas.

A variation of gas metal arc welding uses a tubular electrode containing metallic powders that also requires a gas shield to protect the molten **weld pool** from atmospheric contamination. For most home and shop applications, the power source and wire feeder controller automatically control the arc length and electrode feed.

Fume exhaust



Welding fixture used to hold parts in position while welding



Gas metal arc welding gun components

The gas metal arc process deposits the weld metal in the joint by one of three methods: **short-circuiting transfer, globular transfer,** or **spray transfer.** Several factors determine the type of transfer, including magnitude and type of welding current, electrode diameter, electrode composition, electrode extension, and shielding gas.

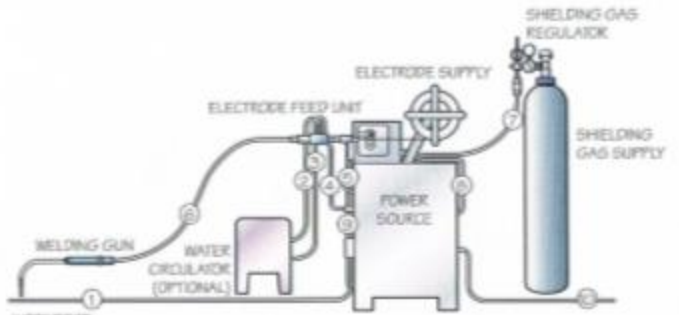
Short-circuiting transfer uses the lowest range of welding currents and electrode diameters. It produces a small, fast-freezing weld pool that is generally suited for joining thin sections, for out-of-position welding, and for bridging large root openings. In short-circuiting transfer, the wire contacts the workpiece and the arc is extinguished. Current continues to flow and the resistance causes the wire to separate and the arc to reignite, thereby causing the weld to be deposited drop by drop.

Globular transfer occurs at low currents in relation to the size of the electrode, regardless of the type of shielding gas, although CO_2 is commonly used to weld mild steel. Low current density at the electrode tip produces large, irregular drops

of metal that transfer to the pool without much direction, and is typically used only in the flat position. The result is increased amounts of spatter, as compared to spray transfer.

With higher welding current and voltage and a shielding gas greater than 80 percent argon, the welder can produce a stable, spatter-free weld in the axial spray transfer mode. Above the transition current level, the metal "pinches off" in fine droplets many times per second. The current propels the droplets axially down the center of the arc, away from the electrode, and straight into the pool. This mode of transfer is best suited for flat and horizontal position welding.

Shielding gases protect gas metal arc welds from the atmosphere. Fluxes are not used in this process. All deoxidizers and alloying **elements** are incorporated into the electrode wire. The shielding gas and flow rate also effect arc characteristics, modes of metal transfer, penetration and weld bead profile, speed of welding, undercutting tendency, cleaning action, and weld metal mechanical properties.



A typical gas metal arc welding setup (secure cylinder)

ADVANTAGES AND DISADVANTAGES OF GAS METAL ARC WELDING

Gas metal arc welding is useful when the presence of hydrogen could cause problems. When no slag is present as with shielded metal arc welding, the welder can more easily observe the action of the arc and the weld puddle to improve control. With little or no cleaning after welding, overall operator productivity is greatly improved. Efficiency increases because the continuous spool of wire does not require changing as often as the individual electrodes used in shielded metal arc welding.

Gas metal arc welding has its disadvantages. For one, it can result in most of the common weld discontinuities except slag inclusions. Welding without adequate shielding permits atmospheric oxygen and nitrogen to dissolve in the molten metal, resulting in porosity. Higher shielding gas flow rates may also result in porosity, due to the vortex action that draws atmospheric gases into the arc region.

Drafts or wind may disperse shielding gases, making gas metal arc welding unsuitable for field welding. Incomplete **fusion** is possible, especially in welds made with short-circuiting transfer. The presence of undercut and underfill reflects poor welding technique. Overlap is more prevalent in globular transfer and with the short-circuiting arc. The equipment used is more complex than that used for shielded metal arc welding, increasing the possibility of mechanical problems that can affect quality.

The American Welding Society lists specifications for filler wires for various metals and related alloys. Shielding gases that protect the weld puddle from the atmosphere include carbon dioxide, argon, and helium, used individually and in mixtures that may include oxygen. Used for short-circuiting transfer to 200 amps, carbon dioxide gives a stable arc. Additions of argon smooth the arc and reduce spatter.

EQUIPMENT FOR GAS METAL ARC WELDING

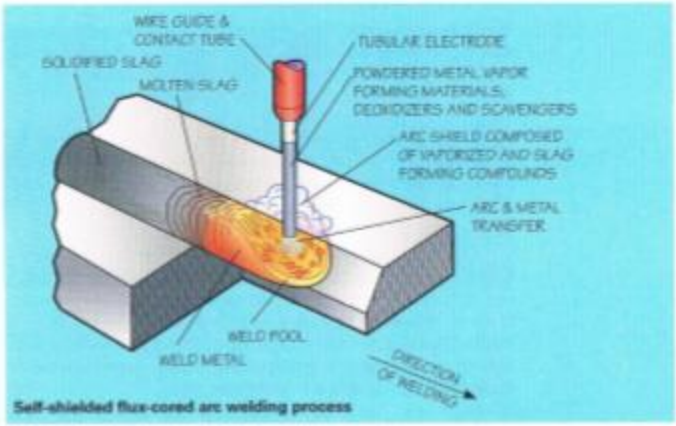
Gas metal arc welding requires a welding power supply, wire feeder, welding gun, a supply of shielding gas with flow meter and regulator, electric cables, and hoses to convey the shielding gas and cooling water. The welding gun guides filler wire and shielding gas into the weld puddle, transmitting current through a cable from the power source. High-amperage guns come with tubing for water to cool the gun.

Stored under pressure for ready access in cylinders or in bulk containers, shielding gas travels through hoses, gun, and into the weld zone. Regulators and flow meters control gas flow. Cables are constructed of drawn copper strands. The electrode lead carries current to the gun; the work lead, grounded, completes the circuit.

Gas hoses with accessories such as connectors and clamps route the shielding gas from the cylinder or tank to the welding gun. Water for cooling high-amperage guns comes through a flexible hose. Gas metal arc welding typically uses solid wire, spooled or reeled, for continuous feeding to the gun, with diameters from 0.035 to 1/16 inch.

Flux-Cored Arc Welding

After the introduction of CO_2 with gas metal arc welding, **flux-cored arc welding (FCAW)**, a variation using a special electrode wire, was developed. This wire was tubular in cross-section, with the fluxing agents on the inside. More developments eliminated the external gas, leading to the self-shielded welding wire. Flux-cored arc welding uses the heat of an arc between the electrode wire and the work.



Self-shielded flux-cored arc welding process