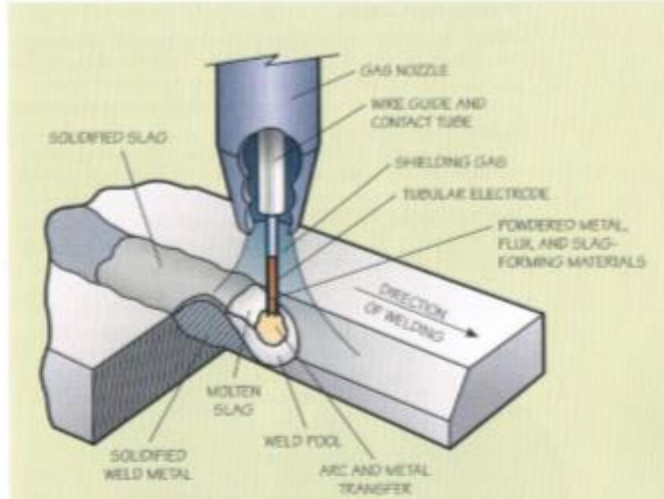
The American Welding Society's identification system for flux-cored arc welding electrodes follows the general pattern. Shielding is obtained, in whole or part, from a flux contained within the tubular electrode. Self-shielded electrodes require no external gas protection. Non-self-shielded flux-cored electrodes use additional external gas shielding (commonly, carbon dioxide or argon/carbon dioxide mixes) supplied through the welding gun. CO_2, which is the least costly, gives globular transfer. With a mix of 75 percent argon and 25 percent CO_2, transfer approaches spray. Inert gases increase the efficiency of oxidizers in the wire core. Argon protects the molten weld pool at all weld temperatures.

Flux-cored arc welding owes its versatility to the wide variety of ingredients that can be included in the core of a tubular electrode. The tube contains granular flux, deoxidizers, and alloying elements within the tubular wire. The selection of filler alloys depends on the base metal composition, base metal cleanliness, thickness, and service.

ADVANTAGES AND DISADVANTAGES OF FLUX-CORED ARC WELDING

Due to increased deposition rates and a high tolerance for contamination, flux-cored arc welding has replaced shielded metal arc welding and gas metal arc welding in many applications. Flux-cored arc welding can be used in both shop and field applications and provides high productivity in terms of the amount of weld metal that can be deposited in a given time, particularly for the handheld process. This process is characterized by an aggressive, deeply penetrating arc that tends to reduce the possibility of fusion-type discontinuities. Flux-cored arc welding can be used in all positions.

As for the disadvantages of flux-cored arc welding, because a flux is present during flux-cored arc welding, a layer of solidified slag must be removed. The flux also generates a significant amount of smoke, which can be hazardous and can reduce the welder's visibility, making the weld puddle more difficult to observe. Often, welders use welding guns equipped with built-in fume extractors ducted to a filter canister and an exhaust pump.



Gas shielded flux-cored arc welding process

Discontinuities in Flux-Cored Arc Welding

The most prevalent discontinuities in flux-cored arc welding are porosity and slag entrapment. Inadequate shielding or a disruption in the shielding gas atmosphere causes porosity. Improper travel speed or incorrect manipulation of the welding gun often results in slag entrapment.

Plasma Arc Cutting

Plasma arc cutting uses the heat of a plasma arc (40,000 degrees Fahrenheit) to cut through any metal, ferrous or nonferrous. The plasma arc torch, which features a copper electrode recessed into a copper tip with a small opening, constricts the plasma gas in order to heat and ionize it.

A trigger switch controls most manual torches: Press to start the gas and cutting arc; release to stop. A pilot arc is established, and when the torch is close enough to the workpiece that the pilot arc touches it, an electrically conductive path from the electrode to the workpiece is created. The material melts and the cutting gas blows the molten metal away.

The plasma gas cuts a bevel on one side of the kerf and a right-angle edge on the opposite side. The gas swirls clockwise, placing the bevel on the left. This requires the worker to plan for the bevel on the scrap side of the cut. The welder can rate the cut quality according to surface smoothness, kerf width, parallelism of faces, adherence of dross to the cut bottom, and sharpness of the bottom faces.

ADVANTAGES AND DISADVANTAGES OF PLASMA ARC CUTTING

Plasma arc cutting is faster than other types of thermal cutting for material less than 1 inch (25.4 mm) thick. Because it works with a high-velocity jet of gas, the plasma arc cuts molten material without preheating.

Its disadvantages are that plasma arc cutting is noisy, bright, and hot. All operators must wear ear protection (earplugs), a shaded face shield or helmet, and protective clothing. This method also involves hazards such as fire, electric shock, intense light, fumes, gases, and high noise levels. Another disadvantage is that the equipment costs more than oxy-fuel cutting equipment, and setups require both compressed air or gas and electrical power.

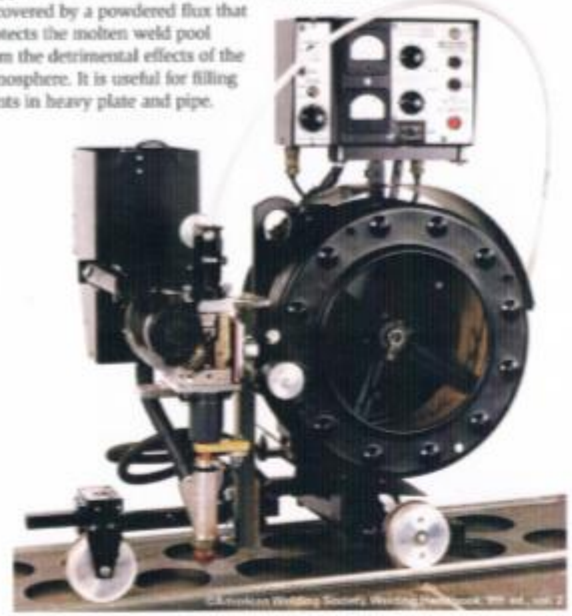
In addition to thermal methods of cutting, there are also mechanical methods such as grinding, shaping, sawing, shearing, chipping, and milling. The major concern for preparation after mechanical cutting is the thorough removal of all oils and lubricants used during cutting that will interfere with later welds.

Other Welding Methods

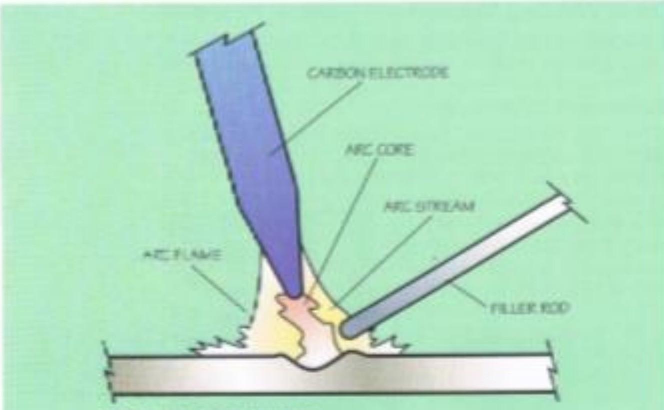
A few other welding and cutting methods are discussed briefly here.

Submerged Arc Welding

In the 1930s, the automatic process of **submerged arc welding (SAW)** was developed and became popular in the piping and shipyard industries. In this process, the electric arc is covered by a powdered flux that protects the molten weld pool from the detrimental effects of the atmosphere. It is useful for filling joints in heavy plate and pipe.



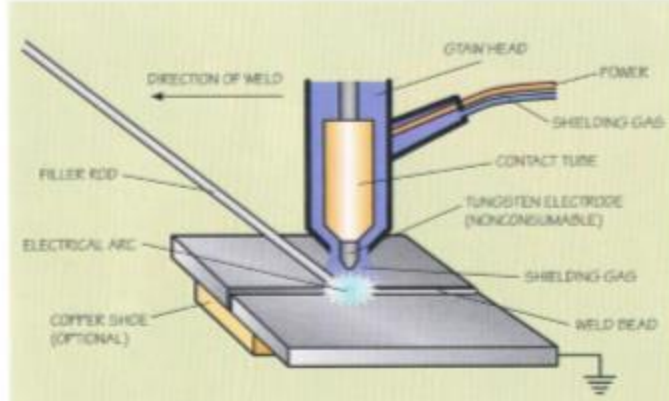
Self-propelled tractor used for submerged arc welding ships



Carbon arc welding process

Carbon Arc Welding

The production of an arc between two carbon electrodes using a battery was first credited to the British chemist Sir Humphry Davy in 1820. In 1885, Russian researcher Nikolai Benardo, working in a French laboratory, was granted a patent for carbon arc welding to join lead plates together for storage batteries. Efforts were also made to join iron components, and the process became popular in the late 1890s and early 1900s.



Gas tungsten arc welding

Gas Tungsten Arc Welding

Gas tungsten arc welding (GTAW) uses a nonconsumable tungsten electrode to produce an arc to melt the base metal. The weld area is protected from atmospheric contamination by a shielding gas (usually argon and a filler metal).

Plasma arc welding is a variation of gas tungsten arc welding whereby the electric arc is contained inside the torch and the heat energy is transferred to the work through a plasma jet. This process can be used for metal spraying and for cutting. The plasma arc has a higher temperature than a tungsten arc.

Preparation for Welding and Cutting

Determining the Method

Skilled welders know the right questions to ask themselves to determine which method of welding or cutting is best suited for the particular job they are doing. They consider **weldability**, **metallurgy**, and **discontinuities**.

Weldability

Weldability is the capacity of a material to be welded. The thickness of the metal often determines the best welding process to use. For heavy sections, flux-cored arc welding or shielded metal arc welding are good options. For sheet metal, oxy-fuel welding or gas metal arc welding are good choices.

Metallurgy

Skilled welders have a knowledge of *metallurgy*, the physical and chemical behavior of metals and their mixtures (alloys).

The welding position relates to the place where the two pieces of metal meet. This is called the joint. When the joint is not in the flat position, the force of gravity limits the use of arc and gas welding.

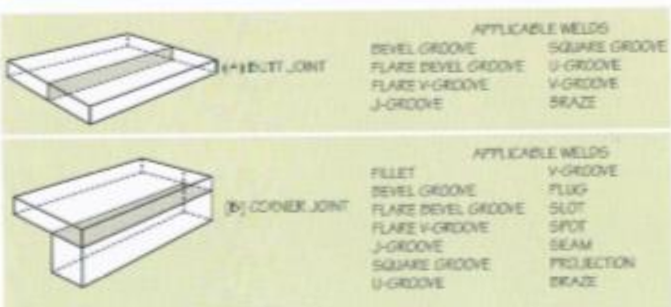
Backside accessibility is sometimes a factor in determining the welding or cutting process to use. When the back side of a joint must be reached, the angle may be difficult to reach and weld effectively. Incomplete **fusion** or incomplete joint penetration can result.

Discontinuities

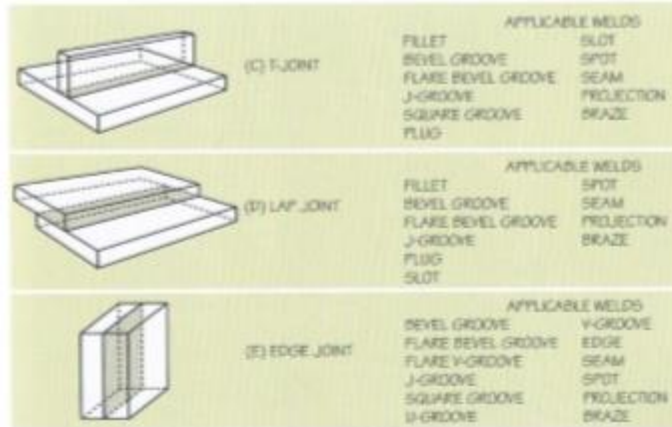
When welding, you may see *discontinuities* (or irregularities) that you can correct:

1. Uniformly scattered porosity usually means the welding technique was faulty or an improper filler metal was used, or the base metal was contaminated.
2. Incomplete fusion of the base metal edges can occur when the edges are inadvertently oxidized, even with the best flame adjustment; it usually is the result of improper torch manipulation.
3. Undercut, underfill, and overlap are weld faults attributable to the skill of the welder.
4. Cracks are generally hot cracks in oxy-fuel welds.
5. Throat cracks may result if the weld deposit is too thin to resist weld shrinkage stresses.

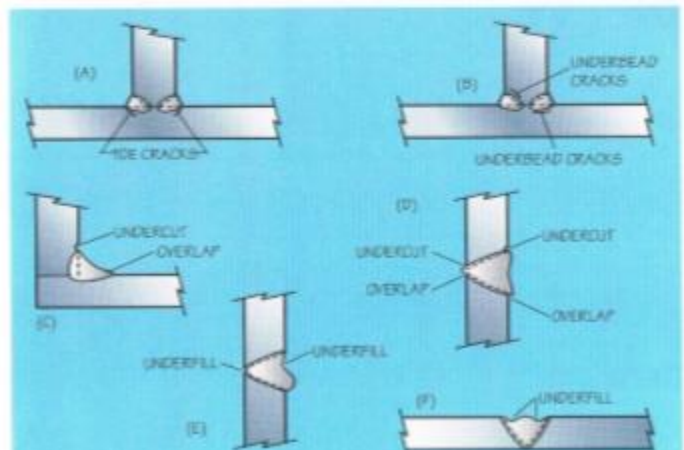
Discontinuities that result in a poor weld are porosity, incomplete fusion, incomplete joint penetration, undercut, underfill, overlap, and cracks. You can eliminate most problems by cleaning the joint and sides of the base metal, and by using proper welding technique.



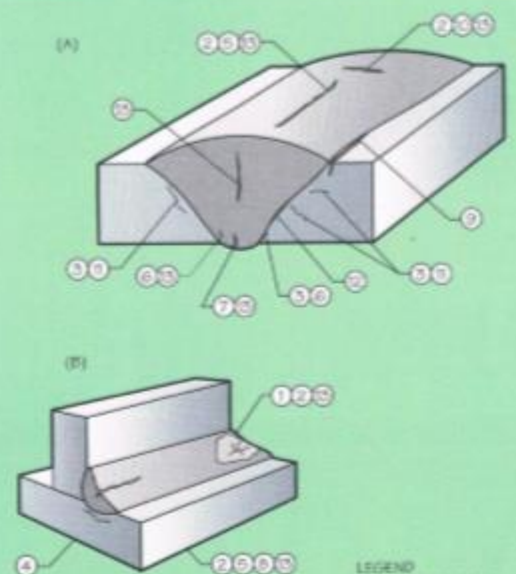
Weld joints



Weld joints



Weld discontinuities



Types of cracks

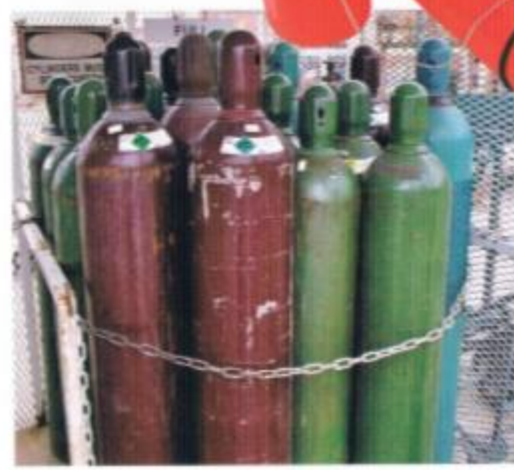
LEGEND
1 CRATER CRACK
2 FACE CRACK
3 HEAT-AFFECTED ZONE CRACK
4 LAMELLAR TEAR
5 LONGITUDINAL CRACK
6 ROOT CRACK
7 ROOT SURFACE CRACK
8 THROAT CRACK
9 TOE CRACK
10 TRANSVERSE CRACK
11 UNDERBEAD CRACK
12 WELD INTERFACE CRACK
13 WELD METAL CRACK

Welders can choose from a number of electrodes, metals, and alloys. A welder must stop periodically to replace electrodes and remove solidified slag. Low-hydrogen electrodes must be kept in special storage to minimize moisture absorption.

Welding Equipment and Materials

The equipment and materials discussed here are conventional tools of welding. For instance, common C-clamps and bar clamps hold parts to ensure precise, repeatable alignment. With portable grinders that are either electrically or pneumatically powered, you can bevel joints, grind off weld spatter, remove weld reinforcement, and help clean the scale from base material before welding. Discs and brushes offer various finishes.

Electrodes



Cylinders

Filter lenses must be worn when observing thermal cutting (oxy-fuel or plasma arc) operations. Safety goggles with side shields are required to protect eyes and face from sparks and spatter. Hearing protection (wearing earplugs) is required, as noise can exceed safe levels. Oil and grease in the presence of oxygen may spontaneously combust and burn.

Gas metal arc welding gun

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Accessories for oxy-fuel include a friction lighter to ignite the gas, tip cleaners, an adjustable wrench, a cylinder truck, and safety goggles and clothing.

To prevent a flashback, which occurs when mixed gases burn behind the torch mixer, a flashback arrestor should be installed at the torch to protect the hose from burning.

Gas regulators reduce the cylinder gases from storage pressure to working pressure at the torch and maintain this lowered pressure during gas flow. Each regulator is designed to work with a specific gas. The oxygen-cylinder pressure, which can be as high as 3,000 pounds per square inch, is reduced to a working pressure of 1 to 25 pounds per square inch. The fuel gas storage pressure is reduced from 250 pounds per square inch to 1 to 12 pounds per square inch.

Base Metal Preparation

For any welding process, the first step is to clean the base metal along the joint and sides to remove any buildup of dirt, oil, and oxides that can cause a weak weld. Grinding the surface of the base metal to a smooth, shiny finish typically removes the oxides. Carefully space the part for welding; follow all specifications. The root opening should allow for bridging the gap but should be large enough for full penetration.

Edge preparation depends on the material thickness. Sheet metal can normally be butted together and welded. For material that is 1/16 to 1/4 inch thick, a slight root opening or groove and a filler metal are necessary for complete penetration. Thicker materials should be beveled for better penetration and fusion at the sides.

Revisit the "Health and Safety" chapter whenever necessary.

Hazards of oxy-fuel welding are heat and light radiation, fumes and gases, noise, fire, and explosion. Proper use of equipment—especially of compressed-gas cylinders—is vital. The oxy-fuel flame is less intense than the electric arc but requires that shaded lenses be worn. For heat protection, wear a shaded or clear face shield. Always wear goggles to protect your eyes from sparks, spatter, and molten slag. Keep your head out of the fume plume.

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Cutting steel with an oxy-fuel torch

Plasma arc cutting

Shielded metal arc welding (or "stick welding")

Oxy-fuel operators should wear a number 4 or 5 lens when welding material is less than ⅛ inch thick, number 5 or 6 when welding material is ⅛ inch to ½ inch thick, and number 6 or 8 when material is thicker than ½ inch.

Oxy-fuel welding equipment

Be sure the grinder you use is safe by using this checklist from the Occupational Safety and Health Administration, which can also be found at www.osha.gov/SLTC/machineguarding/new-grinder-checklist.html. Address questions answered with a "no" before using the grinder.

Checklist for Abrasive Wheel Equipment Grinders

Do side guards cover the spindle, nut and flange, and 75 percent of the wheel diameter?	Yes ❑	No ❑
Is the work rest used and kept adjusted to within ⅛ inch (0.3175 cm) of the wheel?	Yes ❑	No ❑
Is the adjustable tongue guard on the top side of the grinder used and kept to within ¼ inch (0.6350 cm) of the wheel?	Yes ❑	No ❑
Is the maximum RPM rating of each abrasive wheel compatible with the RPM rating of the grinder motor?	Yes ❑	No ❑
Before new abrasive wheels are mounted, are they visually inspected and ring-tested?	Yes ❑	No ❑
Is cleanliness maintained around grinders?	Yes ❑	No ❑
Are dust collectors and powered exhausts provided on grinders used in operations that produce large amounts of dust?	Yes ❑	No ❑
Are goggles or face shields always worn when grinding?	Yes ❑	No ❑
Are bench and pedestal grinders permanently mounted?	Yes ❑	No ❑
Is each electrically operated grinder effectively grounded?	Yes ❑	No ❑
Are fixed or permanently mounted grinders connected to their electrical supply system with metallic conduit or other permanent method?	Yes ❑	No ❑
Does each grinder have an individual on and off control switch?	Yes ❑	No ❑

Fume exhaust equipment removes chemical fumes and vapors, oil mist, and dust. Equipment ranges from fans and blowers to exhaust hoods and smoke-extraction welding guns.

Gases

Oxygen for welding and cutting should be at least 99.5 percent pure. Burning acetylene gas with pure oxygen fed through a torch produces the oxy-fuel flame. Oxygen in the air completes the combustion. For most applications, the 5,600-degrees-Fahrenheit flame provides both the heat and necessary shielding of the molten metal. Fluxes improve the cleaning action on some materials.

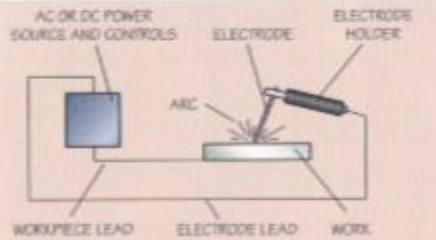
Oil or grease in the presence of oxygen may spontaneously combust and burn. Oxygen cylinders must be stored away from flammable and combustible material. Do not store oxygen or acetylene cylinders in confined spaces such as boxes, trunks, or vehicles. Acetylene cylinders should be kept upright. Keep equipment free of grease and oil.

Filler Metal and Electrodes

Filler rods, used for welding of material thicker than 1/16 inch with oxy-fuel welding, are fed manually. Rods are ¼ inch or slightly less in diameter; standard lengths are 18, 24, and 36 inches. Electrodes for shielded metal arc welding are usually 5/16 inch or less in diameter and standard lengths of 14 inches, while electrodes for gas metal arc welding and flux cored arc welding are in coils.

Focus on the Arc

What happens in the weld puddle determines the weld quality. For arc welding processes, the heat of the arc melts the base metal and the tip of a consumable covered electrode. Understanding the electrical circuit will help you become familiar with the process. The following descriptions explain shielded metal arc welding but are similar for other common arc welding processes.



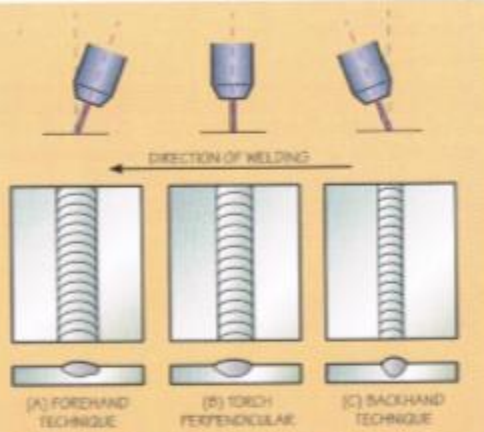
Arc welding circuit

This circuit begins with the electric power source and includes the welding cables, an electrode holder, a workpiece connection, the workpiece **(weldment)**, and an arc welding electrode.

One of the two cables from the power source is attached to the work. The other is attached to the electrode holder. When the arc strikes between the electrode and the workpiece, welding begins.

The heat of the arc, measured above 9,000 degrees Fahrenheit, melts the tip of the electrode and the surface of the work, near the arc. Tiny globules of molten metal rapidly form on the electrode tip, then transfer through the arc stream into the weld pool, depositing the filler metal as the electrode is consumed.

The amount of electric current needed at the arc depends on the size of the electrode and the gap between the electrode tip and the base metal. The sizes and types of electrodes for shielded metal arc welding define the arc voltage and amperage requirements. The current may be either alternating or direct (electrode positive or electrode negative), depending on the electrode being used. Manufacturers add alloying elements to the electrode covering to strengthen a shielded metal arc weld. Some ingredients and the binder in the covering can attract and hold moisture, which may cause cracking.



Effect of travel angle on the weld bead profile, no matter which process is used

The electrode coating:

1. Provides a gas to shield the arc and prevent excessive atmospheric contamination of the molten filler metal.
2. Provides ingredients to cleanse the weld.
3. Establishes the electrical characteristics of the electrode.
4. Provides a slag blanket to protect the hot weld metal from the air and enhance the mechanical properties, bead shape, and surface cleanliness of the weld metal.
5. Provides a means of adding alloying elements to change the mechanical properties of the weld metal.

Arc Shielding

The method of shielding and the volume of slag produced vary by type of electrode. On some electrodes, most of the covering materials are converted to gas by the heat of the arc, with only minimal slag. The gaseous shield prevents atmospheric contamination. Other electrodes convert most of the covering to slag that coats the globules of metal being transferred across the arc, then floats to the surface of the weld puddle because it is lighter than the metal. The slag solidifies after the weld metal has solidified.

The choice of electrode type depends on the application. Electrodes that produce heavy slag can carry high amperage and provide high deposition rates, ideal for heavy weldments in the flat position. Those with a light slag and lower amperage and deposition rates produce a smaller weld pool and work in all welding positions.

The American Welding Society classifies welding rods and electrodes for steel on the basis of strength, position, and chemistry.

How to Select an Electrode

Consider these factors in approximate order of importance:

1. Composition of the base material. For stainless steels, low-alloy steels, nickel and copper alloys, and materials that serve in corrosive atmospheres, chemical composition is important.
2. Mechanical properties of the base material. **Tensile strength** and yield strength of the weld metal should equal or exceed that of the base material.

For your own comfort, choose the smallest size electrode holder that will hold your electrode without overheating.

3. Welding position. This is the first performance characteristic to consider. High-cellulose coating, like those on E6010 and E6011 electrodes, generate a light slag that makes for rapid solidifying of the weld metal, good for out-of-position welds.
4. Weld current. Covered electrodes run on alternating current, or direct current, or both. When welding DC, the positive lead typically connects to the electrode (direct current electrode positive, or reverse polarity). Some suppliers design electrodes that weld with the electrode negative (direct current electrode negative, or straight polarity). Ensure that the electrode will perform with the type of current available.
5. Joint design and material thickness. Some electrodes create an arc that penetrates deeply, performing well on thick sections with narrow grooves or no bevel. Poor fit-up calls for electrodes that can bridge wide gaps.
6. Productivity. Meeting all other conditions, select the electrode that gives the highest deposition rate.
7. The American Welding Society electrode numbering for shielded metal arc welding electrodes is shown in *AWS A5.1, Specification for Covered Carbon Steel Welding Electrodes.* "E" stands for electrode. The first two digits (or the first three digits in a five-digit number) are the tensile strength of the weld deposit times 1,000. For example, an E7014 electrode has a tensile strength of 70,000 psi (70 x 1,000). The third digit is the position in which the electrode can be used. "1" is all positions, "2" is flat and horizontal only, and "4" is a vertical down low-hydrogen electrode. The last digit is the composition of the flux coating.

Power Sources

A combination AC/DC power source is common at home. Power sources are static converters (transformers), rotating converters (generators/alternators), or inverters to produce the electrical power needed for shielded metal arc welding. These produce 25 to 400 amps at 15 to 35 volts. Either AC or DC may be used, depending on the current supplied by the power source and the electrode selected. The type of current used influences the performance of the electrode. Following are some factors to consider:

- Voltage drop in welding cables is lower with AC, thus improving welding at a distance from the power supply.

- Low current requirements of small-diameter electrodes and low welding currents make DC a good choice for a more stable arc and better operating characteristics.
- Arc starting is generally easier with DC, particularly if small-diameter electrodes are used. With AC, the welding current passes through zero each half-cycle; this can present problems for arc starting and arc stability unless special electrodes are used.
- Arc length is better controlled with DC when welding with a short arc length (low arc voltage) than with AC.
- Arc blow is seldom a problem with AC because the magnetic field is constantly reversing (120 times per second). Welding position in the vertical and overhead is somewhat better with DC because lower amperage can be used. With suitable electrodes, however, satisfactory welds can be made in all positions with AC.

Accessory Equipment

An electrode holder is a clamping device with an insulated handle that allows the welder to hold the electrode. The electrode holder conducts the welding current from the welding cable to the electrode through the jaws of the holder. The jaws must be kept clean and in good condition to prevent overheating and causing an excessive voltage drop in the welding circuit.

The workpiece connection is a device that connects the workpiece lead to the workpiece. It should produce a strong connection, yet allow for quick and easy attachment. For light duty, a spring-loaded clamp may work. For high current, a screw clamp can provide a good connection.

Welding cables connect the electrode holder and workpiece clamp to the power source as part of the welding circuit. The cable size depends on the maximum amperage to be used for welding, the length of the welding circuit (welding and **work cables** combined), and the duty cycle of the welding machine. Miscellaneous hand tools include a steel wire brush, hammer, chisel, and chipping hammer to clean dirt, slag, and foreign matter from the welding area.

Welding for the Novice

After you have set up an area for the welding process you have chosen, your merit badge counselor will inspect and approve the area. Before you begin, you must be trained in the proper use of regulators, if they are required, and be supervised by your merit badge counselor. Always follow the manufacturer's recommended procedures.

This section will outline the steps for only two of the most common welding processes, oxy-fuel welding and shielded metal arc welding.

Preparing to Weld With Oxy-Fuel Welding

Cylinders should be secured to a wall or post for stability. Select the correct regulator, hose, torch, and nozzle; check to ensure that the fittings are tight and grease-free. The regulator should be clean and in good working condition at all times. When opening the cylinder valve, always stand with the cylinder valve between you and the regulator. Turn the oxygen cylinder valve slowly to full open in order to gradually increase the pressure in the regulator. Turn the oxygen regulator adjusting screw clockwise to working pressure. Close the torch-oxygen valve; then open the acetylene cylinder valve a quarter to one and a half turns.

Turn the adjusting screw on the acetylene regulator clockwise to the recommended pressure, no more than 15 *psi*, or pounds per square inch. Close the fuel gas torch valve. As the welder, you must regulate the torch flame to burn under neutral condition. With the primary reaction exactly balanced, yielding only carbon monoxide and hydrogen, the flame atmosphere is then neither carburizing nor oxidizing. This flame adjustment must be determined from the appearance of the inner flame cone. The hot metal is then protected from the atmosphere by the combustion products in the neutral flame and the fluxes, if used.

There are three types of usable flames: carburizing, oxidizing, and neutral (see page 35). A carburizing flame has an excess fuel gas in the flame, while an oxidizing flame has excess oxygen. A neutral flame has no excess of either gas and thus is the best flame for welding steel. Using a carburizing or oxidizing flame can degrade the material properties.

Torch and Tip Technique

Before you try it yourself, your merit badge counselor can demonstrate how to hold the torch for the proper work and travel angles to weld a bead.

Practice before attempting to weld a bead into the shape of your initial.

Welding beads with shielded metal arc welding

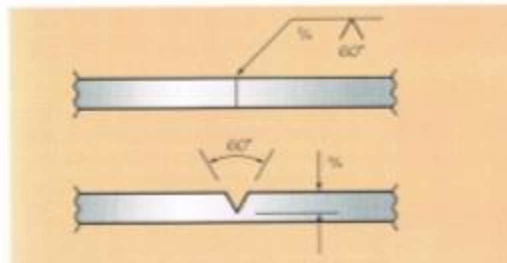
How to Weld a Bead

To begin welding, rotate the torch flame in a small circle at the starting edge to establish a puddle; then push the puddle along the joint. Continue this action, oscillating the torch tip across the joint in a circular or semicircular motion. Forehand and backhand welding indicate the direction of the tip relative to the completed weld.

APPLYING WELD BEADS

Once you get the hang of it, you can take your skills to the next level and cover a plate with weld beads side by side. It will take a steady hand, but with some guidance you will have fun with this welding technique. Be sure to follow your counselor's instructions.

When you are ready to close down the equipment, turn off the torch-oxygen valve; then, turn off the fuel valve. Close the cylinder valves, then open the torch oxygen valve to allow the oxygen to drain, and close the torch oxygen valve. Release the adjusting screw on the oxygen regulator. Open the torch-fuel valve to drain fuel gas, and then close it. Release the adjusting screw on the fuel-gas regulator. Always follow the manufacturer's recommendations for startup and shutdown of the equipment you are using.



V-groove weld

How to Weld Two Plates Together

After practicing lighting the torch and running beads on a flat steel plate, you will now learn how to weld two pieces of metal. Common joints are butt joints, T-joints, and lap joints. Welded joints are designed primarily on the basis of the strength and safety required of the weldment.

Thicker members normally require some edge preparation to allow puddle to reach the point where the weld metal must be deposited. Often on thick members, the bevel is on both sides or weld backing is used to prevent the molten metal from seeping through the root of the joint.

Although the steps here are for oxy-fuel welding, the same steps can be followed for most welding processes in which your counselor has experience and for the equipment available.

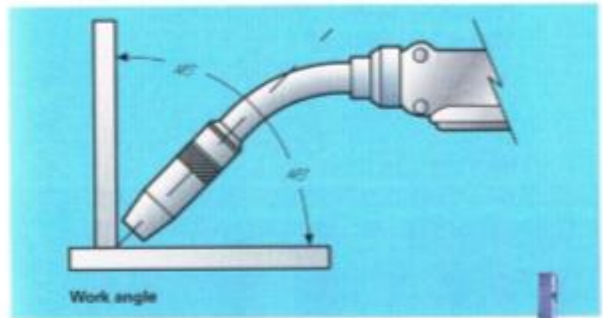
Start with a butt joint. With a weld bead, you can fill the space between the two pieces to create a single piece of metal. The two pieces can have a closed root with a square groove, or an open root with a square groove. For greater strength, you can bevel a groove angle with either a closed root or an open root with a root face.

In working with a deep groove, you may need multiple beads to fill the space. Between each pass, clean all slag from the bead surface. To fill a groove, you can make stringer beads (run beads side by side) or create a series of weave beads.

A *weave bead* means to move the weld puddle from side to side, or to weave it the width of about two or three times the electrode diameter. A *tack* or *tack weld* is a small weld bead, usually ¼ to ½ inch long, used to hold the two pieces of steel together while you complete the weld. If the two pieces of steel have not been tacked together, the heat distortion will cause them to move apart or cause what is called angular distortion once you start to weld.

Tack welds at bottom ends of plate

Tack holds weld in place as weld progresses



Normally, in addition to clamps, a butt weld will require a tack weld to hold the pieces in place during the heating from the weld bead. Place the tack welds on each end of the joint. Depending on the shape of the workpiece, you may need to tack welds in other places, too, to control warping.

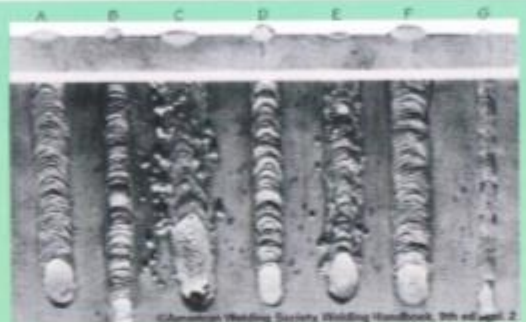
T-joints and lap joints can be joined with fillet welds at the intersection of the two workpieces. If the pieces are square, no end preparation is necessary. When possible, use double-fillet welds (as shown here) on both sides of the joint, between the two pieces.

A fillet weld requires holding the torch at a 45-degree work angle and the same 10-degree to 30-degree travel angle as in the flat position. Tack weld the end and other points as needed, as with a butt weld. Practice welding the flat and vertical up and down positions to learn how the heat helps or hinders your efforts.

A *fillet weld* is a right triangular–shaped weld formed at the interface between the vertical and horizontal members of a T-joint. A *double fillet weld* is a T-joint with a fillet weld on both sides of the vertical member of the joint.

Preparing to Weld With Shielded Metal Arc Welding

As a welder, you can control four shielded metal arc welding parameters: current setting (amperes), arc length (voltage), electrode angles (degrees), and travel speed (inches per minute). You can see the results of your skills as you weld. Compare your beads to the ones shown.



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(A) PROPER AMPERAGE, ARC LENGTH, AND TRAVEL SPEED
(B) AMPERAGE TOO LOW
(C) AMPERAGE TOO HIGH
(D) ARC LENGTH TOO SHORT
(E) ARC LENGTH TOO LONG
(F) TRAVEL SPEED TOO LOW
(G) TRAVEL SPEED TOO FAST

Effects of parameters on shielded metal arc welds

Electrical Current Setting

To test the effects of current settings, use a ⅛-inch diameter E6013 electrode at varying welding currents, beginning at 115 to 125 amps, then dropping down by 5 to 10 amps. Run beads at each setting. As the amps are lowered, check the change in the weld bead until the heat is insufficient to melt the base metal. Then, start over with the 115- to 125-amp setting and increase by 5 to 10 amps. With too much heat, the electrode covering will turn black, the bead will be flat with a lot of spatter, and the base metal will become hot. With practice, and by using the manufacturer's amp setting recommendations, you will soon learn what your current settings should be.

Arc Length

After striking the arc, the electrode is consumed, so the welder must constantly correct the arc length—the distance between the workpiece and the end of the electrode core wire. The length is approximately the diameter of the core wire of the electrode. A short arc will not generate enough heat to fully melt the base metal or the electrode. This can result in the electrode sticking to the base metal, shallow penetration, or an uneven bead with irregular shape and slag trapped in the weld.

Electrode Angles

Shielded metal arc welding requires skill in holding the electrode in two related angles—travel angle and work angle. The travel angle, movement away from the weld bead, refers to the direction of travel the welder holds the electrode during welding. When welding on a flat plate, start with 15 to 25 degrees from vertical, tilted in the direction of travel. The work angle is 0 degrees from the vertical, or 90 degrees off the base metal.

Travel Speed

As you move the electrode along the joint, you can determine the best travel speed for building the width and height of the weld bead. The correct travel speed should create a weld bead about twice as wide as the outer diameter of the electrode, with half-moon or crescent-shaped ripples, similar to laying down a stack of dimes.

Slow travel speed produces a bead with too much height and width and poor fusion to the base metal. High travel speed results in a low, narrow bead, a V-shaped ripple, and possible undercut along the edges.

Prepare and Practice

Use SMAW to practice striking arcs and running beads. Then, learn to join two pieces of metal as butt joints, T-joints, and lap joints. **Follow the steps used with oxy-fuel welding.** Hold the correct electrode angle as you would when running the beads on plate.

Discontinuities

If the SMAW process is not applied properly, the welder can produce almost any discontinuity. Improper manipulation of the electrode can cause mistakes like incomplete fusion, incomplete joint penetration, undercut, overlap, incorrect weld size, and improper weld profile.

Slag inclusions are most often the result of improper welding technique, insufficient cleaning, or insufficient access for welding within the joint.

Porosity normally results when moisture or contamination is present in the electrode coating on the surface of the material or in the atmosphere. Faulty technique can also cause porosity. Cluster porosity occurs due to long arcing at the start and stop of the arc. Porosity can result from the presence of arc blow, the deflection of an arc from its normal path because of magnetic forces. As you develop your welding technique with your merit badge counselor, you will learn to minimize arc blow.

Variables for Arc Welding Processes

The welder has control over a number of variables that affect weld penetration, bead geometry, and overall weld quality. The variables include:

1. Welding current (electrode feed speed)
2. Polarity
3. Arc voltage (arc length)
4. Travel speed
5. Electrode extension
6. Electrode orientation (trail or lead angle)
7. Weld joint position
8. Electrode diameter
9. Shielding gas composition and flow rate

To consistently produce a satisfactory weld, you will need to learn how to control these variables. Generally, changing one variable requires changing one or more of the other variables for a good weld. Experience builds the skill to recognize how the type of base metal, electrode composition, welding position, and quality requirements affect optimum results. Your merit badge counselor can help you build these welding skills. Practice running beads on flat plate; then, work on the basic joint to gain confidence and skill.

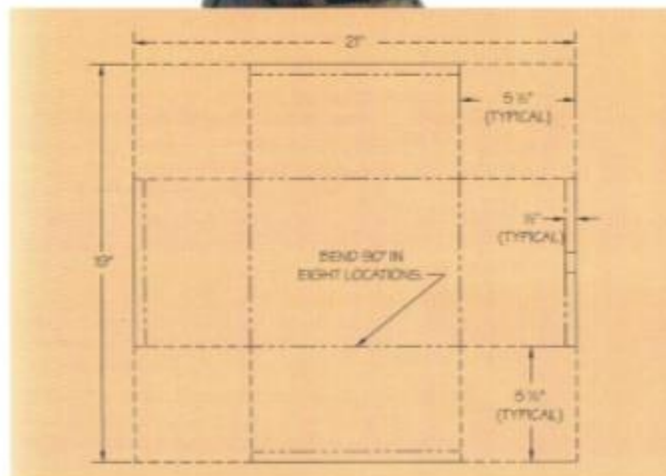
Take responsibility and precautions for minimizing risk and avoiding injury by following the information in the "Health and Safety" chapter.

Safety First

Review safety practices before welding. Being prepared will minimize accidents. Eye damage and skin burn are the most common injuries resulting from gas metal arc welding. Hazards include fumes, gaseous emissions, and electrical shock.

Build a Patrol Popcorn Popper

Now that you have some welding knowledge, you can build this patrol popcorn popper with your fellow patrol members. With your merit badge counselor's close supervision, this makes an ideal group project.



Tools Needed

- Metal cutting shears
- Plasma cutting torch (optional, for use in place of metal cutting shears)
- Builder's square
- Tape measure
- Paint pen
- Vise
- Sturdy table with square edge
- Scrap piece of plywood, at least 11" x 13"
- Hammer
- Hacksaw
- Pliers
- Small pry bar or screwdriver
- Punch
- 2 C-clamps
- Drill with ¼" bit and ⅜" bit
- Angle grinder, 4 ½"
- Grinding disk and sanding disk

Materials Needed

- 22-gauge sheet, cut to 21" x 19"
- 22-gauge sheet, cut to 12 ¼" x 10 ¼"
- Round bar, 2 pieces, each 10" x ¼"
- Round bar, 1 piece, 8 ½" x ¼"
- Round bar, 2 pieces, each 6" x ¼"
- Round bar, 1 piece, 56" x ¼"
- Wooden knob

Required Skills

The following skills are needed for this welding project: layout, cutting, fitting, welding, grinding, drilling.

Let the Building Begin

This project can be built from mild steel or aluminum sheet, depending on the welding process available. If it is built from aluminum, you might need more insulation for the handle to protect the cook's hands.

If you need to alter the design, be sure to write down your changes and make a new sketch on another piece of paper. Include dimensions, material callouts, and welding symbols. Have your counselor review your altered design to check for constructability and strength.

Step 1—Place your 21" x 19" sheet metal on a flat surface, and from all four corners, measure and mark 5 ½" vertically and 5 ½" horizontally. Then, using the builder's square, draw straight lines from your marks to create a 5 ½" square in each corner.

Step 2—Measure and mark the 1" x ½" handle notch found at one end.

Step 3—Using shears (or the plasma cutting torch), cut out the squares in each corner.

Step 4—Cut the two ½" lines for the handle notch. (This tab will be folded back.)

Step 5—Next, measure and mark the fold lines, ½" from the edge of the remaining outside lines. The lines remaining in the center are also fold lines.

Step 6—Line up the fold lines at the top edges with a sharp metal table edge, and clamp securely. Tap with a hammer to get the folds started; bend to 90 degrees.

Step 7—Line up the inside fold lines in the same way, securely clamping, then tapping with a hammer on a sharp metal table edge.

Step 8—Get all four folds started. Finish bending by hand. Tack the full length of the inside edges, tapping the outside edges with a hammer as needed, to bring them together tightly.

Step 9—Place a ½" long fillet weld in each corner to keep the popcorn oil from leaking. Full-length welds are not necessary. You can clamp thicker metal to the outside to absorb excess heat if you have trouble with burn-through.

Step 10—To start the handle, use the hacksaw to cut the ¼" round stock into pieces of the following sizes:

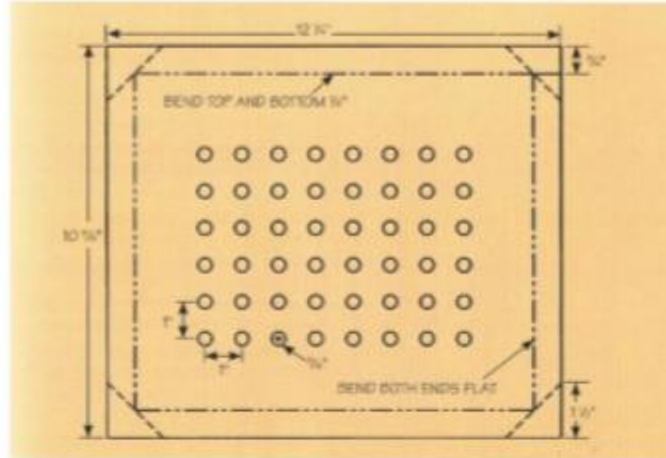
- One 56" piece
- Two 10" pieces
- One 8½" piece
- Two 6" pieces

Step 11—Find the center of the 56" piece and mark it. Place it in a vise with the mark at the edge of the vise. Bend it in half, by hand, until it has a slightly rounded middle. Place the two 6" pieces in between the bent rod and adjust them until they fit securely together. Clamp and weld.

Step 12—For the end of the handle, measure and mark each piece of the handle at 4 inches. Place the pieces of the handle in the vise, lining up the marks with the edge of the vise. Bend each end outward.

Step 13—Turn the box upside down on the table and place the remaining pieces of round stock on each of the three sides of the box. The handle becomes the fourth side of the box. Weld securely. Smooth the rough corners by grinding.

Step 14—Build the lid from the 12¼" x 10¾" sheet. Measure ¼" vertically and horizontally on both sides of each of the four corners, and draw lines to create four squares. Measure and mark 1½" on both sides of each corner, and draw a straight line between the two. Cut off the corners. Measure and mark the steam holes. In the diagram, 1" blocks are used, but you may use any hole pattern you want. Place the lid on a piece of plywood and use a punch and hammer to mark the holes.



Step 15—Clamp the lid to the table, lining up the ¼" fold lines with the edge. Tap the edge with a hammer to get the fold started. Do this on all four sides. Completely bend the two shorter sides until they are flat.

Step 16—Bend the two longer sides to 90 degrees. Place the lid upside down on the table and place the box upside down on the lid. Use the hammer to tap the 90-degree lid folds around the round stock on the box. Turn it over, drill the punch marks, first with the smaller drill bit, then with the ¼" drill bit. To prevent injury from the rough sides, use an angle grinder with a flap, or a sanding disk, to smooth both sides of the drilled holes. Use a screwdriver to adjust the folds on the lid so it slides easily. Attach a wooden knob to the lid, and you are finished!

Careers in Welding

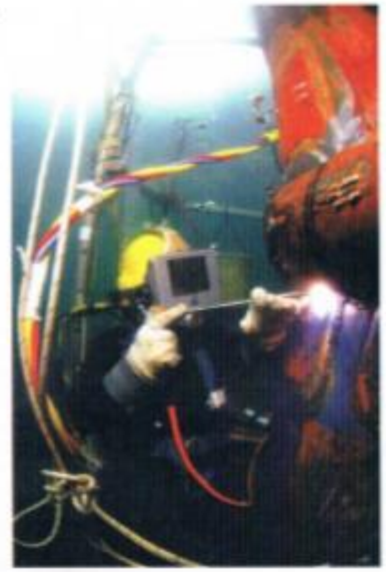
Manufacturing businesses are experiencing a shortage of skilled welders. As baby boomers (those born between 1946 and 1964) continue to retire, skilled welders are needed to replace them. Despite the lure of $40,000 to $70,000 salaries after college graduation and on-the-job training, it has been difficult to recruit newcomers. This may be because the dreary image of the past century's industrial age lingers. But that era has passed. Thanks to advances in science and technology, welding has a new spark.

Welding can also be applied in the arts. Sculptor Jean Woodham created this 28-foot-high sculpture, which required a crane, cherry picker, and flatbed truck for installation.

Skilled and talented welders have a brand new place in our contemporary world. Numerous welding careers offer flexible and appealing lifestyles. Skilled welders can advance to robotic welding technicians, inspectors, supervisors, salespersons, professors, and business owners. The best place to start is right here. The American Welding Society provides information about exciting careers in the welding industry.

The American Welding Society Foundation awards scholarships to students seeking two-year technical degrees, four-year degrees, and postgraduate education. Welding education programs are modernizing and expanding. The Southeastern Institute of Manufacturing and Technology in Florence, South Carolina, with the support of the Lincoln Electric Company and ESAB Welding and Cutting, has invested heavily in new welding and cutting equipment.

A large part of the U.S. economy is dependent on welding; continued advances will help drive our nation's productivity. Whether you enjoy working with your hands, traveling the world, inspecting and analyzing, crunching numbers, communicating, or inspiring others, a career in welding may await you.



- If you enjoy building things, try welding skyscrapers in the construction industry.
- Swimmers and divers should consider underwater welding.
- Car and aeronautics enthusiasts should try the automotive or aerospace industry.
- If you are a math and science whiz, think about welding engineering and technology.
- If traveling is in your blood, welding inspection can take you to faraway places.
- For those who enjoy working with others, welding equipment manufacturers need sales and service representatives.
- Artists can try their hand at metal sculpting and ironworks.
- Aspiring entrepreneurs and business owners can open a welding repair shop.

For more information, contact the American Welding Society (see the resources section) for a copy of *Your Career in Welding: A Guide for Students, Parents, Teachers, and Career-Changers.*

Glossary

alloy. The mixing together or dissolving of one or more elements in a metallic matrix. These solutions can create complex microstructures (*see* **microstructure**) that can be modified with the application of heat (*see* **heat treatment**) or plastic deformation (cold working). Alloys usually have different properties from those of the component elements.

American Welding Society. A nonprofit organization dedicated to the advancement of welding and allied processes.

amperage. A unit of measurement that indicates the amount of current flowing in a circuit.

arc. The area in which electricity jumps from the electrode to the workpiece. The heat generated by the arc melts the base metals.

arc welding. A fusion welding process that uses electricity to generate heat to melt the base metals.

auto-darkening welding shield. A welding shield that automatically darkens to the predetermined welding shade when the arc is established.

base metal. The workpiece and the materials to be joined.

combustible material. An object that can quickly catch fire if it comes in contact with sparks or fire. Combustibles must never be present in a weld area.

discontinuities. Interruptions of the typical structure of a material, such as a lack of homogeneity in its mechanical, metallurgical, or physical characteristics.

electric current. The flow of electrons resulting from an electric charge. This flow, when meeting resistance either through metal or across an arc, generates large quantities of heat.

electrical shock. The flow of electricity through the human body that can be fatal.

electrode. A device that conducts electricity. In welding, it is used to conduct electrical current through a workpiece to fuse two pieces together. Depending upon the process, the electrode is either consumable, in the case of gas metal arc welding or shielded metal arc welding, or nonconsumable, as in gas tungsten arc welding. Electrodes can emit harmful fumes.

electrode holder. The insulated handle that clamps onto the electrode. The electrode holder must be dry and in good condition.

element. A pure substance that cannot be refined or purified further without the loss of its unique properties.

exhaust. Any of various devices used to suck harmful fumes.

face shield. A hand-held welding shield used for the protection of bystanders.

filler metal. A metal that is added in the making of a joint through welding, brazing, or soldering.

filter plate. The shaded protective lens inside the welder's helmet that filters out harmful rays and intensely bright light.

fire shield. A large, flame-resistant screen placed around the welding area to protect bystanders from spatter or from the arc's harmful rays and bright light.

fire watcher. A person who keeps watch over the welding area for the welder. The fire watcher must be able to respond quickly in the event of a fire or other emergency.

flammable material. An object that can quickly catch fire if it comes in contact with sparks or fire. Flammables must never be present in a weld area.

flux. A chemical cleaning agent that facilitates soldering, brazing, and welding by removing oxidation from the metals to be joined.

flux-cored arc welding (FCAW). A semiautomatic or automatic arc welding process using a continuously fed consumable tubular electrode containing a flux. An externally supplied shielding gas is sometimes used, but often the flux itself is relied upon to generate the necessary protection from the atmosphere.

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forge welding. A welding process in which two or more pieces of metal are heated, then hammered together. Used since ancient times, it is one of the simplest methods of joining metals.

fume. Metallic vapor emitted during welding, solidified into tiny particles in a weld area.

fume plume. A cloudlike area where welding fume collects.

fusion. A process of heating metal that results in the phase change of a substance from solid to liquid. The liquid metals flow together and, when cooled, form a single, uninterrupted connection.

gas metal arc welding (GMAW). Also known as metal inert gas welding, or MIG. A semiautomatic or automatic arc welding process in which a continuous and consumable wire electrode and shielding gas are fed through a welding gun. There are four primary methods of metal transfer in GMAW: globular, short-circuiting, spray, and pulsed-spray (*see* **pulsed-spray**). Each has distinct properties and corresponding advantages and limitations.

gas tungsten arc welding (GTAW). Also known as tungsten inert gas, or TIG. An arc welding process that uses a nonconsumable tungsten electrode to produce an arc to melt the base metal.

globular transfer. A method of transferring the filler metal, typically from a wire welding process, across the arc in molten droplets larger than the diameter of the wire.

heat treatment. A process of changing the mechanical and physical properties of metal by applying cycles of heating and cooling controlled by specific intervals of time.

inert. Gas that is inactive; not chemically reactive. Many shielding gases are inert.

infrared rays. Invisible rays emitted during welding; these rays can damage vision.

insulation. Material that does not allow for the easy flow of electricity.

iron. An elemental metal first smelted during the Middle Ages (15th to 17th century) as the early Bronze Age civilizations transitioned into the Iron Age. When alloyed with carbon, it forms steel. When mixed with slag, it becomes wrought iron (*see* **wrought iron**).

joint. The junction of edges to be joined during welding.

lead (welding lead or work lead). A conductor that provides an easy path for electricity to flow.

metal. A solid material, typically hard, shiny, malleable, fusible, and easily shaped; a good conductor of electricity and heat. Metals normally have high luster and density, and can be deformed under stress without breaking.

metallurgy. The study of the physical and chemical behavior of metals and their mixtures (*see* **alloy**). It is also the technology of metals, including extraction from the ground and the manipulation of the mechanical properties by the application of heat (*see* **smelting**).

microstructure. The interaction of very small structures of metals and alloys generally not visible to the human eye except under 25 times magnification. The microstructure of a material can strongly influence physical properties such as strength, toughness, ease of shaping, and hardness.

oxy-fuel welding and cutting. Sometimes called oxyacetylene or gas welding and cutting, this process combines pressurized fuel gases (usually hydrogen, acetylene, or natural gas) with oxygen to form a high-intensity flame of up to 6,000 degrees Fahrenheit. The addition of a concentrated oxygen stream allows for efficient cutting of most iron that contains alloys.

primary voltage shock. An electrical shock from 120 to 480 volts that occurs in arc welding from touching a lead inside a switched-on welder and touching the welder case or other grounded metal at the same time.

pulsed-spray. Increasing and decreasing (pulsing) the welding current to control the properties of the electric arc and the transfer of filler.

regulator. A device controlling the amount of gas flow from a cylinder during a weld.

secondary voltage shock. An electrical shock from 60 to 100 volts that occurs in arc welding from touching the electrode while another part of the body touches the workpiece.

shielded metal arc welding (SMAW). Also known as stick welding. A manual arc welding process that uses a consumable electrode coated in flux to lay the weld. An electric current forms an electric arc between the electrode and the metals to be joined. As the weld is laid, the flux coating of the electrode disintegrates, giving off vapors that serve as a shielding gas, providing a layer of slag, which doubly protect the weld area from atmospheric contamination. Because of the versatility and simplicity of its equipment and operation, shielded metal arc welding is one of the world's most popular welding processes.

shielding. Protecting the weld metal from contamination by means of the decomposition of the flux coating the electrode. The electrode core wire and its covering supply the filler metal.

short-circuiting transfer. A method of transferring the filler metal from a wire welding process by a sequence of events in which the filler metal touches the base metal and then burns back to reestablish the welding arc.

slag. Cooled flux that forms on top of the weld bead. Slag protects the cooling metal and is then chipped off.

smelting. A form of extractive metallurgy used to produce a metal from the ore extracted from the ground.

spatter. Liquid metal droplets expelled from the welding process that can spray up to 35 feet from the work area.

spray transfer. A method of transferring the filler metal, typically from a wire welding process, across the arc in molten droplets, smaller than the diameter of the wire.

steel. An alloy of iron and small amounts of other elements such as carbon, manganese, chromium, vanadium, nickel, and tungsten.

submerged arc welding (SAW). An automatic welding process in which the electric welding arc is covered by a powdered flux. It is useful for filling joints in heavy plate and pipe. It is one of the most productive and popular welding processes.

tensile strength. The resistance to breakage exhibited by material when subjected to a pulling stress. The unit of tensile strength is the psi.

thermoplastic. A plastic that turns to liquid when heated, and freezes when cooled. Thermoplastic differs from thermosetting plastic, which can be remelted and remolded.

ultraviolet rays. Harmful invisible rays emitted by the arc during welding that can damage a welder's vision and burn skin.

ventilation. A means of providing fresh air for the welder's safety.

weldability. The capacity of material to be welded under imposed fabrication conditions into a specific, suitably designed structure and to perform satisfactorily in the intended service.

welding. The process of joining metals or thermoplastics by fusion. This is often done by melting the workpieces and adding a filler material to form a pool of molten material (the weld pool) that cools to become a strong joint.

welding helmet. A protective eye and face device worn by the welder for protection from the arc's harmful rays and intensely bright light. Sometimes called welding shield.

welding screen. A large fire-resistant screen placed around a weld area to protect bystanders and to block stray spatter.

weldment. An assembly of component parts joined by welding.

weld pool. The molten metal in a weld prior to its solidification as weld metal.

weld root. The point at which the weld metal extends farthest into a joint and intersects the base metal.

welder's flash. An extremely painful condition that can result from exposure to UV rays. It can feel like sunburn on the eye and is usually a temporary condition.

work cable. The path used in welding to conduct electricity from the welder to the workpiece. To prevent injury, the work cables must be correctly installed and in good condition.

workpiece. The part that is welded, brazed, soldered, thermally cut, or thermally sprayed.

wrought iron. A pure form of iron mixed with slag, creating a fibrous material with the appearance of a "grain" resembling wood that is visible when etched or bent to the point of failure. Wrought iron is tough, malleable, ductile, and easily welded.

Welding Resources

The resources listed below represent only a fraction of available welding information. Check your local library, bookstores, and the Internet for additional titles, including older or out-of-print books. Most welding techniques are timeless.

Scouting Resources

Drafting, Electronics, Engineering, First Aid, Inventing, Metalwork, Robotics, and *Safety* merit badge pamphlets

With your parent's permission, visit the Boy Scouts of America's official retail website at www.scoutstuff.org for a complete list of all merit badge pamphlets and other Scouting materials and supplies.

Books

American National Standards Institute (ANSI) Accredited Standards Committee Z49. *Safety in Welding, Cutting, and Allied Processes.* ANSI Z49.1:2005. American Welding Society, 2005.

American Welding Society. *Welding Handbook, Vol. 1,* 9th ed. American Welding Society, 2001.

——. *Welding Handbook, Vol. 2,* 9th ed. American Welding Society, 2004.

——. *Welding Handbook, Vol. 3,* 9th ed. American Welding Society, 2007.

Minnick, William H. *Gas Tungsten Arc Welding Handbook,* 5th ed. Goodheart-Willcox Company, 2005.

O'Brien, Robert L. *Jefferson's Welding Encyclopedia,* 18th ed. American Welding Society, 1997.

Organizations and Websites

American Welding Society
Website: www.aws.org

ESAB Education Resources
Website: www.esabna.com/us/en/education/index.cfm

Hobart Institute of Welding Technology
Website: www.welding.org

James F. Lincoln Arc Welding Foundation
Website: www.jflf.org

Lincoln Electric Company
Website: www.lincolnelectric.com

Miller Electric Manufacturing Company
Website: www.millerwelds.com/resources/

Thermadyne Industries Inc.
Website: http://thermadyne.com

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John McDearmon—all illustrations on pages 33, 36, 40, 41, 43, 45, 48, 49, 52–54, 61–62, 69, 71, and 84

American Welding Society

The American Welding Society has published guidelines, definitions, and facts to help you gain knowledge about being safe while welding. This information can be downloaded for free at www.aws.org/technical/facts. Further information about welding safety can be found at the American Welding Society's website at www.aws.org.

Acknowledgments

This edition of the *Welding* merit badge pamphlet was written by a special committee to the Professional Development Council of the American Welding Society. Members of the committee include:

- David Landon, Vermeer Corporation—committee chair and vice president, American Welding Society
- Jack Compton (retired), College of the Canyons
- Richard Harris, retired editor, *Welding Design & Fabrication* magazine
- J. Jones, Thermadyne Industries
- Roy Lanier, Pitt Community College
- Dennis Marks, American Welding Society
- Neil Shannon, Carlson Testing

MERIT BADGE LIBRARY

Though intended as an aid to Boy Scouts, Varsity Scouts, and qualified Venturers and Sea Scouts in meeting merit badge requirements, these pamphlets are of general interest and are made available by many schools and public libraries. The latest revision date of each pamphlet might not correspond with the copyright date shown below, because this list is corrected only once a year, in January. Any number of merit badge pamphlets may be revised throughout the year; others are simply reprinted until a revision becomes necessary.

If a Scout has already started working on a merit badge when a new edition for that pamphlet is introduced, *he may continue to use the same merit badge pamphlet to earn the badge and fulfill the requirements therein.* In other words, the Scout need not start over again with the new pamphlet and possibly revised requirements.

Merit Badge Pamphlet	Year
American Business	2002
American Cultures	2005
American Heritage	2005
American Labor	2006
Animal Science	2006
Archaeology	2006
Archery	2004
Architecture and Landscape Architecture	2010
Art	2006
Astronomy	2010
Athletics	2006
Automotive Maintenance	2008
Aviation	2006
Backpacking	2007
Basketry	2003
Bird Study	2005
Bugling (see Music)	
Camping	2005
Canoeing	2004
Chemistry	2004
Chess	2011
Cinematography	2008
Citizenship in the Community	2005
Citizenship in the Nation	2005
Citizenship in the World	2005
Climbing	2011
Coin Collecting	2008
Collections	2008
Communication	2009
Composite Materials	2006
Computers	2009
Cooking	2007
Crime Prevention	2005
Cycling	2003
Dentistry	2006
Disabilities Awareness	2005
Dog Care	2003
Drafting	2008
Electricity	2004
Electronics	2004
Emergency Preparedness	2008
Energy	2005
Engineering	2008

Merit Badge Pamphlet	Year
Entrepreneurship	2006
Environmental Science	2006
Family Life	2005
Farm Mechanics	2008
Fingerprinting	2003
Fire Safety	2004
First Aid	2007
Fish and Wildlife Management	2004
Fishing	2009
Fly-Fishing	2009
Forestry	2005
Gardening	2002
Genealogy	2005
Geocaching	2010
Geology	2005
Golf	2002
Graphic Arts	2006
Hiking	2007
Home Repairs	2009
Horsemanship	2010
Indian Lore	2008
Insect Study	2008
Inventing	2010
Journalism	2006
Landscape Architecture (see Architecture)	
Law	2003
Leatherwork	2002
Lifesaving	2008
Mammal Study	2003
Medicine	2009
Metalwork	2007
Model Design and Building	2010
Motorboating	2008
Music and Bugling	2003
Nature	2003
Nuclear Science	2010
Oceanography	2009
Orienteering	2003
Painting	2008
Personal Fitness	2006
Personal Management	2003
Pets	2003
Photography	2005

Merit Badge Pamphlet	Year
Pioneering	2006
Plant Science	2005
Plumbing	2004
Pottery	2008
Public Health	2005
Public Speaking	2002
Pulp and Paper	2006
Radio	2008
Railroading	2003
Reading	2003
Reptile and Amphibian Study	2005
Rifle Shooting	2001
Robotics	2011
Rowing	2006
Safety	2006
Salesmanship	2003
Scholarship	2004
Scouting Heritage	2010
Scuba Diving	2009
Sculpture	2007
Shotgun Shooting	2005
Skating	2005
Small-Boat Sailing	2004
Snow Sports	2007
Soil and Water Conservation	2004
Space Exploration	2004
Sports	2006
Stamp Collecting	2007
Surveying	2004
Swimming	2008
Textile	2003
Theater	2005
Traffic Safety	2006
Truck Transportation	2005
Veterinary Medicine	2005
Water Sports	2007
Weather	2006
Welding	2012
Whitewater	2005
Wilderness Survival	2007
Wood Carving	2006
Woodwork	2011